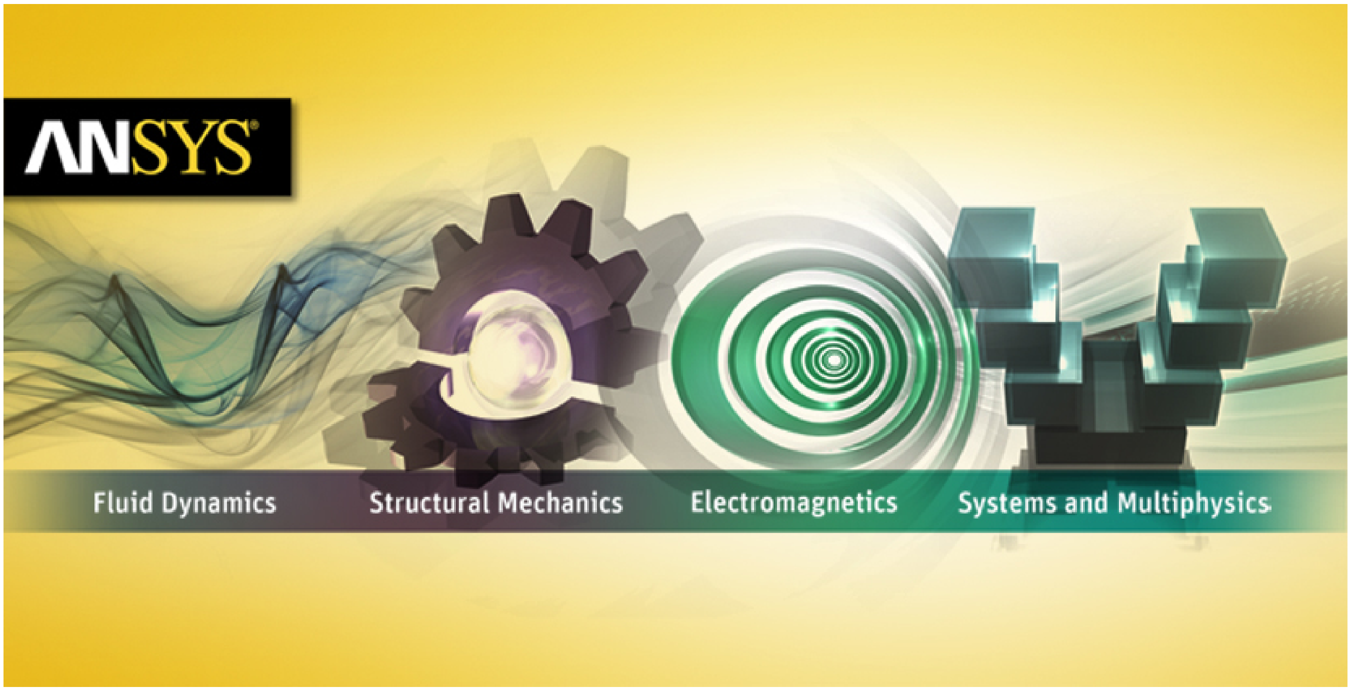

ANSYS Mechanical APDL Verification Manual

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Chapter 1: Introduction

The Mechanical APDL computer program is a large-scale multipurpose finite element program which may be used for solving several classes of engineering analyses. The analysis capabilities of Mechanical APDL include the ability to solve static and dynamic structural analyses, steady-state and transient heat transfer problems, mode-frequency and buckling eigenvalue problems, static or time-varying magnetic analyses, and various types of field and coupled-field applications. The program contains many special features which allow nonlinearities or secondary effects to be included in the solution, such as plasticity, large strain, hyperelasticity, creep, swelling, large deflections, contact, stress stiffening, temperature dependency, material anisotropy, and radiation. As Mechanical APDL has been developed, other special capabilities, such as substructuring, submodeling, random vibration, kinetostatics, kinetodynamics, free convection fluid analysis, acoustics, magnetics, piezoelectrics, and coupled-field analysis have been added to the program. These capabilities contribute further to making Mechanical APDL a multipurpose analysis tool for varied engineering disciplines.

The Mechanical APDL (ANSYS) program has been in commercial use since 1970, and has been used extensively in the aerospace, automotive, construction, electronic, energy services, manufacturing, nuclear, plastics, oil, and steel industries. In addition, many consulting firms and hundreds of universities use Mechanical APDL for analysis, research, and educational use. Mechanical APDL is recognized worldwide as one of the most widely used and capable programs of its type.

The primary purpose of this manual is to demonstrate a wide range of Mechanical APDL elements and capabilities in straightforward problems which have "classical" or readily-obtainable theoretical solutions. Furthermore, the close agreement of the Mechanical APDL solutions to the theoretical results in this manual is intended to provide user confidence in the Mechanical APDL solutions. An attempt has been made to include most element types and major solution capabilities of Mechanical APDL in this set of test cases. These problems may then serve as the basis for additional validation and qualification of Mechanical APDL capabilities by the user for specific applications that may be of interest.

The following *Mechanical APDL Verification Manual* topics are available:

1.1. Program Overview

The Mechanical APDL element library contains more than sixty elements for static and dynamic analyses, over twenty for heat transfer analyses, and includes numerous magnetic, field, and special purpose elements. This variety of elements allows the Mechanical APDL program to analyze 2-D and 3-D frame structures, piping systems, 2-D plane and axisymmetric solids, 3-D solids, flat plates, axisymmetric and 3-D shells and nonlinear problems including contact (interfaces) and cables.

The input data for a Mechanical APDL analysis are prepared using a preprocessor. The general preprocessor (PREP7) contains powerful solid modeling and mesh generation capabilities, and is also used to define all other analysis data (geometric properties (real constants), material properties, constraints, loads, etc.), with the benefit of database definition and manipulation of analysis data. Parametric input, user files, macros and extensive online documentation are also available, providing more tools and flexibility for the analyst to define the problem. Extensive graphics capability is available throughout the Mechanical APDL program, including isometric, perspective, section, edge, and hidden-line displays of 3-D structures, x-y graphs of input quantities and results, and contour displays of solution results.

A graphical user interface is available throughout the program, to guide new users through the learning process and provide more experienced users with multiple windows, pull-down menus, dialog boxes, tool bar, and online documentation.

The analysis results are reviewed using postprocessors, which have the ability to display distorted geometries, stress and strain contours, flow fields, safety factor contours, contours of potential field results (thermal, electric, magnetic), vector field displays mode shapes and time history graphs. The postprocessors can also be used for algebraic operations, database manipulations, differentiation, and integration of calculated results. Root-sum-square operations may be performed on seismic modal results. Response spectra may be generated from dynamic analysis results. Results from various loading modes may be combined for harmonically loaded axisymmetric structures.

1.2. Program Verification

The Mechanical APDL program is continuously being verified by the developers (ANSYS, Inc.) as new capabilities are added. The verification of the Mechanical APDL program is conducted in accordance with written procedures that form a part of an overall Quality Assurance program at ANSYS, Inc. This manual represents a small subset of the Quality Assurance test case library which is used in full when testing new versions of Mechanical APDL. This test library and the test cases in this manual represent comparisons of Mechanical APDL solutions with known theoretical solutions, experimental results, or other independently calculated solutions.

The test cases explore the functionality of Mechanical APDL in validated results. The test cases are based on published works in the disciplines of structures, dynamics, heat transfer, electromagnetics, and fluid flow. While the Mechanical APDL solution to these test cases has been verified, some differences have been examined and are considered acceptable.

In order to solve some test cases, specific Mechanical APDL products may be required. The test cases appropriate to each product can be determined from the following table. Most test cases can be solved within the limitations of the educational Mechanical APDL product. The test case input listings are available through a hyperlink in the test description.

For Mechanical APDL users who may have further need for formal verification of the program, ANSYS, Inc. has testing services available that allow automated testing of Mechanical APDL on a customer's computer. The user is provided with input data, output data, comparator software, and procedures for automating the testing and reporting process. Readers interested in contracting for such services may contact the ANSYS, Inc. Quality Assurance Group.

1.3. Finding Test Cases of Interest

There are several possible methods of locating a test which contains topics of interest to the user. The Index topics display the related verification problem number. If you are using the online documentation, the verification problem numbers in Index by Element Number (p. 11) are hyperlinks to each verification test case description. You can always do a text search while using the online documentation to find specific information. Finally, the code for each VM problem is contained in an appendix at the end of this manual.

1.4. Accessing Test Case Inputs

In the online help, the input file for each test case is linked to its description in each Overview section labeled "Input Listing." If you select the link, the test case input file appears in the browser window. The input listing may be printed.

To read an input listing into Mechanical APDL, copy the input listing into a text editor, save it as a text file, then select **File>Read Input from...** on the Mechanical APDL main menu to send the input to Mechanical APDL. Nested macros may not function properly unless they are read from a file. Formatting commands will not function interactively if not read from a file.

Additionally, each test case input listing appears in Appendix A (p. 1183).

1.5. Verification Manual Versus Other Manuals

The test cases in this manual are primarily intended for verification of the Mechanical APDL program. An attempt has been made to include most significant analysis capabilities of the Mechanical APDL program in this manual. Although they are valuable as demonstration problems, the test cases are not presented as step-by-step examples with lengthy data input instructions and printouts. Most users with limited finite element experience should be able to fill in the missing details by reviewing the finite element model and the input data listing with its accompanying comments. Problem sketches and modeling notes are included. The reader should refer to the online help and to this manual for complete input data instructions.

Users desiring more detailed instructions for solving problems or in-depth treatment of specific topics should refer to other Mechanical APDL documentation as described in Guide to the Mechanical APDL Documentation in the *Command Reference*. Introductory documentation such as the *Mechanical APDL Introductory Tutorials* should be the first stop for new and existing users needing basic information on using the Mechanical APDL program. Seminar notes on several broad topics are also available. These notes are written in a form designed for classroom instruction, and include theory, Mechanical APDL implementation, exercises, and examples. Broad subjects such as dynamics, heat transfer, nonlinearities, magnetics, and optimization are covered in these notes. *Mechanical APDL Introductory Tutorials* are also available for various specific topics. These publications focus on particular features or program areas, supplementing other Mechanical APDL reference documents with theory, procedures, guidelines, examples, and references.

1.6. Verification Manual Contents

The intent of this manual is to demonstrate the full scope of the analysis capability available in the Mechanical APDL program. This manual will also assist new users of the Mechanical APDL program in running compact test cases and for understanding basic capability. All report results and input listings correspond to ANSYS 15.0.

Mechanical APDL Verification Manual test cases are available on the ANSYS 15.0 installation media provided to the customer in the `verif` subdirectory under the `data` directory. All test cases also appear in three appendixes at the end of this manual.

1.7. Expected Results

Mechanical APDL is a program intended for solving practical engineering problems. Many theoretical problems are not realistic in that the assumptions necessary to obtain a closed-form analytical solution make the mathematical model depart from a practical application problem. Examples of these assumptions are: step force changes, step temperature changes, perfectly plastic impacts, infinitely rigid supports, etc. Imposing these conditions in a finite element analysis often requires more effort to duplicate the theoretical result than would be required to solve the "real world" problem.

Theoretical solutions are generally based on a continuous or differential approach. In some cases, an exact comparison with a finite-element solution would require an infinite number of elements and/or an infinite number of iterations separated by an infinitely small step size. Such a comparison is neither practical nor desirable.

Some of the Mechanical APDL solutions in this manual are also compared against experimental data obtained from textbooks or technical publications. The experimental measurements are often presented in the form of graphs of relevant parameters. Hence the simulation results are also presented as graphs so that the corresponding values can be compared on the same graph. Experimental data represent the real-world physics reproduced in a controlled manner, and provides more complex details than theoretical solutions.

The examples in this manual have been modeled to give reasonably accurate comparisons ("engineering accuracy") with a low number of elements and iterations. In some cases, even fewer elements and/or iterations will still yield an acceptable engineering accuracy. There are also cases where larger differences may exist with regard to references, for example when comparing against experimental solutions. These differences have been examined and are considered acceptable. A survey of the results comparisons in this manual shows an average accuracy within 1-2% of the target solution.

1.8. Test Case Selection and Method of Solution

The problems solved in this manual and the method of solution were selected with verification as the primary objective. Some problems could have been solved more directly or in a manner other than the way presented. In some cases the same problem is solved in several different ways to demonstrate and verify other elements or capabilities of the program.

Since Mechanical APDL is a program capable of solving very complicated practical engineering problems having no closed-form theoretical solutions, the relatively simple problems solved in this manual do not illustrate the full capability of the Mechanical APDL program.

1.9. Numerical Comparisons

The Mechanical APDL solutions in this manual are compared with solutions from textbooks or technical publications. In some cases noted below, the target (theoretical) answers reported in this manual may differ from those shown in the reference. Any problems having significantly different recalculated values are noted as such. Differences between Mechanical APDL results and target values are reported as ratios (Mechanical APDL:Target) except in cases where the target solution is zero or non-numerical in nature.

Some textbook solutions are based on slide rule accuracy. For example, the reference for problem number 3 reports the stress to be 10,200 psi. Using a hand calculator to recalculate the results shows the result to be 10,152.258 psi. The Mechanical APDL calculation yields 10,152 psi. In problems like this, an appropriate number of significant digits are used in comparing solutions.

Some references have incorrect answers printed and some have incorrect equations. Reference's answers presented without regard to sign are reported with the appropriate sign. Theoretical derivations not having a specific numerical example in the text are solved for a representative numerical example and both the theoretical and Mechanical APDL results are given. In cases where only the results but not the input data are given in the theoretical reference (for example, where only tabular or graphical results are presented), the input data are back-calculated from a convenient solution point. Graphical solution results are reported to an appropriate accuracy.

Different computers and different operating systems may yield slightly different results for some of the test cases in this manual, since numerical precision varies from machine to machine. Solutions which are nonlinear, iterative, or have convergence options activated, are among the most likely to exhibit machine-dependent numerical differences. Because of this, an effort has been made to report an appropriate and consistent number of significant digits in both the target and the Mechanical APDL solution. If you run these test cases on your own computer hardware, be advised that a Mechanical APDL result reported in this manual as 0.01234 may very well show up in your printout as 0.012335271.

It should be noted that only those items corresponding to the given theoretical solution values are reported for each problem. In most cases the same finite element solution also contains a considerable amount of other useful numerical solution data.

1.10. References

The textbooks and references used for the verification tests were chosen for several reasons. Well known and recognized textbooks were used whenever possible; other texts were used if they were readily available to the author. Periodical or technical journal references were used in instances where no textbook solutions could be found for an application of interest. The books should be available for purchase or through most engineering libraries. Periodicals are of the type normally available in university libraries. In most cases the reference listed is not the only source of the theory or of a similar sample problem.

1.11. Test Case Format

Test cases use the following format:

- A description of the test case, including the dimensions, loading, material properties, and other relevant data.
- Theoretical reference(s).
- Figures describing the problem, including either the Mechanical APDL finite element model showing node and element locations, or the Mechanical APDL "solid model," showing keypoints, line segments, areas and/or volumes (as applicable).
- Analysis assumptions, modeling notes, and comments.
- Target results, Mechanical APDL results, and normalized ratio.
- Mechanical APDL input data listing, including comments.

- Graphics displays of the results (optional).
- Additional information containing references to analysis guides with similar problems and other test cases using similar features (optional).

1.12. Symbols and Nomenclature

The majority of the nomenclature used in this manual follows what is considered commonly-used form. Exceptions and special circumstances are described when used. A few specific cases deserve definition, where many authors vary in their usage of nomenclature/symbols and there is no clear "standard."

In the text, vectors are shown by {A} or $\bar{A}$, the former being used primarily when symbolizing vector unknowns. Matrices are shown as [K], and |a| is used to denote absolute value. Natural logarithms use "ln" and base 10 logarithms are shown as "log".

In the figures, node and keypoint locations are denoted by • in the figures. Node numbers are unitalicized (1), keypoint numbers are shown italicized (*1*) and line numbers are shown italicized with prefix "L" (*L2*). Element numbers are enclosed with a circle ○, area numbers are enclosed with a box □, and volume numbers are enclosed with a hexagon ⬡.

1.13. Memory Requirements and Run Times

The Mechanical APDL program is supported on many different computers. Memory size, run time, and cost will vary from computer to computer. The test cases in this manual are small enough to require only a minimum memory size.

The test cases generally require a very short run time each, although some are somewhat larger and longer running to allow the inclusion of meaningful tests for some of the more advanced capabilities included in Mechanical APDL.

The benchmark test cases in Description of the Benchmark Studies (p. 825) are small to moderately-sized tests as well, but the run time for these is very dependent on the parameters chosen for the specific test.

1.14. Abbreviation and Symbol List

Abbreviation	Explanation
a	Acceleration
A	Area, Vector magnetic potential, Amplitude
B	Magnetic flux density
B_r	Residual induction
c	Viscous damping constant, Specific heat
C	Thermal capacitance, Fluid conductance
d	Diameter
MDOF	Master Degrees of freedom
E	Young's modulus of elasticity
f	Frequency of vibration, Friction factor

Abbreviation	Explanation
F	Force
g	Gravitational acceleration
G	Shear modulus
h	Average convection coefficient, Height
H	Magnetic field intensity
H_c	Coercive force
I	Moment of inertia, Electrical current
ITS	Integration time step
J	Torsional moment of inertia, Electrical current density
k	Spring constant, Thermal conductivity
KI	Stress intensity factor
ℓ	Length
L	Inductance, Length
m	Mass
M	Moment
Nu	Nusselt number
P, p	Pressure
Pr	Prandtl number
q	Heat flow rate
$\ddot{q}$	Heat generation rate
r	Radius
R	Electrical resistance, Reaction
Re	Reynolds number
t	Thickness, Time
T	Temperature
u	Displacement
V, v	Velocity, Voltage
w	Flow rate, Width
W	Weight
$\bar{y}$	Centroid location
α	Coefficient of thermal expansion, Thermal diffusivity
γ	Weight density
δ, Δ	Deflection
ε	Strain, Emissivity, Permittivity
ν	Poisson's ratio
Θ	Angle
ξ	Damping ratio

Abbreviation	Explanation
μ	Magnetic permeability, Viscosity, Coefficient of friction
ρ	Mass density, Electrical resistivity
σ_{yp}	Yield stress
τ	Period of vibration, Shear stress
ω	Circular frequency of vibration, Fluid flow rate, Angular velocity
σ	Electrical conductivity, direct stress

Other symbols and abbreviations are defined where used.

1.15. Units Abbreviation List

Abbreviation	Units
AbA	AbAmpere
A	Ampere
A	t-Ampere-turns
BTU	British Thermal Unit
cm	centimeter
°C	Celsius
C	Coulomb
°F	Fahrenheit
F	Farad
ft	feet
G	Gauss
gm	gram
H	Henry
Hz	Hertz
hr	hour
in	inch
kg	Kilogram
kip	Kilopound (1000 pound force)
ksi	Kilopounds per square inch
m	meter
mm	millimeter
MPa	Megapascal
N	Newton
Oe	Oersted
Pa	Pascal
lb	pound force
psi	pounds per square inch
psig	pounds per square inch (gauge)

Abbreviation	Units
rad	radian
rpm	revolutions per minute
sec	second
S	Siemen
T	Tesla
W	Watt
Wb	Weber
Ω	Ohm

1.16. Index by Element Number

Element and Keywords	Element Options	Test Cases
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	Longitudinal	VM52, VM261
	Seismic	VM70
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Element and Keywords	Element Options	Test Cases
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Element and Keywords	Element Options	Test Cases
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Static Structural		VM25, VM56, VM142, VM143, VM180, VM201, VM211, VM238, VM243, VM248, VM249, VM251, VM252, VM256, VM279
	Axisymmetric	VM63, VM200
	Rate-independent Viscoplasticity	VM198
	Rate-dependent Viscoplasticity	VM199
Static Structural, Substructure	Plane Stress with Thickness Input	VM141
PLANE223 - 2-D 8-Node Coupled-Field Solid		
Coupled Field		VM174
Static and Transient Piezoelectric		VM237
Static Piezoresistive		VM238
Static Structural		VM23, VM207
Steady-State Thermal		VM119
Transient Thermal		VM229, VM236
PLANE233 - 2-D 8-Node Electromagnetic Solid		
Coupled Field	AZ and VOLT Degree of Freedom, Multi-field Coupling	VM185
Static Magnetic		VM186
	AZ Degree of Freedom	VM165
Static Structural		VM207, VM270
Static Structural, Harmonic		VM206
Transient Magnetic	AZ Degree of Freedom	VM167
PRETS179 - Pretension		
Static Structural	Preloading	VM225
REINF263 - 2-D Smeared Reinforcing Element		
Static Structural		VM209
SHELL28 - Shear/Twist Panel		
Modal		VM202
SHELL41 - Membrane Shell		
Static Structural		VM20, VM153
Static Structural, Modal		VM153

Element and Keywords	Element Options	Test Cases
SHELL61 - Axisymmetric-Harmonic Structural Shell		
Modal	Mode 0, 1, and 2	VM151
Modal, Static Structural	Mode 0, 1, and 2	VM152
Static Structural	Mode 1	VM44
SHELL63 - Elastic Shell [1]		
Coupled Field, Harmonic		VM177
Modal		VM54, VM62, VM66
Static Structural		VM34, VM39, VM54,VM139
	Snap-Through Buckling	VM17
SHELL131 - 4-Node Thermal Shell		
Steady State Thermal		VM97, VM103
SHELL132 - 8-Node Thermal Shell		
Steady State Thermal		VM103
SHELL157 - Coupled Thermal-Electric Shell		
Coupled-Field		VM215
SHELL181 - 4-Node Finite Strain Shell		
Harmonic		VM177
Modal		VM54, VM62, VM66, VM153, VM244, VM281
Static Structural		VM6, VM7, VM17, VM20, VM26, VM34, VM39, VM42, VM54, VM82
	Large Deflection	VM26, VM218
Substructure		VM141
Transient Dynamic		VM265
SOLID185 - 8-Node Finite Strain Shell		
Modal		VM281
SHELL208 - 2-Node Finite Strain Axisymmetric Shell		
Static Structural		VM13, VM15, VM22, VM209
	Large Deflection	VM218
	Large Deflection, Stress Stiffening	VM137, VM138
Modal		VM55
SHELL281 - 8-Node Finite Strain Shell		
Harmonic		VM177

Element and Keywords	Element Options	Test Cases
Modal		VM54, VM60, VM62, VM66, VM244
Modal Harmonic		VM203
Response Spectrum Analysis		VM203
Static Structural		VM6, VM17, VM34, VM42, VM26, VM35, VM78, VM82, VM144, VM218
Substructure		VM141
SOLID5 - 3-D Coupled-Field Solid		
Coupled Field	Multi-field Coupling	VM173
	MAG Degree of Freedom	VM168
Coupled Field, Harmonic	Multi-field Coupling, Anisotropic Material Properties	VM176
Coupled Field, Modal	Multi-field Coupling, Anisotropic Material Properties	VM175
	Multi-field Coupling	VM33
Static Structural	Displacement Field	VM184, VM187
	Multi-field Coupling	VM173
SOLID65 - 3-D Reinforced Concrete Solid		
Static Structural	Cracking	VM146
SOLID70 - 3-D Thermal Solid		
Static Analysis		VM271
Steady-State Thermal		VM95, VM101, VM118
Transient Thermal		VM192
SOLID87 - 3-D 10-Node Tetrahedral Thermal Solid		
Steady-State Thermal		VM96
SOLID90 - 3-D 20-Node Thermal Solid		
Steady-State Radiosity		VM228
Steady-State Thermal		VM161, VM162
SOLID96 - 3-D 20-Node Structural Solid		
Static Structural		VM210
SOLID98 - Tetrahedral Coupled-Field Solid		
Static Structural	Displacement Field	VM184, VM187, VM233
Static Magnetic	MAG Degree of Freedom	VM169, VM190
SOLID122 - 3-D 20-Node Electrostatic Solid		

Element and Keywords	Element Options	Test Cases
Electrostatic		VM51
SOLID123 - 3-D 10-Node Tetrahedral Electrostatic Solid Element		
Electrostatic		VM51
SOLID185 - 3-D 8-Node Structural Solid		
Modal		VM244, VM274
Static Structural		VM7, VM37, VM38, VM56, VM82, VM143, VM144, VM189, VM191, VM196, VM201, VM211, VM221, VM225, VM234, VM240, VM248, VM250, VM251, VM253, VM256, VM272, VM273, VM274, VM279
	Material Matrix	VM145
	Rate-independent Viscoplasticity	VM198
	Rate-dependent Viscoplasticity	VM199
SOLID186 - 3-D 20-Node Structural Solid		
Static Structural		VM56, VM82, VM143, VM144, VM148, VM200, VM210, VM211, VM246 VM250, VM253, VM256, VM269, VM275, VM279
Modal		VM244, VM275
SOLID187 - 3-D 10-Node Tetrahedral Structural Solid		
Modal		VM244
Static Structural		VM184, VM187, VM246
SOLID226 - 3-D Thermal-Electric Solid		
Coupled Field		VM119
Coupled Field, Harmonic	Multi-field Coupling, Anisotropic Material Properties	VM176
Coupled Field, Modal	Multi-field Coupling, Anisotropic Material Properties	VM175
Transient Thermal		VM33
SOLID227 - 3-D 10-Node Coupled-Field Solid		
Static Structural		VM223
SOLID231 3-D 20-Node Electric Solid		
Static Magnetic		VM241
SOLID232 3-D 10-Node Tetrahedral Solid		
Static Magnetic		VM241
SOLID236 3-D 20-Node Electromagnetic Solid		
Static Analysis		VM277
Static Magnetic		VM213, VM214, VM241

Element and Keywords	Element Options	Test Cases
Transient Analysis		VM121
SOLID237 3-D 20-Node Tetrahedral Electromagnetic Solid		
Static Magnetic		VM241
SOLID239 3-D 20-Node Diffusion Solid		
Transient Analysis		VM150, VM276
SOLID272 - General axisymmetric solid with 4 base nodes		
Modal Analysis		VM263
SOLID273 - General axisymmetric solid with 8 base nodes		
Modal Analysis		VM263
SOLID278 - 3-D 8-Node Thermal Solid		
Steady-State Thermal		VM280
SOLID279 - 3-D 20-Node Thermal Solid		
Steady-State Thermal		VM280
SOLSH190 - 3-D Structural Solid Shell		
Static Structural		VM37, VM54, VM82, VM139, VM144
Modal		VM54, VM66, VM244
Full Harmonic		VM283
SOURC36 - Current Source		
Static Magnetic		VM168, VM190
SURF151 - 2-D Thermal Surface Effect		
Steady-State Thermal	AUX12	VM147
		VM58
SURF152 - 3-D Thermal Surface Effect		
Static Structural		VM271
	No Midside Nodes	VM192
SURF153 - 2-D Structural Surface Effect		
Static Structural		VM135, VM272
	Axisymmetric, No Midside Nodes	VM38
SURF154 - 3-D Structural Surface Effect		
Static Structural		VM272
	Axisymmetric, No Midside Nodes	VM38
SURF251 - 2-D Radiosity Surface Elements		
Steady-State Radiosity		VM228
SURF252 - 3-D Radiosity Surface		

Element and Keywords	Element Options	Test Cases
Steady-State Radiosity		VM228
TARGE169 - 2-D Target Segment		
Static Structural		VM23, VM64, VM65, VM211, VM255, VM272
Thermal Structural Contact		VM229
TARGE170 - 3-D Target Segment		
Static Structural		VM211, VM239, VM266, VM272, VM274, VM275
	Rate-dependent Viscoplasticity	VM199
Static Analysis		VM278
Transient Dynamics		VM257, VM265
Modal		VM274, VM275
Mode-Superposition Harmonic		VM282
TRANS126		
Modal		VM219
Static Structural		VM235

1. Documentation for this element is found in the *Feature Archive*.

VM1: Statically Indeterminate Reaction Force Analysis

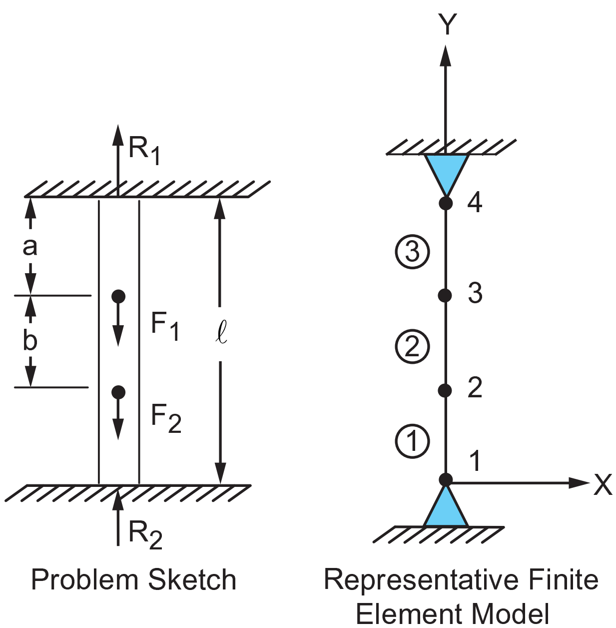
Overview

Reference:	S. Timoshenko, *Strength of Material, Part I, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 26, problem 10.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Spar (or Truss) Elements (LINK180)
Input Listing:	vm1.dat

Test Case

A prismatic bar with built-in ends is loaded axially at two intermediate cross-sections by forces F_1 and F_2. Determine the reaction forces R_1 and R_2.

Figure 1.1: Prismatic Bar Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi	$\ell = 10$ in. $a = b = 0.3\ \ell$	$F_1 = 2F_2 = 1000$ lb

Analysis Assumptions and Modeling Notes

Nodes are defined where loads are to be applied. Since stress results are not to be determined, a unit cross-sectional area is arbitrarily chosen.

Results Comparison

	Target	Mechanical APDL	Ratio
R_1 , lb	900.0	900.0	1.000
R_2 , lb	600.0	600.0	1.000

VM2: Beam Stresses and Deflections

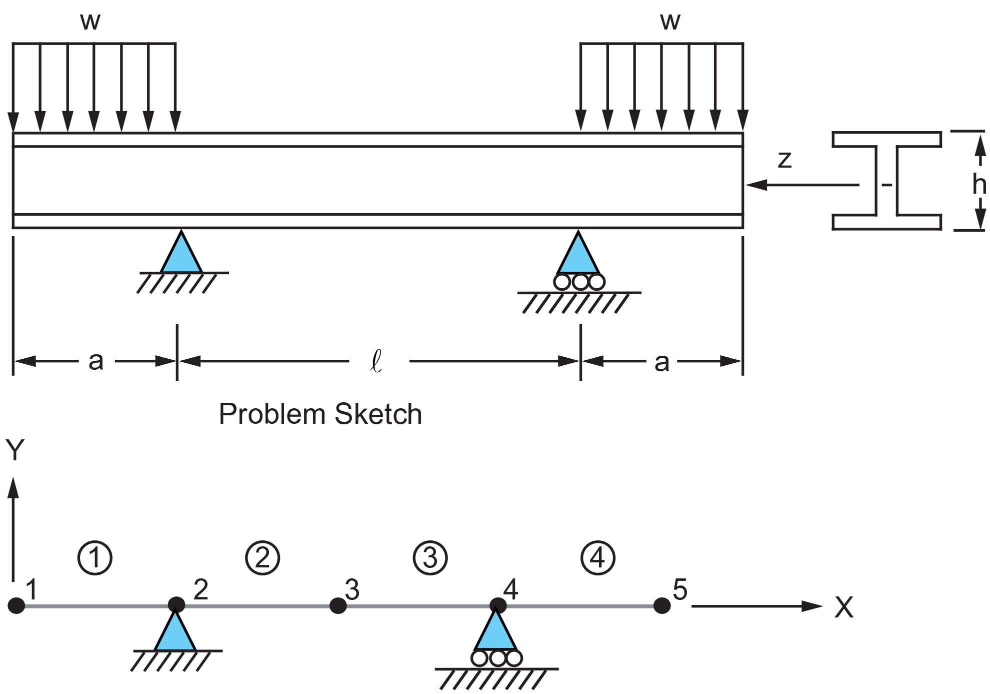
Overview

Reference:	S. Timoshenko, *Strength of Material, Part I, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 98, problem 4.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 2 Node Beam (BEAM188)
Input Listing:	vm2.dat

Test Case

A standard 30" WF beam, with a cross-sectional area A, is supported as shown below and loaded on the overhangs by a uniformly distributed load w. Determine the maximum bending stress σ in the middle portion of the beam and the deflection δ at the middle of the beam.

Figure 2.1: Beam with Cross Section Problem Sketch



Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi	ℓ = 20 ft = 240 in. a = 10 ft = 120 in. h = 30 in. $A = 50.65\ in^2$ $I_z = 7892\ in^4$	w = 10000 lb/ft = (10000/12) lb/in

Analysis Assumptions and Modeling Notes

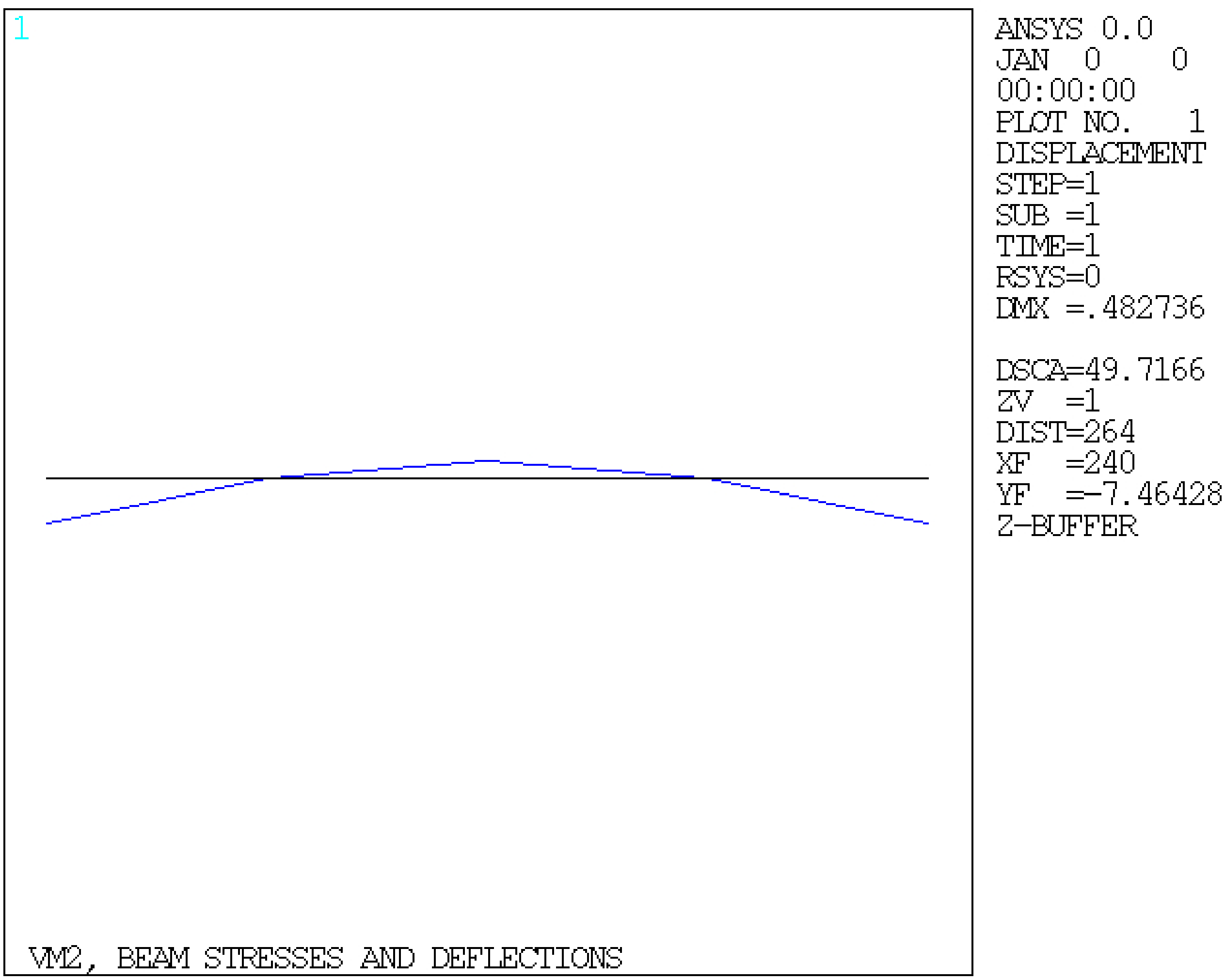
An I-section beam is modeled. The width, depth, and thickness of the flanges are chosen to obtain the required area and moment of inertia values. Consistent length units (inches) are used. A half-model could also have been used because of symmetry.

Results Comparison

	Target	Mechanical APDL	Ratio
Stress, psi	-11400.000	-11440.746	1.004
Deflection, in	0.182	0.182	1.003

1. occurs at the bottom flange of the beam

Figure 2.2: Displaced Geometry Display



VM3: Thermally Loaded Support Structure

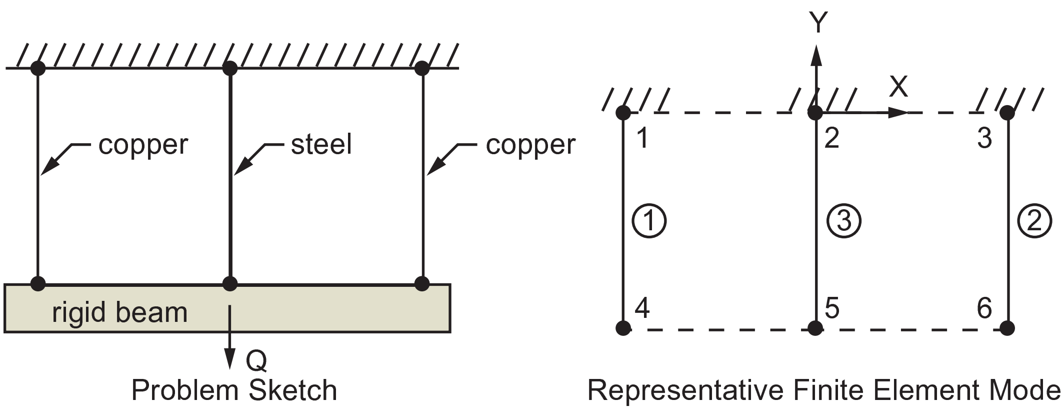
Overview

Reference:	S. Timoshenko, *Strength of Material, Part I, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 30, problem 9.
Analysis Type(s):	Static, Thermal Stress Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Spar (or Truss) Elements (LINK180)
Input Listing:	vm3.dat

Test Case

Find the stresses in the copper and steel wire structure shown below. The wires have a cross-sectional area of A. The structure is subjected to a load Q and a temperature rise of ΔT after assembly.

Figure 3.1: Support Structure Problem Sketch



Material Properties	Geometric Properties	Loading
E_c = 16 x 10^6 psi α_c = 92 x 10^{-7} in/in-°F E_s = 30 x 10^6 psi α_s = 70 x 10^{-7} in/in-°F	A = 0.1 in^2	Q = 4000 lb ΔT = 10°F

Analysis Assumptions and Modeling Notes

Length of wires (20 in.), spacing between wires (10 in.), and the reference temperature (70°F) are arbitrarily selected. The rigid lower beam is modeled by nodal coupling.

Results Comparison

	Target	Mechanical APDL	Ratio
Stress in steel, psi	19,695.	19,695.	1.000
Stress in copper, psi	10,152.	10,152.	1.000

VM4: Deflection of a Hinged Support

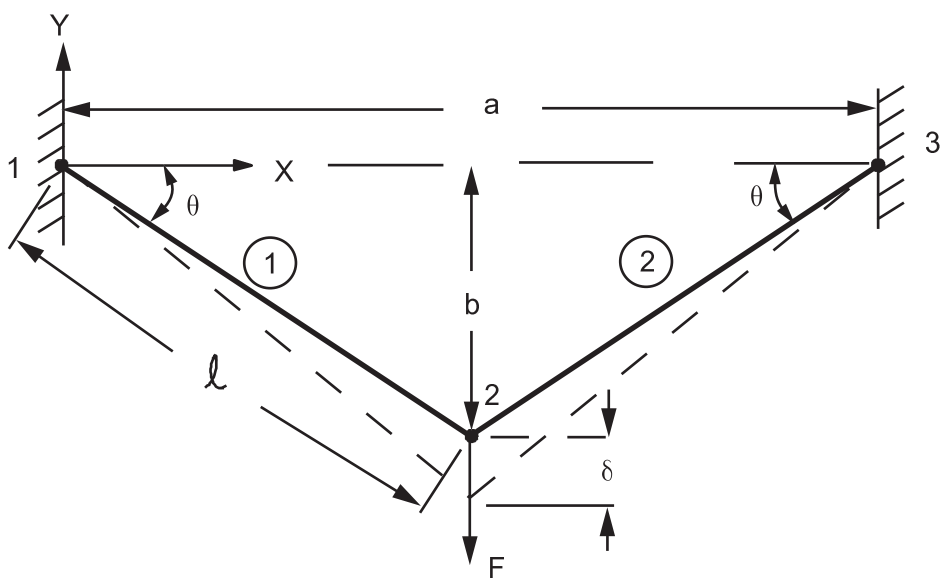
Overview

Reference:	S. Timoshenko, *Strength of Material, Part I, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 10, problem 2.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Spar (or Truss) Elements (LINK180)
Input Listing:	vm4.dat

Test Case

A structure consisting of two equal steel bars, each of length ℓ and cross-sectional area A, with hinged ends is subjected to the action of a load F. Determine the stress, σ, in the bars and the deflection, δ, of point 2. Neglect the weight of the bars as a small quantity in comparison with the load F.

Figure 4.1: Hinged Support Problem Sketch



Problem Model

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi	ℓ = 15 ft $A = 0.5$ in^2 $\Theta = 30°$	F = 5000 lb

Analysis Assumptions and Modeling Notes

Consistent length units are used. The dimensions a and b are calculated parametrically in the input as follows: $a = 2 \ell \cos \Theta$, $b = \ell \sin \Theta$.

Results Comparison

	Target	Mechanical APDL	Ratio
Stress, psi	10,000.	10,000.	1.000
Deflection, in	-0.120	-0.120	1.000

VM5: Laterally Loaded Tapered Support Structure

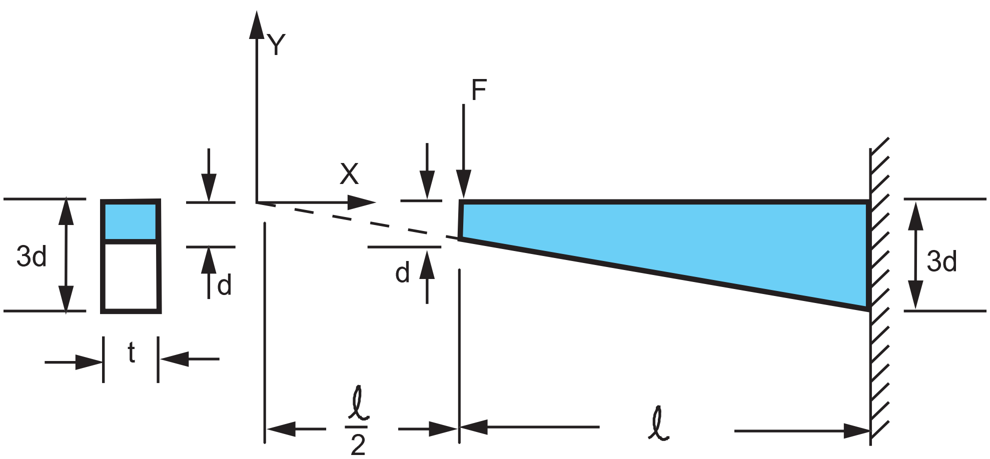
Overview

Reference:	S. H. Crandall, N. C. Dahl, *An Introduction to the Mechanics of Solids*, McGraw-Hill Book Co., Inc., New York, NY, 1959, pg. 342, problem 7.18.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4-Node Srructural Solid Elements (PLANE182) 2-D 8-Node Structural Solid Elements (PLANE183)
Input Listing:	vm5.dat

Test Case

A cantilever beam of thickness t and length ℓ has a depth which tapers uniformly from d at the tip to 3d at the wall. It is loaded by a force F at the tip, as shown. Find the maximum bending stress at the mid-length (X = ℓ) and the fixed end of the beam.

Figure 5.1: Cantilever Beam Problem Sketch



Material Properties	Geometric Properties	Loading
E = 30 x 10^6 psi υ = 0.0	ℓ = 50 in d = 3 in t = 2 in	F= 4000 lb

The PLANE183 model uses the same node numbering at the element corners as the PLANE182 model and has additional midside nodes added to all elements.

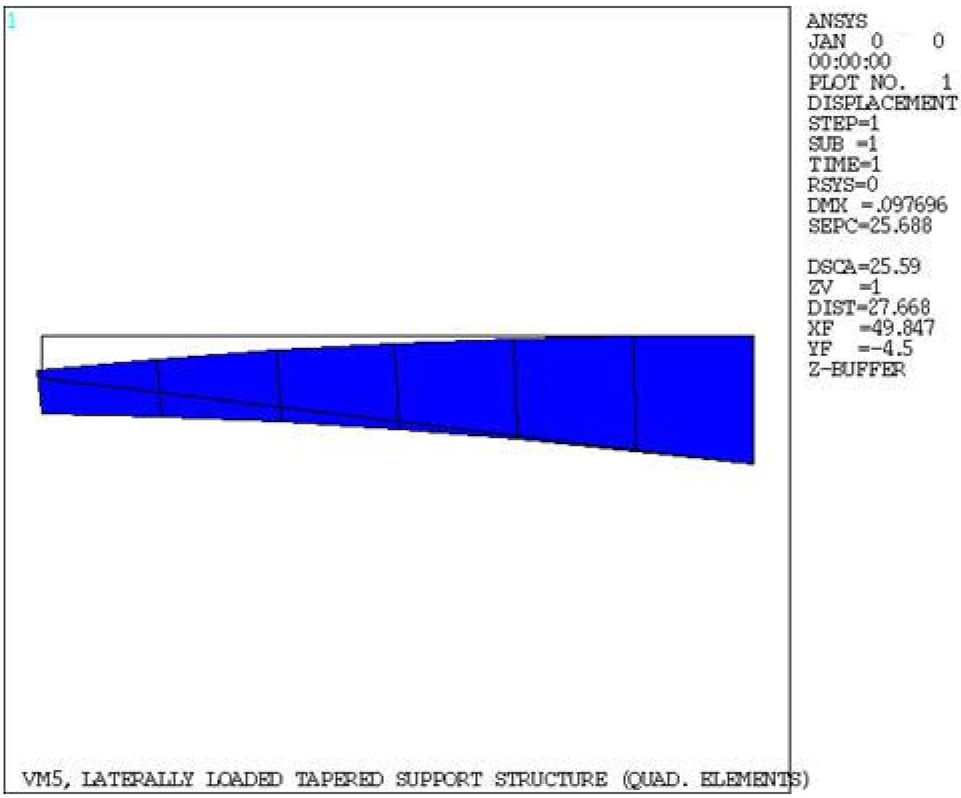
Analysis Assumptions and Modeling Notes

Two different solutions are obtained. The first solution uses lower order PLANE182 elements and the second solution uses higher order PLANE82 elements. The 2 inch thickness is incorporated by using the plane stress with thickness option. Poisson's ratio is set to 0.0 to agree with beam theory.

Results Comparison

		Target	Mechanical APDL	Ratio
PLANE182	at mid-length stress, psi	8,333.	8,163.656	.980
	at fixed end stress, psi	7,407.	7,151.096	.965
PLANE183	at mid-length stress, psi	8,333.	8,363.709	1.004
	at fixed end stress, psi	7,407.	7,408.980	1.000

Figure 5.2: Displacement Display



VM6: Pinched Cylinder

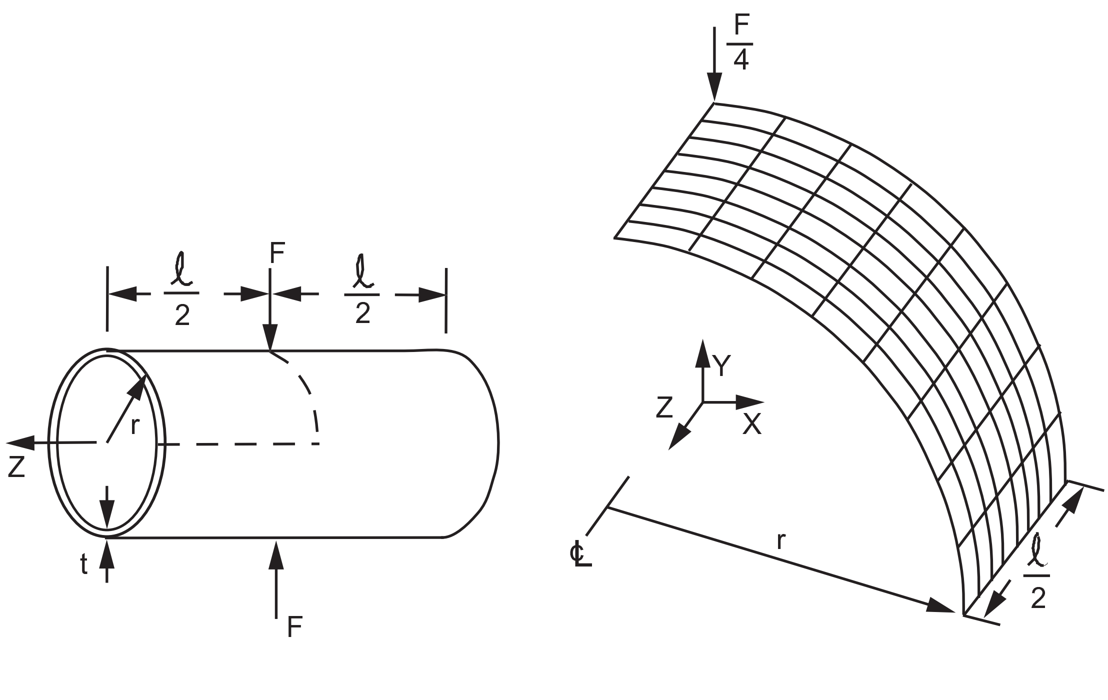
Overview

Reference:	R. D. Cook, *Concepts and Applications of Finite Element Analysis*, 2nd Edition, John Wiley and Sons, Inc., New York, NY, 1981, pp. 284-287. H. Takemoto, R. D. Cook, "Some Modifications of an Isoparametric Shell Element", *International Journal for Numerical Methods in Engineering*, Vol. 7 No. 3, 1973.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	4-Node Finite Strain Shell Elements (SHELL181) 8-Node Finite Strain Shell Elements (SHELL281)
Input Listing:	vm6.dat

Test Case

A thin-walled cylinder is pinched by a force F at the middle of the cylinder length. Determine the radial displacement δ at the point where F is applied. The ends of the cylinder are free edges.

Figure 6.1: Pinched Cylinder Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 10.5 \times 10^6$ psi $\upsilon = 0.3125$	ℓ = 10.35 in r = 4.953 in t = 0.094 in	F = 100 lb

Analysis Assumptions and Modeling Notes

A one-eighth symmetry model is used. One-fourth of the load is applied due to symmetry.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
Deflection, in SHELL181	0.1139	0.1100	0.965
Deflection, in SHELL281	0.1139	0.1137	0.998

1. H. Takemoto, R. D. Cook, "Some Modifications of an Isoparametric Shell Element".

VM7: Plastic Compression of a Pipe Assembly

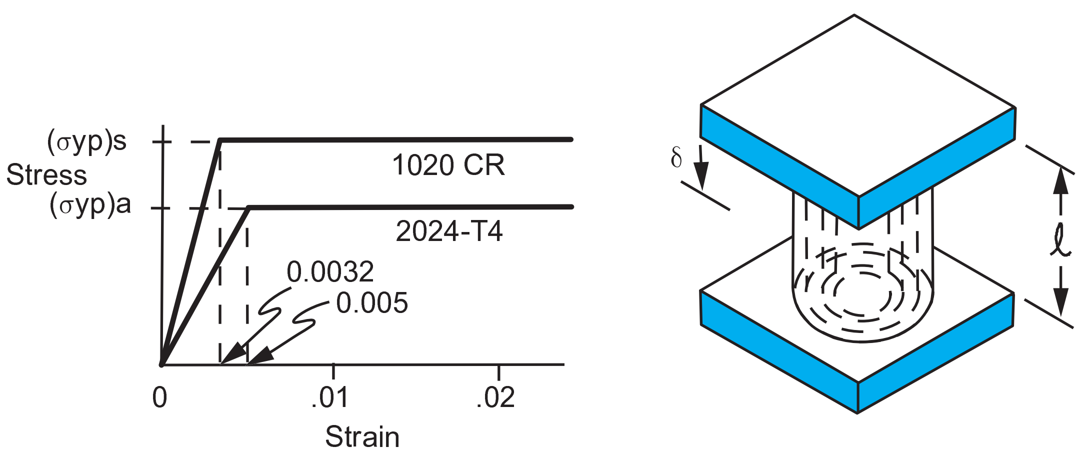
Overview

Reference:	S. H. Crandall, N. C. Dahl, *An Introduction to the Mechanics of Solids*, McGraw-Hill Book Co., Inc., New York, NY, 1959, pg. 180, ex. 5.1.
Analysis Type(s):	Static, Plastic Analysis (**ANTYPE** = 0)
Element Type(s):	Plastic Straight Pipe Element (PIPE288) 4-Node Finite Strain Shell (SHELL181) 3-D Structural Solid Elements (SOLID185)
Input Listing:	vm7.dat

Test Case

Two coaxial tubes, the inner one of 1020 CR steel and cross-sectional area A_s, and the outer one of 2024-T4 aluminum alloy and of area A_a, are compressed between heavy, flat end plates, as shown below. Determine the load-deflection curve of the assembly as it is compressed into the plastic region by an axial displacement. Assume that the end plates are so stiff that both tubes are shortened by exactly the same amount.

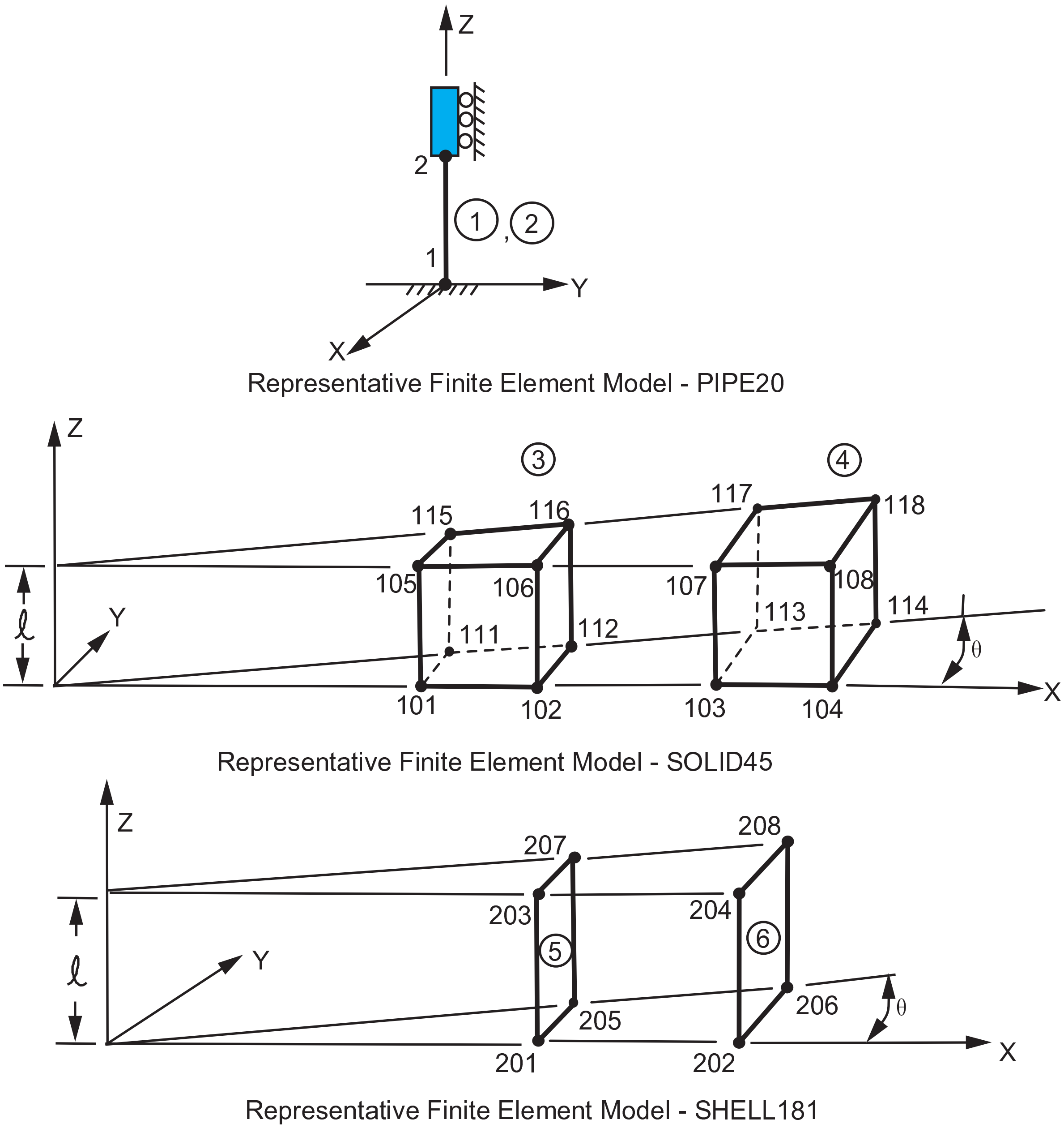
Figure 7.1: Pipe Assembly Problem Sketch



Stress - Strain Curve

Problem Sketch

Figure 7.2: Pipe Assembly Finite Element Models



Material Properties	Geometric Properties	Loading
E_s = 26,875,000 psi $\sigma_{(yp)s}$ = 86,000 psi E_a = 11,000,000 psi $\sigma_{(yp)a}$ = 55,000 psi υ = 0.3	ℓ = 10 in A_s = 7 in^2 A_a = 12 in^2	1st Load Step: δ = 0.032 in 2nd Load Step: δ = 0.050 in 3rd Load Step: δ = 0.100 in

Analysis Assumptions and Modeling Notes

The following tube dimensions, which provide the desired cross-sectional areas, are arbitrarily chosen. Inner (steel) tube: inside radius = 1.9781692 in., wall thickness = 0.5 in. Outer (aluminum) tube: inside radius = 3.5697185 in., wall thickness = 0.5 in.

The problem can be solved in three ways:

- using PIPE288 - the plastic straight pipe element
- using SOLID185 - the 3-D structural solid element
- using SHELL181 - the 4-Node Finite Strain Shell

In the SOLID185 and SHELL181 cases, since the problem is axisymmetric, only a one element Θ-sector is modeled. A small angle Θ = 6° is arbitrarily chosen to reasonably approximate the circular boundary with straight sided elements. The nodes at the boundaries have the UX (radial) degree of freedom coupled. In the SHELL181 model, the nodes at the boundaries additionally have the ROTY degree of freedom coupled.

Results Comparison

		Target	Mechanical APDL [1]	Ratio
PIPE288	Load, lb for Deflection = 0.032 in	1,024,400	1,024,400	1.00
	Load, lb for Deflection = 0.05 in	1,262,000	1,262,000	1.00
	Load, lb for Deflection = 0.1 in	1,262,000	1,262,000	1.00

1. From POST1 FSUM of bottom nodal forces (ΣFZ) for PIPE288 model.

		Target	Mechanical APDL [1]	Ratio
SOLID185	Load, lb for Deflection = 0.032 in	1,024,400	1,022,529	0.998
	Load, lb for Deflection = 0.05 in	1,262,000	1,259,695	0.998
	Load, lb for Deflection = 0.1 in	1,262,000	1,259,695	0.998
SHELL181	Load, lb for Deflection = 0.032 in	1,024,400	1,023,932	1.000
	Load, lb for Deflection = 0.05 in	1,262,000	1,261,654	1.000
	Load, lb for Deflection = 0.1 in	1,262,000	1,261,708	1.000

1. From POST1 FSUM of bottom nodal forces (ΣFZ) X 360°/6°(Identified as parameter "LOAD") for SOLID185 and SHELL181 models.

VM8: Parametric Calculation of Point-to-Point Distances

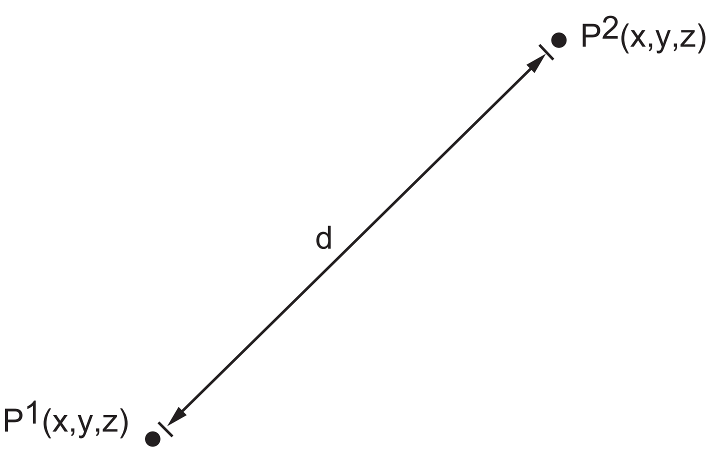
Overview

Reference:	Any Basic Geometry Text
Analysis Type(s):	Parametric Arithmetic
Element Type(s):	None
Input Listing:	vm8.dat

Test Case

Write a user file macro to calculate the distance *d* between either nodes or keypoints in PREP7. Define abbreviations for calling the macro and verify the parametric expressions by using the macro to calculate the distance between nodes N_1 and N_2 and between keypoints K_3 and K_4.

Figure 8.1: Parametric Calculation Problem Sketch



Geometric Properties
N_1 (x, y, z) = 1.5,2.5,3.5
N_2 (x, y, z) = -3.7,4.6,-3
K_3 (x, y, z) = 100,0,30
K_4 (x, y, z) = -200,25,80

Analysis Assumptions and Modeling Notes

The user file is created by the ***CREATE** command within the run. In normal use, this file would most likely already exist locally. Colons are used in the user file to create non-echoing comments (the colon character specifies a branching label in Mechanical APDL). The active coordinate system is saved and restored within the macro to ensure Cartesian coordinates in the distance calculations and to re-establish the active coordinate system after the macro is used. Lowercase input is used throughout. Input case is preserved by Mechanical APDL where appropriate (system-dependent).

Results Comparison

	Target	Mechanical APDL	Ratio
N_1 - N_2 distance (LEN2)	8.5849	8.58	1.000
K_3 - K_4 distance (LEN1)	305.16	305.16	1.000

VM9: Large Lateral Deflection of Unequal Stiffness Springs

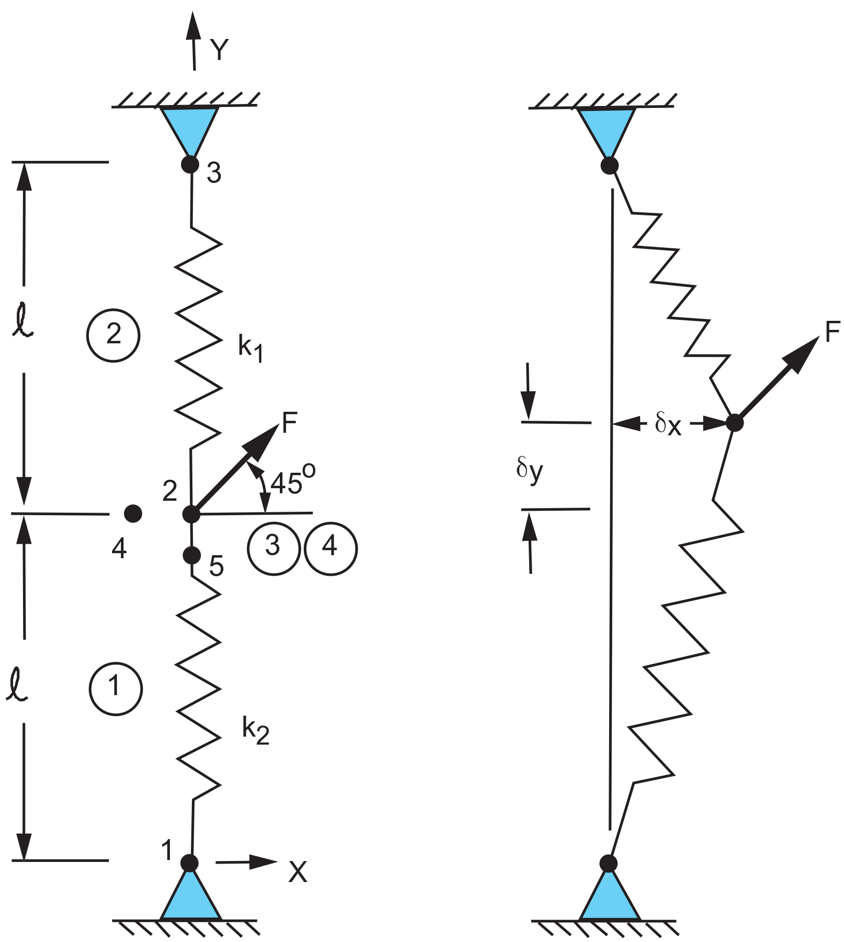
Overview

Reference:	G. N. Vanderplaats, *Numerical Optimization Techniques for Engineering Design with Applications*, McGraw-Hill Book Co., Inc., New York, NY, 1984, pp. 72-73, ex. 3-1.
Analysis Type(s):	Nonlinear Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	Spring-Damper Elements (COMBIN14) Combination Elements (COMBIN40)
Input Listing:	vm9.dat

Test Case

A two-spring system is subjected to a force F as shown below. Determine the strain energy of the system and the displacements δ_x and δ_y.

Figure 9.1: Unequal Stiffness Springs Problem Sketch



Geometric Properties	Loading
ℓ = 10 cm k_1 = 8 N/cm k_2 = 1 N/cm m = 1	$F = 5\sqrt{2}\,N$

Analysis Assumptions and Modeling Notes

The solution to this problem is best obtained by adding mass and using the "slow dynamics" technique with approximately critical damping. Combination elements (COMBIN40) are used to provide damping in the X and Y directions. Approximate damping coefficients c_x and c_y, in the x and y directions respectively, are determined from

$$c_x = 2\sqrt{k_x m} \qquad c_y = 2\sqrt{k_y m}$$

where m is arbitrarily assumed to be unity. k_x and k_y cannot be known before solving so are approximated by $k_y = k_2 = 1$ N/cm and $k_x = k_y/2 = 0.5$ N/cm, hence $c_x = 1.41$ and $c_y = 2.0$. Large deflection analysis is performed due to the fact that the resistance to the load is a function of the deformed position. POST1 is used to extract results from the solution phase.

Results Comparison

	Target	Mechanical APDL	Ratio
Strain Energy, N-cm	24.01	24.011	1.000
Deflection_x , cm	8.631	8.632	1.000
Deflection_y , cm	4.533	4.533	1.000

VM10: Bending of a Tee-Shaped Beam

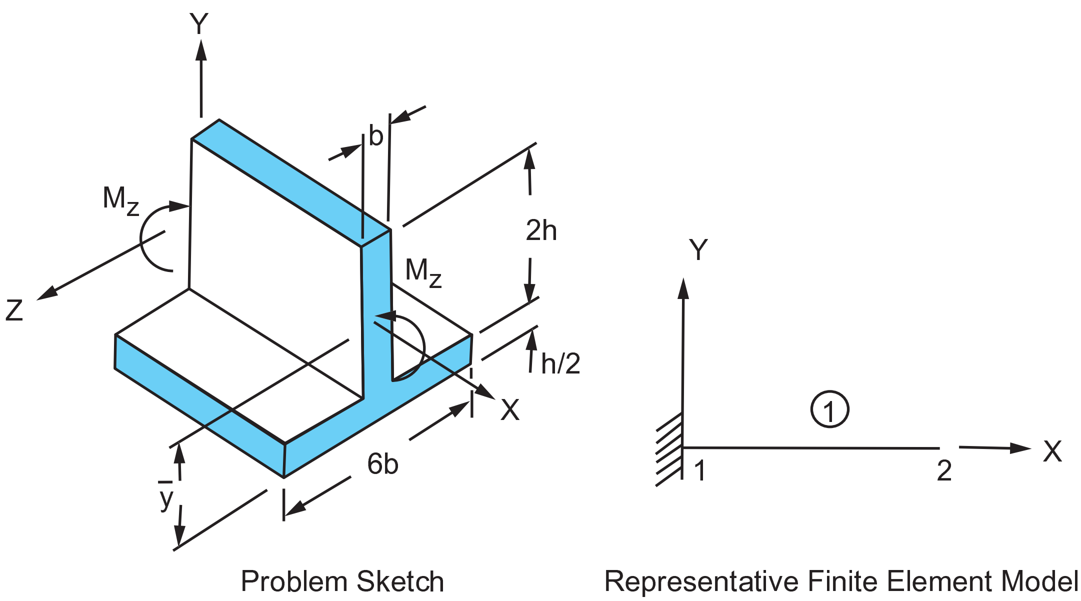
Overview

Reference:	S. H. Crandall, N. C. Dahl, *An Introduction to the Mechanics of Solids*, McGraw-Hill Book Co., Inc., New York, NY, 1959, pg. 294, ex. 7.2.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 2 Node Beam (BEAM188)
Input Listing:	vm10.dat

Test Case

Find the maximum tensile and compressive bending stresses in an unsymmetric T beam subjected to uniform bending M_z, with dimensions and geometric properties as shown below.

Figure 10.1: Tee-Shaped Beam Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi	b = 1.5 in h = 8 in	M_z = 100,000 in-lb

Analysis Assumptions and Modeling Notes

A length of 100 in. is arbitrarily selected since the bending moment is constant. A T-section beam is modeled using flange width (6b), flange thickness (h/2), overall depth (2h + h/2), and stem thickness (b), input using **SECDATA**.

Results Comparison

	Target	Mechanical APDL	Ratio
$Stress_{BEND,Bot}$, psi	300.	300.	1.00
$Stress_{BEND,Top}$, psi	-700.	-700.	1.00

VM11: Residual Stress Problem

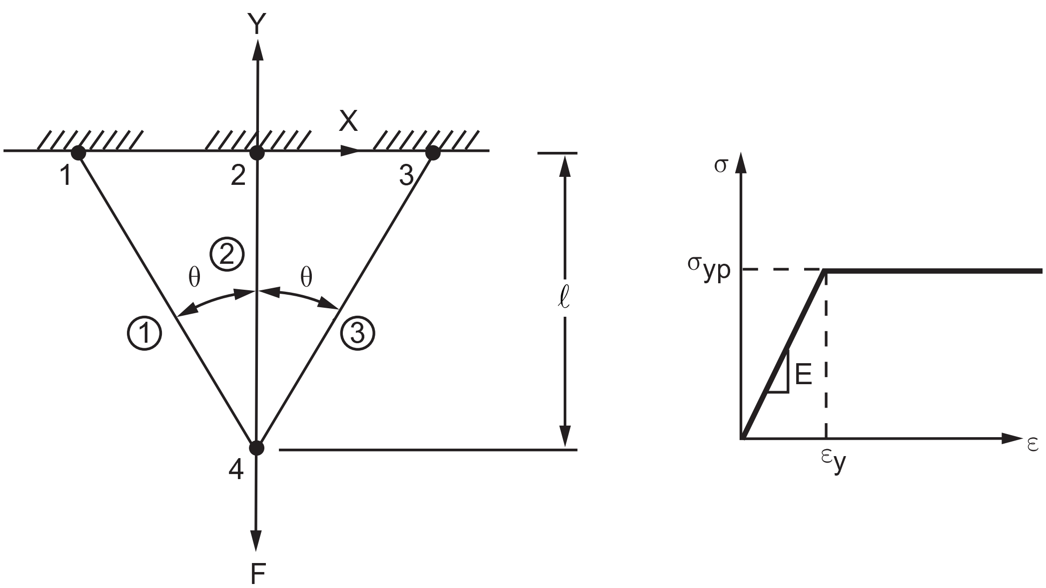
Overview

Reference:	S. H. Crandall, N. C. Dahl, *An Introduction to the Mechanics of Solids*, McGraw-Hill Book Co., Inc., New York, NY, 1959, pg. 234, problem 5.31.
Analysis Type(s):	Static, Plastic Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Spar (or Truss) Elements (LINK180)
Input Listing:	vm11.dat

Test Case

A chain hoist is attached to the ceiling through three tie rods as shown below. The tie rods are made of cold-rolled steel with yield strength σ_{yp} and each has an area A. Find the deflection δ at load F_1 when the deflections are elastic in all three rods. When the frame is loaded to F_2 (where all three rods become fully plastic), and then unloaded, find the residual stress σ_r in the central rod.

Figure 11.1: Residual Stress Problem Sketch



Problem Model

Stress-Strain Curve

Material Properties	Geometric Properties	Loading
σ_{yp} = 30,000 psi E = 30 x 10^6 psi	A = 1 in^2 ℓ = 100 in Θ = 30°	F_1 = 51,961.5 lb F_2 = 81,961.5 lb

Note

F_1 and F_2 values are back-calculated from theoretical relationships.

Analysis Assumptions and Modeling Notes

Automatic load stepping (**AUTOTS**,ON) is used to obtain the nonlinear plastic solution (load steps 2 and 3).

Results Comparison

	Target	Mechanical APDL	Ratio
Deflection at F_1 , in	-0.07533	-0.07534	1.000
$Stress_r$, psi	-5,650	-5,650.34429 [1]	1.000

1. SAXL in element solution printout for element 2.

VM12: Combined Bending and Torsion

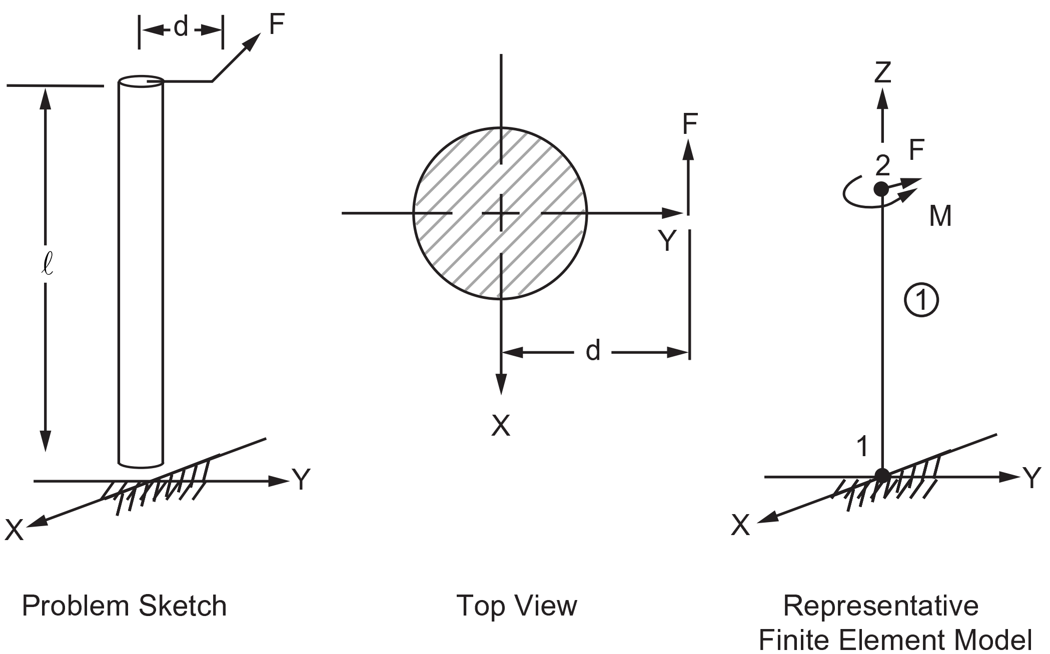
Overview

Reference:	S. Timoshenko, *Strength of Material, Part I, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 299, problem 2.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Elastic Straight Pipe Element (PIPE16) 3-D 2 Node pipe element (PIPE288)
Input Listing:	vm12.dat

Test Case

A vertical bar of length ℓ is subjected to the action of a horizontal force F acting at a distance d from the axis of the bar. Determine the maximum principal stress σ_{max} and the maximum shear stress τ_{max} in the bar.

Figure 12.1: Combined Bending and Torsion Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.3$	ℓ = 25 ft d = 3 ft Section modulus (I/c) = 10 in^3 Outer Diameter = 4.67017 in Wall Thickness = 2.33508 in	F = 250 lb M = Fd = 9000 in-lb

Analysis Assumptions and Modeling Notes

Use consistent length units of inches. Real constants for PIPE16 and section properties for PIPE288 are used to define the pipe Outer Diameter and Wall Thickness. These values are calculated for a solid cross-section from the given section modulus. The offset load is applied as a centroidal force and a moment.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
PIPE16			
Principal stress$_{max}$, psi	7527.	7527.[2]	1.000
Shear stress$_{max}$, psi	3777.	3777.[3]	1.000
PIPE288			
Principal stress$_{max}$, psi	7527.	7527	1.000
Shear stress$_{max}$, psi	3777.	3777	1.000

1. Solution recalculated

2. Corresponds to S1MX in element solution printout

3. Calculated as SINTMX/2 (SINTMX from element solution printout) since SINTMX is defined as twice the maximum shear stress.

VM13: Cylindrical Shell Under Pressure

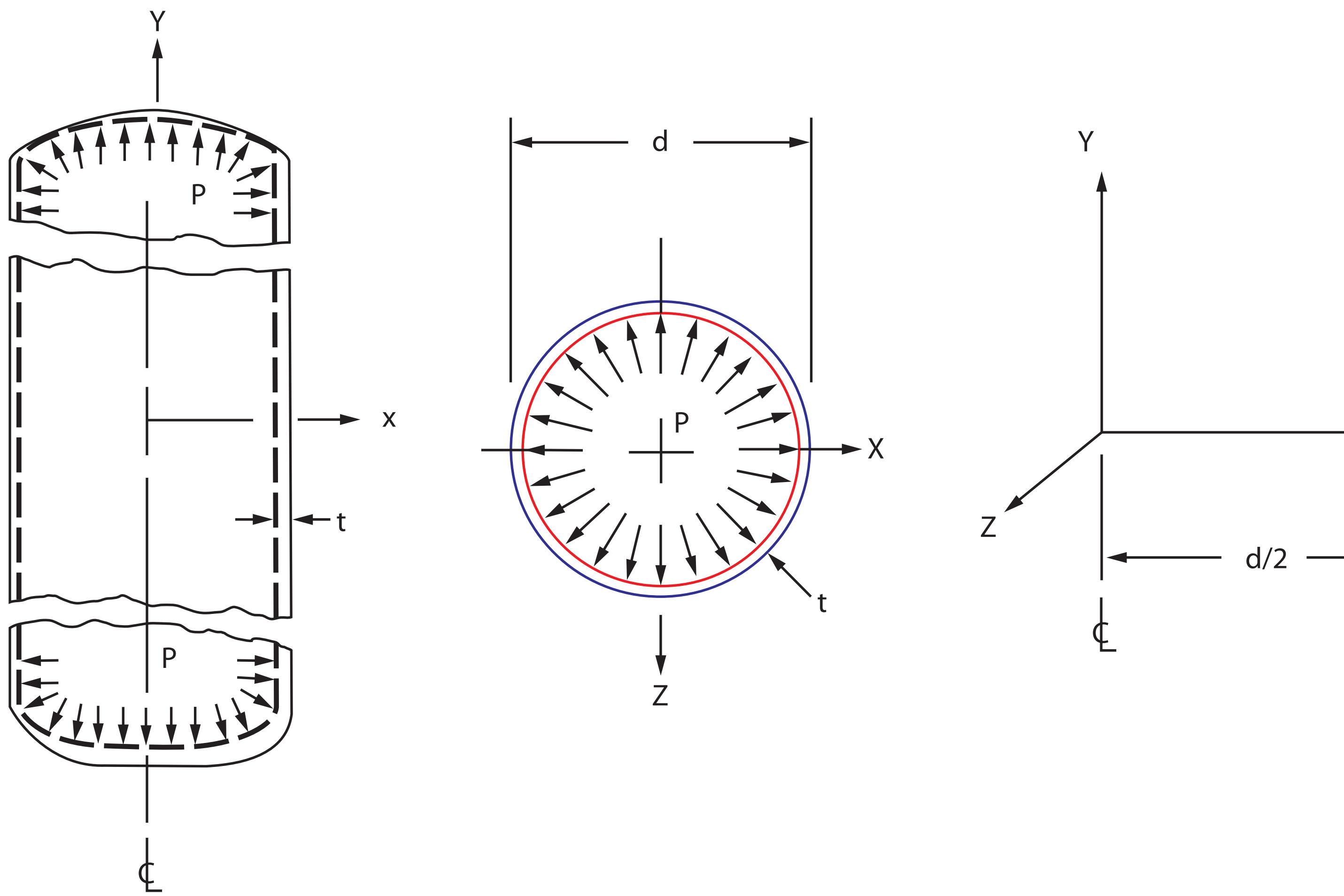
Overview

Reference:	S. Timoshenko, *Strength of Material, Part I, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 45, article 11. A. C. Ugural, S. K. Fenster, *Advanced Strength and Applied Elasticity*, Elsevier, 1981.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-Node Finite Strain Axisymmetric Shell (SHELL208)
Input Listing:	vm13.dat

Test Case

A long cylindrical pressure vessel of mean diameter d and wall thickness t has closed ends and is subjected to an internal pressure P. Determine the axial stress σ_y and the hoop stress σ_z in the vessel at the midthickness of the wall.

Figure 13.1: Cylindrical Shell Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.3$	t = 1 in d = 120 in	P = 500 psi

Analysis Assumptions and Modeling Notes

An arbitrary axial length of 10 inches is selected. Nodal coupling is used in the radial direction. An axial force of 5654866.8 lb ($(P\pi d^2)/4$) is applied to simulate the closed-end effect.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
$Stress_y$, psi	15,000.	15,000.[2]	1.000
$Stress_z$, psi	29,749.	30,000.	1.008

1. Axial Stress σ_y is calculated (per S. Timoshenko, *Strength of Material, Part I, Elementary Theory and Problems*) using thin shell theory. Since SHELL208 uses thick shell logic to determine stress variations through the thickness, the hoop stress σ_z is calculated per A. C. Ugural, S. K. Fenster, *Advanced Strength and Applied Elasticity*.

2. SX in element solution printout since element X-axis is parallel to global Y-axis.

VM14: Large Deflection Eccentric Compression of a Column

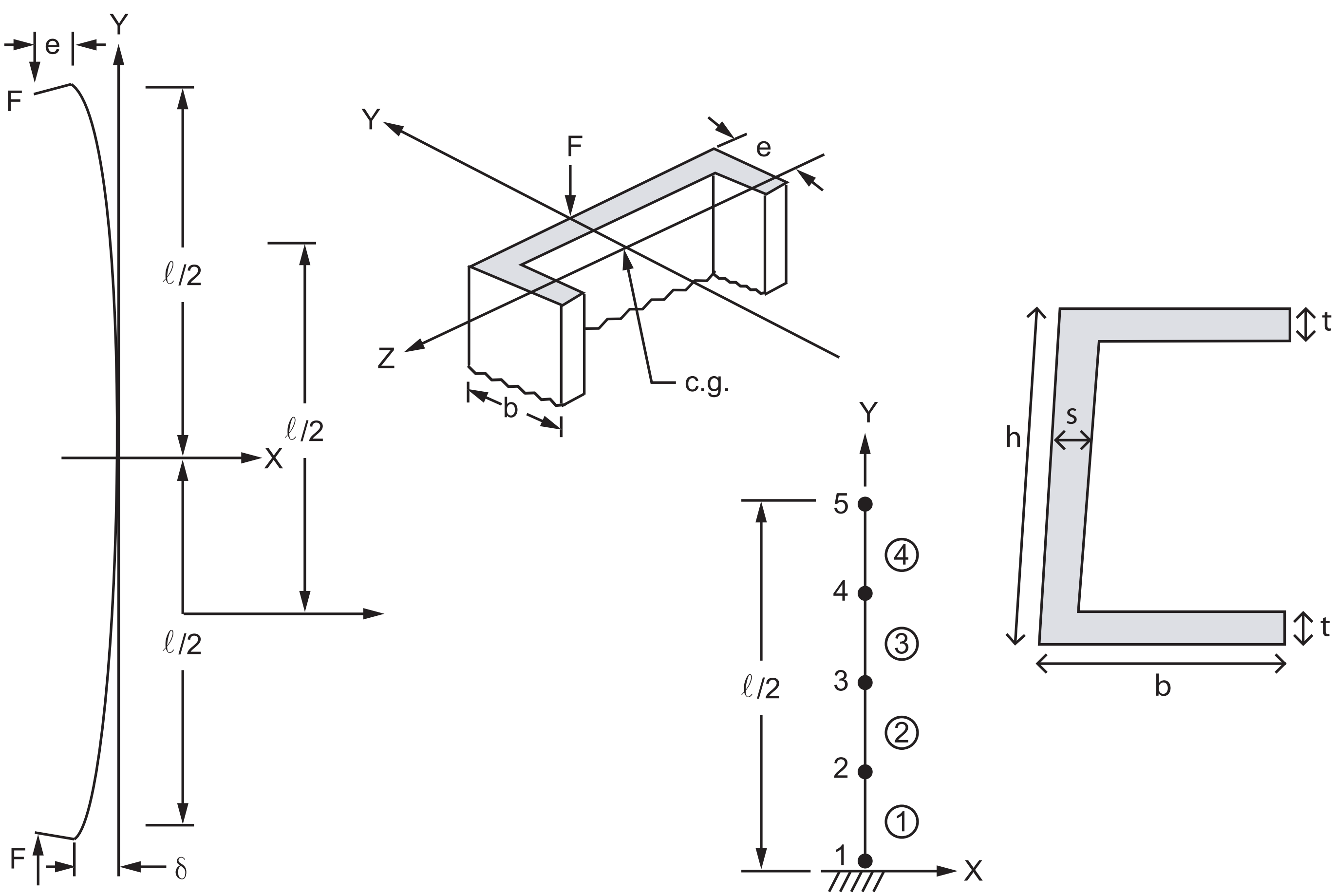
Overview

Reference:	S. Timoshenko, *Strength of Material, Part I, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 263, problem 1.
Analysis Type(s):	Static, Large Deflection Analysis (**ANTYPE** = 0)
Element Type(s):	Elastic Tapered Unsymmetric Beam Elements (BEAM188)
Input Listing:	vm14.dat

Test Case

Find the deflection Δ at the middle and the maximum tensile and compressive stresses in an eccentrically compressed steel strut of length ℓ. The cross-section is a channel with moment of inertia I, area A, and flange width b. The ends are pinned at the point of load application. The distance between the centroid and the back of the channel is e, and the compressive force F acts in the plane of the back of the channel and in the symmetry plane of the channel.

Figure 14.1: Slender Column Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.3$	ℓ = 10 ft h = 8 in A = 0.22 in t = 0.39 in e = 0.6465 in b = 2.26 in	F = 4,000 lb

Analysis Assumptions and Modeling Notes

Only one-half of the structure is modeled because of symmetry. The boundary conditions for the equivalent half model become fixed-free. Large deflection is needed since the stiffness of the structure and the loading change significantly with deflection. The offset e is defined in the element coordinate system.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
Deflection, in	0.1086	0.1088[2]	1.002
$Stress_{tens}$, psi	1803.6	1807.3448	1.002
$Stress_{comp}$, psi	-2394.5	-2396.0007	1.001

1. Solution recalculated

2. Corresponds to negative of X-deflection at node 5

VM15: Bending of a Circular Plate Using Axisymmetric Elements

Overview

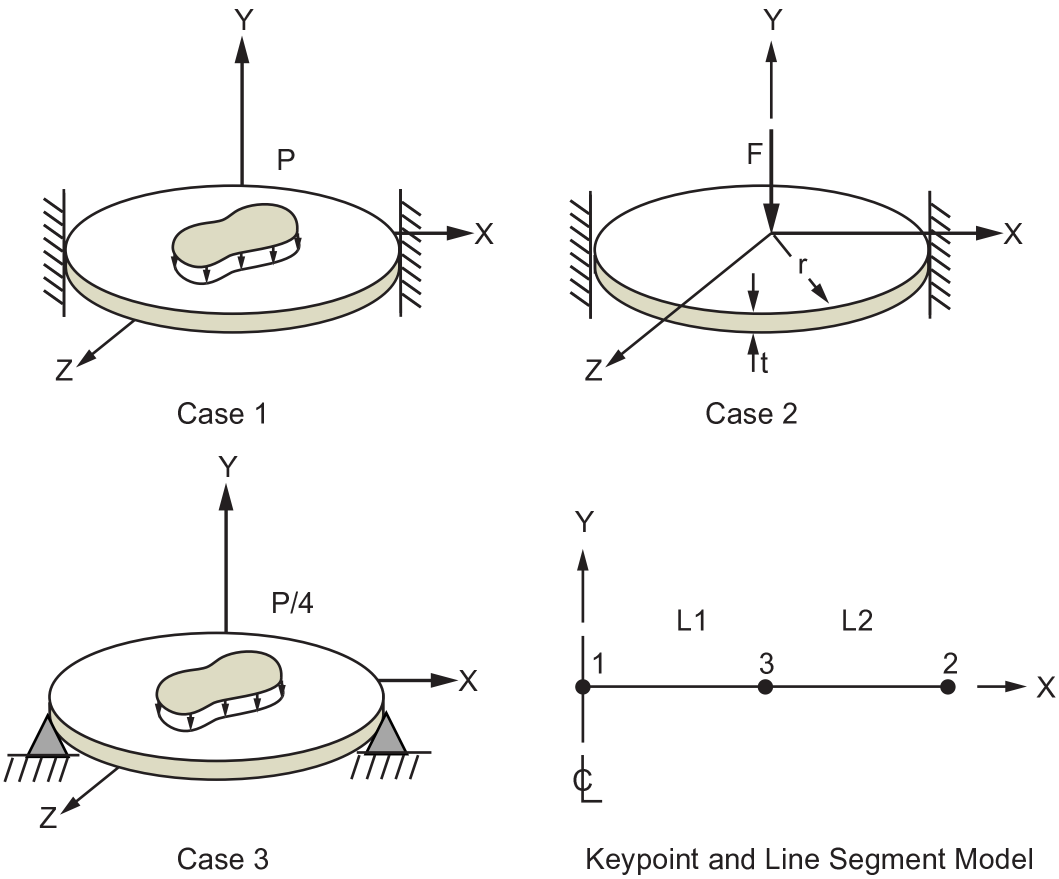
Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pp. 96, 97, and 103.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-Node Finite Strain Axisymmetric Shell (SHELL208)
Input Listing:	vm15.dat

Test Case

A flat circular plate of radius r and thickness t is subject to various edge constraints and surface loadings. Determine the deflection δ at the middle and the maximum stress σ_{max} for each case.

Case 1: Uniform loading P, clamped edge.
Case 2: Concentrated center loading F, clamped edge.
Case 3: Uniform loading P/4, simply supported edge.

Figure 15.1: Flat Circular Plate Problem Sketch



Material Properties	Geometric Properties	Loading
E = 30 x 10^6 psi	r = 40 in	P = 6 psi

Material Properties	Geometric Properties	Loading
$\upsilon = 0.3$	t = 1 in	F = 7,539.82 lb

Analysis Assumptions and Modeling Notes

The stiffness matrix formed in the first load step is automatically reused in the second load step. A new stiffness matrix is automatically formed in the third load step because of changed boundary constraints. The mesh density is biased near the centerline and outer edge to recover stress values near those points.

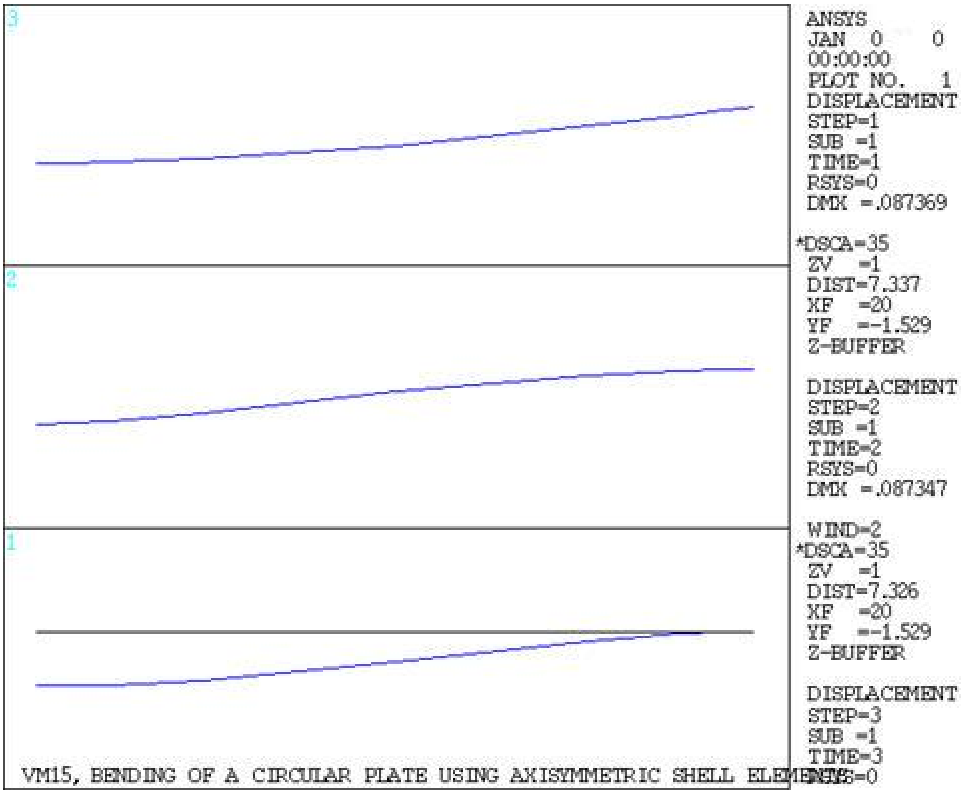
Results Comparison

		Target	Mechanical APDL [1]	Ratio
Case 1	Deflection, in	-0.08736	-0.08764	1.003
	$Stress_{max}$, psi	7200.	7040.373	0.978
Case 2	Deflection, in	-0.08736	-0.08827	1.010
	$Stress_{max}$, psi[2]	3600.	3568.272	0.991
Case 3	Deflection, in	-0.08904	-0.08911	1.001
	$Stress_{max}$, psi	2970.	2966.418	0.999

1. Theoretical σ_{max} occurs at a node location; Mechanical APDL results, taken from element solution printout, are at the centroid of the nearest element.

2. This result is at the edge of the plate since point loading causes (theoretically) infinite stresses at the point of load application.

Figure 15.2: Displaced Geometry Displays



Window 1: Uniform Loading, Clamped Edge
Window 2: Concentrated Loading, Clamped Edge
Window 3: Uniform Loading Simply-supported Edge

VM16: Bending of a Solid Beam (Plane Elements)

Overview

Reference:	R. J. Roark, *Formulas for Stress and Strain*, 4th Edition, McGraw-Hill Book Co., Inc., New York, NY, 1965, pp. 104, 106.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Structural Solid Elements (PLANE42) 2-D 4 Node structural elements(PLANE182)
Input Listing:	vm16.dat

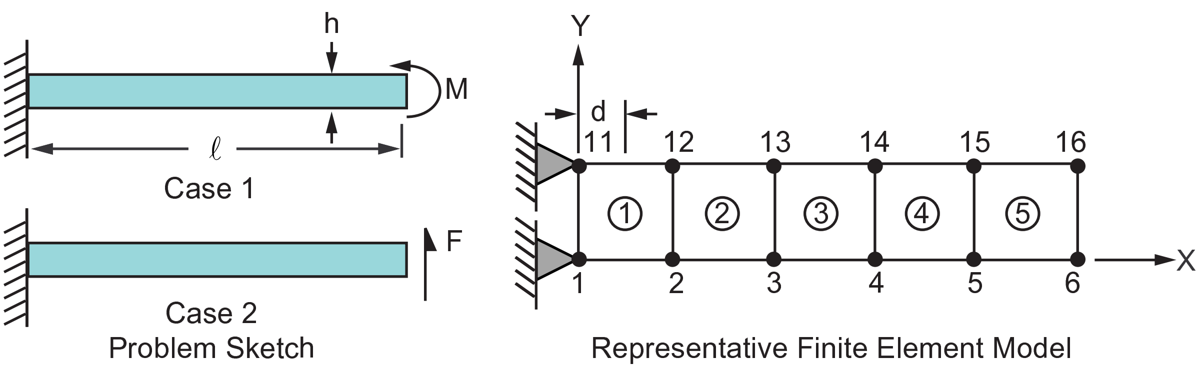
Test Case

A beam of length ℓ and height h is built-in at one end and loaded at the free end with:

- a moment M
- a shear force F

For each case, determine the deflection δ at the free end and the bending stress σ_{Bend} a distance d from the wall at the outside fiber.

Figure 16.1: Bending of a Solid Beam with Plane Elements Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.0$	ℓ = 10 in h = 2 in d = 1 in	Case 1, M = 2000 in-lb Case 2, F = 300 lb

Analysis Assumptions and Modeling Notes

The stiffness matrix formed in the first load step is also used in the second load step (automatically determined by Mechanical APDL). The end moment is represented by equal and opposite forces separated by a distance h. The bending stress is obtained from face stresses on element 1.

Results Comparison

		Target	Mechanical APDL	Ratio
PLANE42				
Case 1	Deflection, in	0.00500	0.00500	1.000
	$Stress_{Bend}$, psi	3000	3000[1]	1.000
Case 2	Deflection, in	0.00500	0.00505	1.010
	$Stress_{Bend}$, psi	4050	4050[1]	1.000
PLANE182				
Case 1	Deflection, in	0.00500	0.00500	1.000
	$Stress_{Bend}$, psi	3000	3000	1.000
Case 2	Deflection, in	0.00500	0.00505	1.010
	$Stress_{Bend}$, psi	4050	4050	1.000

1. S(PAR) in face printout for element 1 in element solution printout.

VM17: Snap-Through Buckling of a Hinged Shell

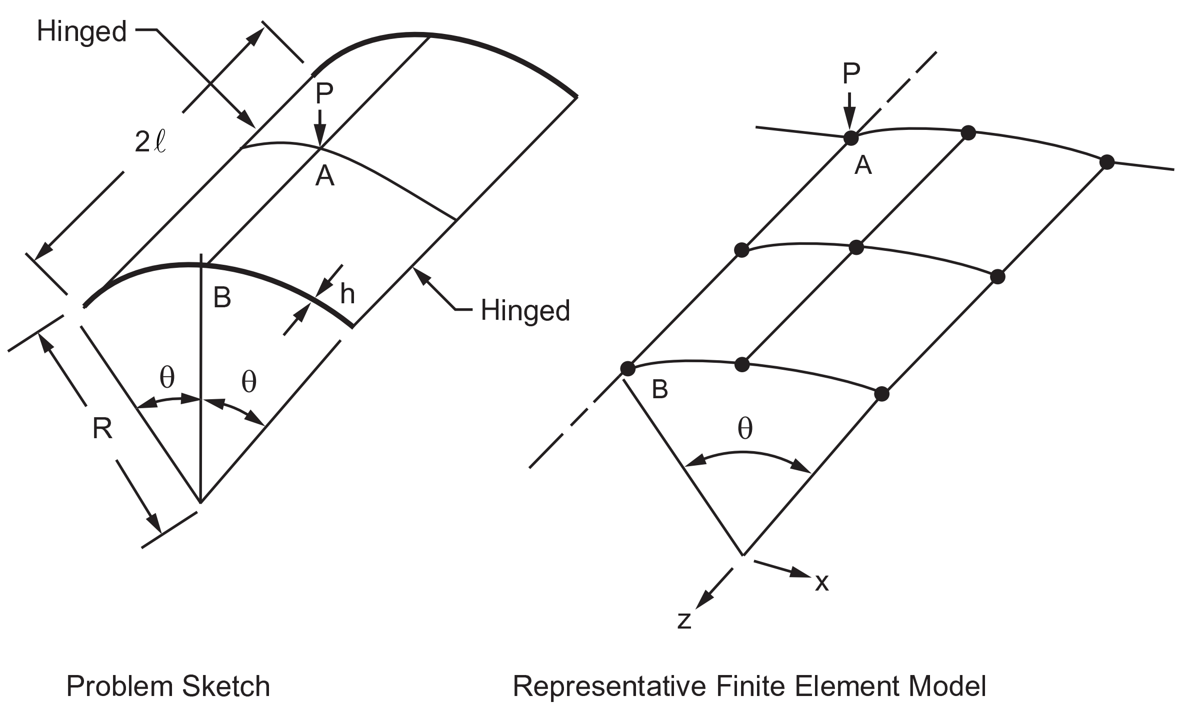
Overview

Reference:	C. C. Chang, "Periodically Restarted Quasi-Newton Updates in Constant Arc-Length Method", *Computers and Structures*, Vol. 41 No. 5, 1991, pp. 963-972.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Elastic Shell Elements (SHELL63) 4-Node Finite Strain Shell Elements (SHELL181) 8-Node Finite Strain Shell Elements (SHELL281)
Input Listing:	vm17.dat

Test Case

A hinged cylindrical shell is subjected to a vertical point load (P) at its center. Find the vertical displacement (UY) at points A and B for the load of 1000 N.

Figure 17.1: Hinged Shell Problem Sketch



Material Properties	Geometric Properties	Loading
E = 3.10275 kN/mm^2 υ = 0.3	R = 2540 m ℓ = 254 m h = 6.35 m Θ = 0.1 rad	P = 1000 N

Analysis Assumptions and Modeling Notes

Due to symmetry, only a quarter of the structure is analyzed. The structure exhibits the nonlinear postbuckling behavior under the applied load. Therefore, a large deflection analysis is performed using the arc length solution technique. The results are observed in POST26.

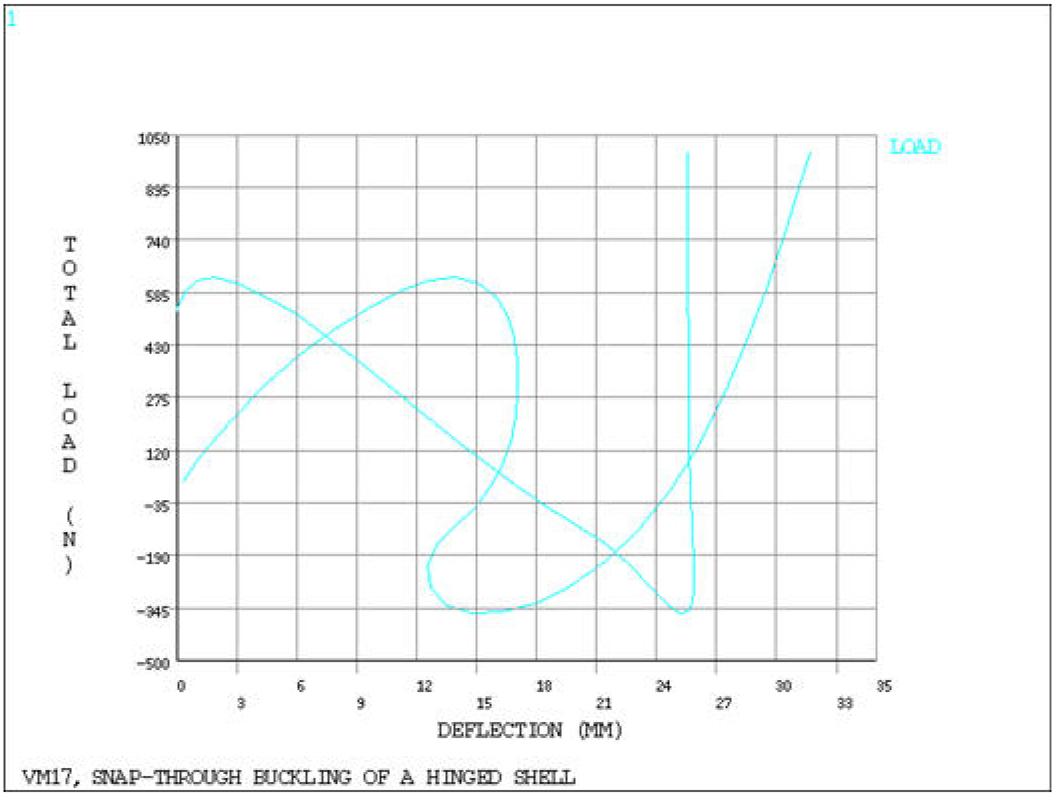
Three different analyses are performed, the first using electric shell elements (SHELL63), the second using low order finite strain shell elements (SHELL181), and the third using high order finite strain shell elements (SHELL281).

Results Comparison

	Target[1]	Mechanical APDL	Ratio
SHELL63			
UY @ A, mm	-30.0	-31.7	1.057
UY @ B, mm	-26.0	-25.8	0.994
SHELL181			
UY @ A, mm	-30.0	-31.5	1.051
UY @ B, mm	-26.0	-26.9	1.035
SHELL281			
UY @ A, mm	-30.0	-31.3	1.043
UY @ B, mm	-26.0	-26.5	1.021

1. Target results are from graphical solution

Figure 17.2: Deflection and Total Load Plot



VM18: Out-of-Plane Bending of a Curved Bar

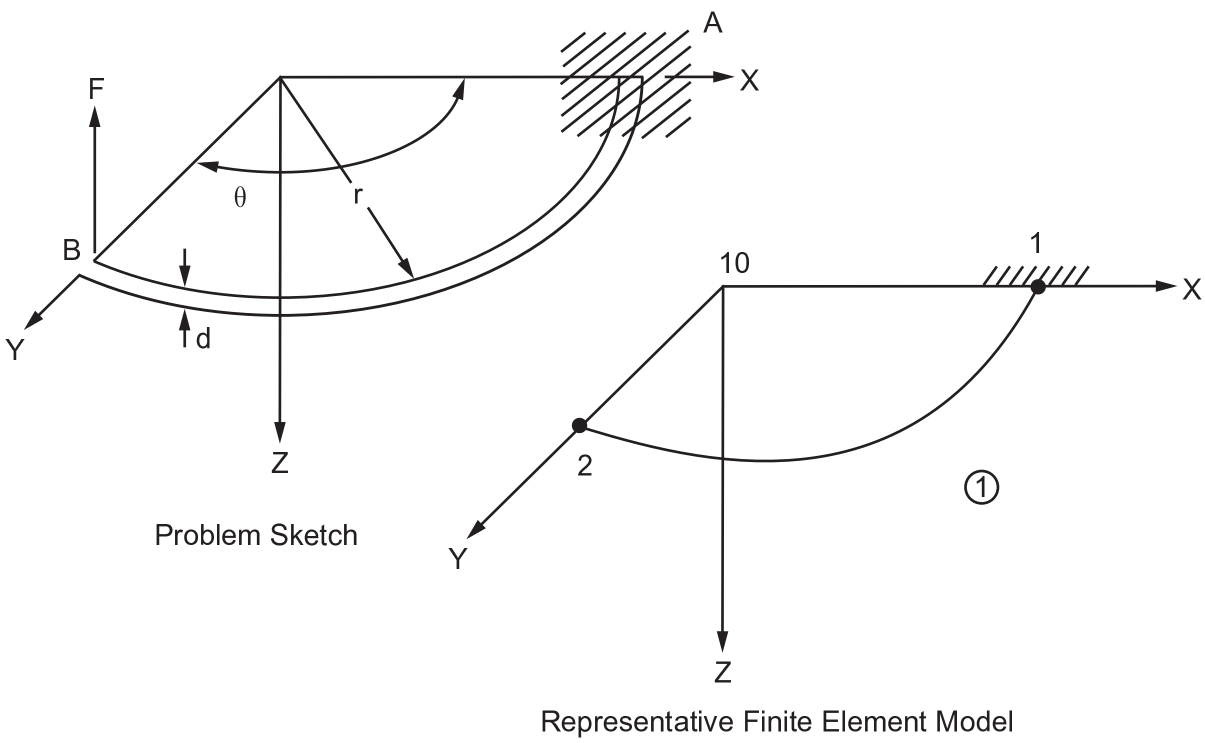
Overview

Reference:	S. Timoshenko, *Strength of Material, Part I, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 412, eq. 241.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Elastic Curved Pipe Element (PIPE18) 3-D 3 Node Elbow Element (ELBOW290)
Input Listing:	vm18.dat

Test Case

A portion of a horizontal circular ring, built-in at A, is loaded by a vertical (Z) load F applied at the end B. The ring has a solid circular cross-section of diameter d. Determine the deflection δ at end B, the maximum bending stress σ_{Bend}, and the maximum torsional shear stress τ.

Figure 18.1: Curved Bar Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.3$	r = 100 in d = 2 in $\Theta = 90°$	F = 50 lb

Analysis Assumptions and Modeling Notes

Node 10 is arbitrarily located on the radius of curvature side of the element to define the plane of the elbow when PIPE18 elements are used. The wall thickness is set to half the diameter for a solid bar.

Results Comparison

	Target	Mechanical APDL	Ratio
PIPE18			
Deflection, in	-2.648	-2.650	1.001
$Stress_{Bend}$, psi	6366.	6366.198[1]	1.000
Shear stress, psi	-3183.	-3183.099[2]	1.000
ELBOW290			
Deflection, in	-2.648	-2.692	1.016
$Stress_{Bend}$, psi	6366.	6283.925	0.987
Shear stress, psi	-3183.	3182.300	1.000

1. Corresponds to maximum SAXL at 0° angle location in element solution output.

2. Corresponds to SXH at 0° angle location in element solution output.

VM19: Random Vibration Analysis of a Deep Simply-Supported Beam

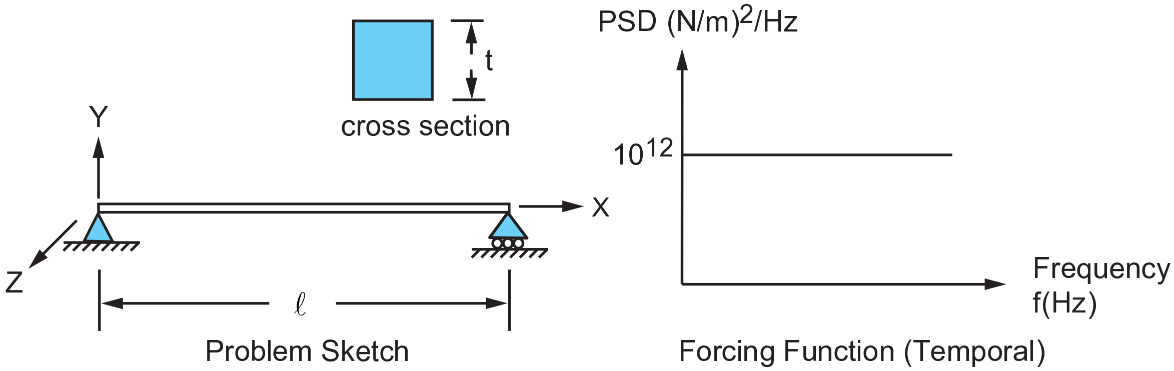
Overview

Reference:	NAFEMS, *Selected Benchmarks for Forced Vibration*, Report prepared by W. S. Atking Engineering Sciences, April 1989, Test 5R.
Analysis Type(s):	Mode-frequency, Spectrum Analysis (**ANTYPE** = 8)
Element Type(s):	3-D 2 node beam (BEAM188)
Input Listing:	vm19.dat

Test Case

A deep simply-supported square beam of length ℓ, thickness t, and mass density m is subjected to random uniform force power spectral density. Determine the peak response PSD value.

Figure 19.1: Simply-Supported Beam Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 200 \times 10^9$ N/m^2 $\upsilon = 0.3$ m = 8000 Kg/m^3	ℓ = 10. m t = 2.0 m	PSD = $(10^6$ N/m$)^2$ /Hz Damping δ = 2%

Analysis Assumptions and Modeling Notes

Modal analysis is performed using Block-Lanczos eigensolver. A frequency range of .1 Hz to 70 Hz was used as an approximation of the white noise PSD forcing function frequency.

Results Comparison

	Target	Mechanical APDL	Ratio
Modal Frequency f (Hz)	42.65	42.63	1.00
PSD Freq (Hz)	42.66	42.63	1.00
Peak d PSD(mm^2/Hz)	180.90	179.18 [1]	0.99
Peak stress PSD(N/mm^2)^2 /Hz	58515.60	57848.39 1]	0.99

1. The peak value occurred at frequency 42.63 Hz.

VM20: Cylindrical Membrane Under Pressure

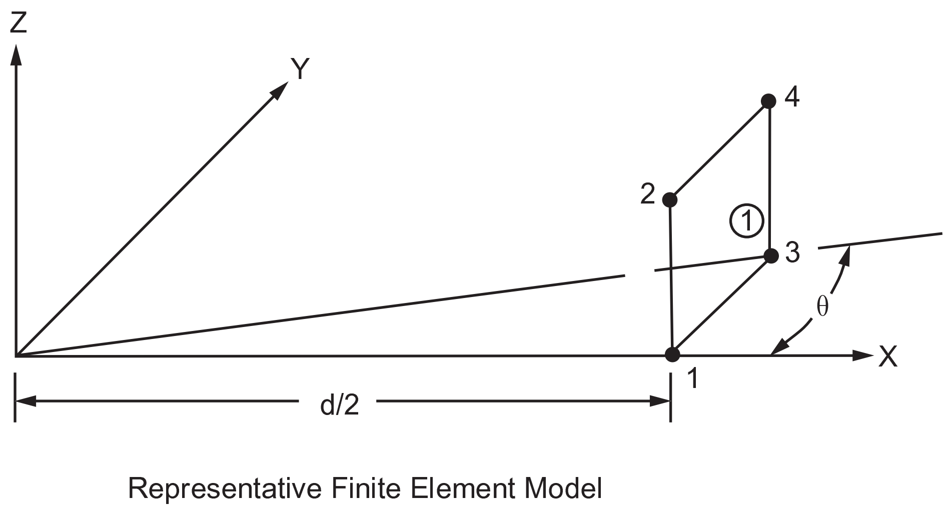
Overview

Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pg. 121, article 25.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Membrane Shell Element (SHELL41) 4-Node Finite Strain Shell Elements (SHELL181)
Input Listing:	vm20.dat

Test Case

A long cylindrical membrane container of diameter d and wall thickness t is subjected to a uniform internal pressure P. Determine the axial stress σ_1 and the hoop stress σ_2 in the container. See VM13 for the problem sketch.

Figure 20.1: Cylindrical Membrane Problem Sketch



Material Properties	Geometric Properties	Loading
E = 30 x 10^6 psi υ = 0.3	d = 120 in t = 1 in	P = 500 psi

Analysis Assumptions and Modeling Notes

An arbitrary axial length is selected. Since the problem is axisymmetric, only a one element sector is needed. A small angle Θ = 10° is used for approximating the circular boundary with a straight-sided element. Nodal coupling is used at the boundaries. An axial traction of 15,000 psi is applied to the edge of the element to simulate the closed-end effect. The internal pressure is applied as an equivalent negative pressure on the exterior (face 1) of the element.

The model is first solved using membrane shell elements (SHELL41) and then using finite strain shell elements (SHELL181) using the membrane option (KEYOPT(1) = 1).

Results Comparison

	Target	Mechanical APDL	Ratio
SHELL41			
$Stress_1$, psi	15,000	15,000	1.000
$Stress_2$, psi	29,749	29,886	1.005
SHELL181			
$Stress_1$, psi	15,000	15,000	1.000
$Stress_2$, psi	29,749	29,886	1.005

VM21: Tie Rod with Lateral Loading

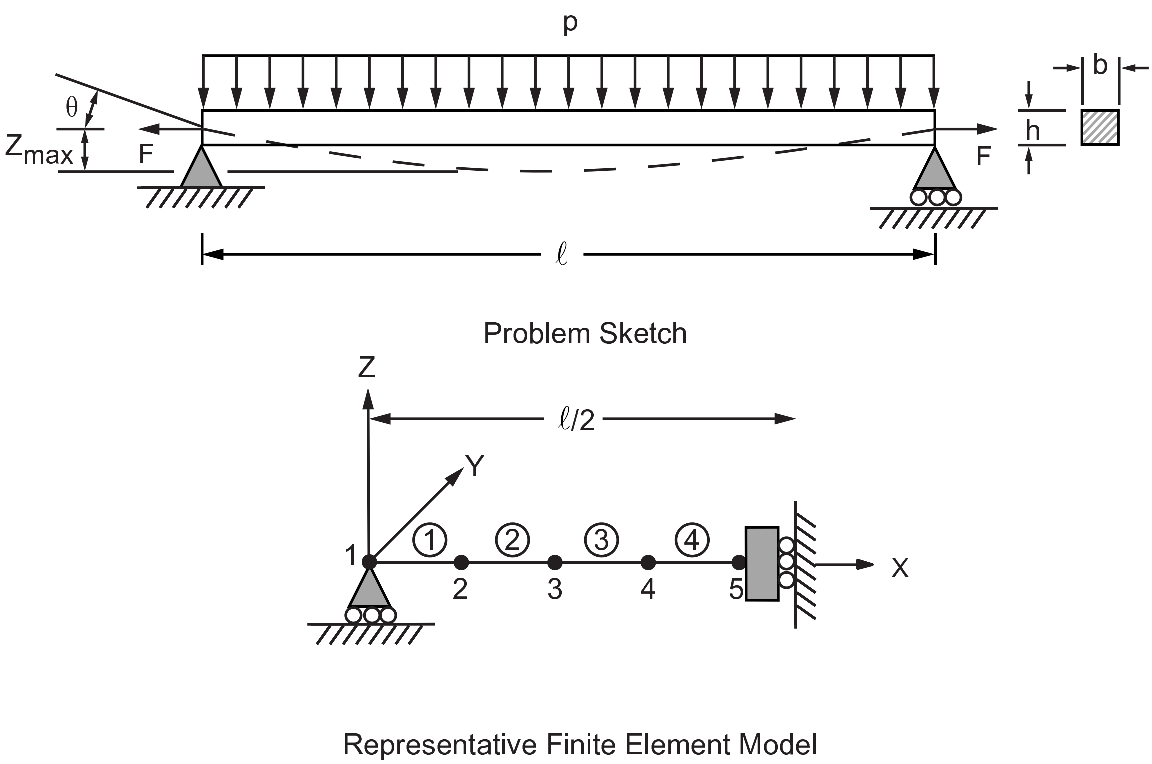
Overview

Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pg. 42, article 6.
Analysis Type(s):	Static, Stress Stiffening Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 2 node beam (BEAM188)
Input Listing:	vm21.dat

Test Case

A tie rod is subjected to the action of a tensile force F and a uniform lateral load p. Determine the maximum deflection z_{max}, the slope Θ at the left-hand end, and the maximum bending moment M_{max}. In addition, determine the same three quantities for the unstiffened tie rod (F = 0).

Figure 21.1: Tie Rod Problem Sketch



Material Properties	Geometric Properties	Loading
E = 30 x 10^6 psi	ℓ = 200 in b = h = 2.5 in	F = 21,972.6 lb p = 1.79253 lb/in

Analysis Assumptions and Modeling Notes

Due to symmetry, only one-half of the beam is modeled. The full load is applied for each iteration. The first solution represents the unstiffened case. The second solution represents the stiffened case.

Results Comparison

		Target	Mechanical APDL	Ratio
F neq 0 (stiffened)	Z_{max} , in	-0.19945	-0.19956	1.001
	Slope, rad	0.0032352	0.0032353	1.000
	M_{max} , in-lb	-4580.1	-4579.818	1.000
F = 0 (un-stiffened)	Z_{max} , in	-0.38241	-0.38255	1.001
	Slope, rad	0.0061185	0.0061185	1.000
	M_{max} , in-lb	-8962.7	-8962.65	1.000

VM22: Small Deflection of a Belleville Spring

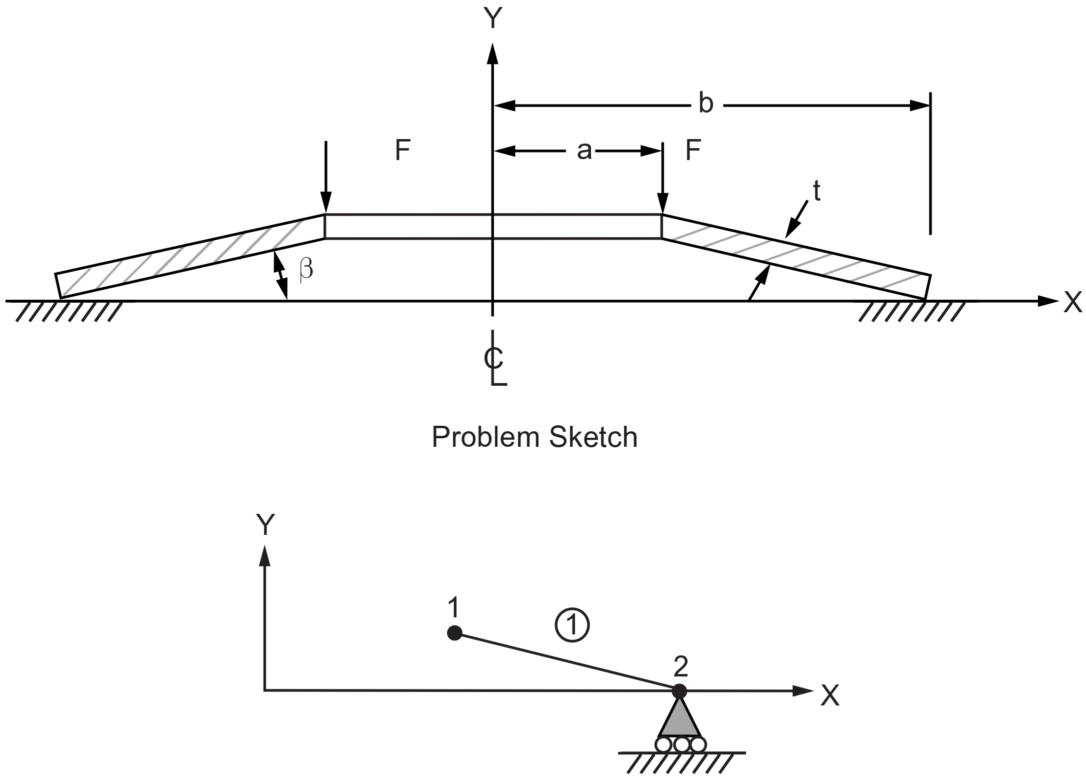
Overview

Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pg. 143, problem 2.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-Node Finite Strain Axisymmetric Shell (SHELL208)
Input Listing:	vm22.dat

Test Case

The conical ring shown below represents an element of a Belleville spring. Determine the deflection y produced by a load F per unit length on the inner edge of the ring.

Figure 22.1: Belleville Spring Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.0$	a = 1 in b = 1.5 in t = 0.2 in $\beta = 7° = 0.12217$ rad	F = 100 lb/in

Analysis Assumptions and Modeling Notes

The input force, $-2\pi F = -628.31853$ lb., is applied per full circumference.

Results Comparison

	Target	Mechanical APDL	Ratio
y, in	-0.0028205	-0.0028571	1.013

VM23: Thermal-structural Contact of Two Bodies

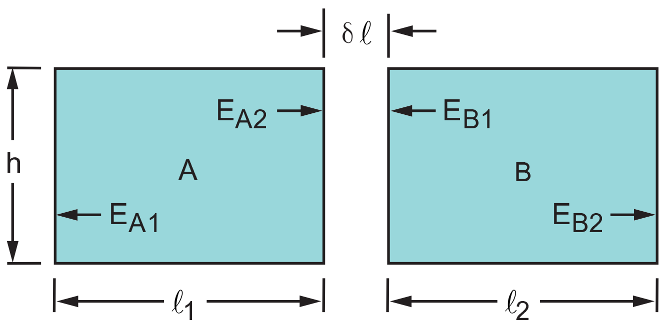
Overview

Reference:	Any Basic Mechanics Text
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Coupled-Field Solid Element (PLANE13) 2-D Coupled-Field Solid Element (PLANE223) 2-D/3-D Node-to-Surface Contact Element (CONTA175) 2-D Target Segment Element (TARGE169)
Input Listing:	vm23.dat

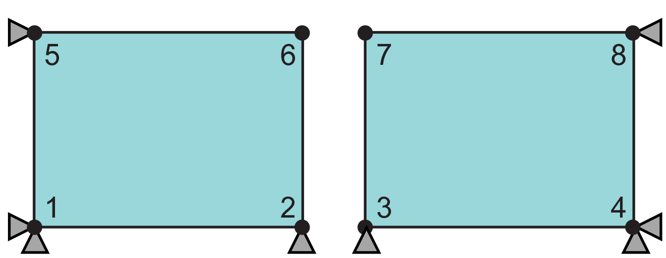
Test Case

Two bodies, A and B, are initially at a temperature of 100°C. A temperature of 500°C is then imposed at the left edge, E_{A1}, of A. Further, the right edge, E_{B2}, of B is heated to attain a temperature of 850°C and is subsequently cooled back to 100°C. Compute the interface temperature (right edge) of A, E_{A2}, and the amount of heat flow through the interface when the right edge of E_{B2} is at 600°C and 850°C, respectively. Also, compute the heat flow through the interface when B is subsequently cooled to 100°C.

Figure 23.1: Contact Problem Sketch



Problem Sketch (not to scale)



Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 10 \times 10^6$ N/m^2	h = 0.1 m	T_{ref} = 100°C

Material Properties	Geometric Properties	Loading
K = 250 W/m°C α = 12 x 10^{-6} m/m°C Contact Conductance = 100 W/°C (per contact element)	ℓ_1 = 0.4 m ℓ_2 = 0.5 m $\delta\ell$ = 0.0035 m	Load Step 1 T@E_1 = 500°C Load Step 2 T@E_2 = 850°C Load Step 3 T@E_2 = 100°C

Analysis Assumptions and Modeling Notes

A coupled-field analysis is performed to solve this thermal/structural contact problem using PLANE13 elements and PLANE223 elements with weak coupling. The interface is modeled using CONTA175 and TARGE169 elements with the heat conduction option.

Results Comparison

		Target	Mechanical APDL	Ratio
Using PLANE13 Elements				
T @ E_{B2} = 600°C	T @ E_{A2} (°C)	539.0	539.0	1.000
	Q W	2439.0	2439.0	1.000
T @ E_{B2} = 850°C	T @ E_{A2} (°C)	636.6	636.6	1.000
	Q W	8536.6	8536.6	1.000
T @ E_{B2} = 100°C	Q W	0.0	0.0	--
Using PLANE223 Elements				
T @ E_{B2} = 600°C	T @ E_{A2} (°C)	539.0	539.0	1.000
	Q W	2439.0	2439.0	1.000
T @ E_{B2} = 850°C	T @ E_{A2} (°C)	636.6	636.6	1.000
	Q W	8536.6	8536.6	1.000
T @ E_{B2} = 100°C	Q W	0.0	0.0	--

VM24: Plastic Hinge in a Rectangular Beam

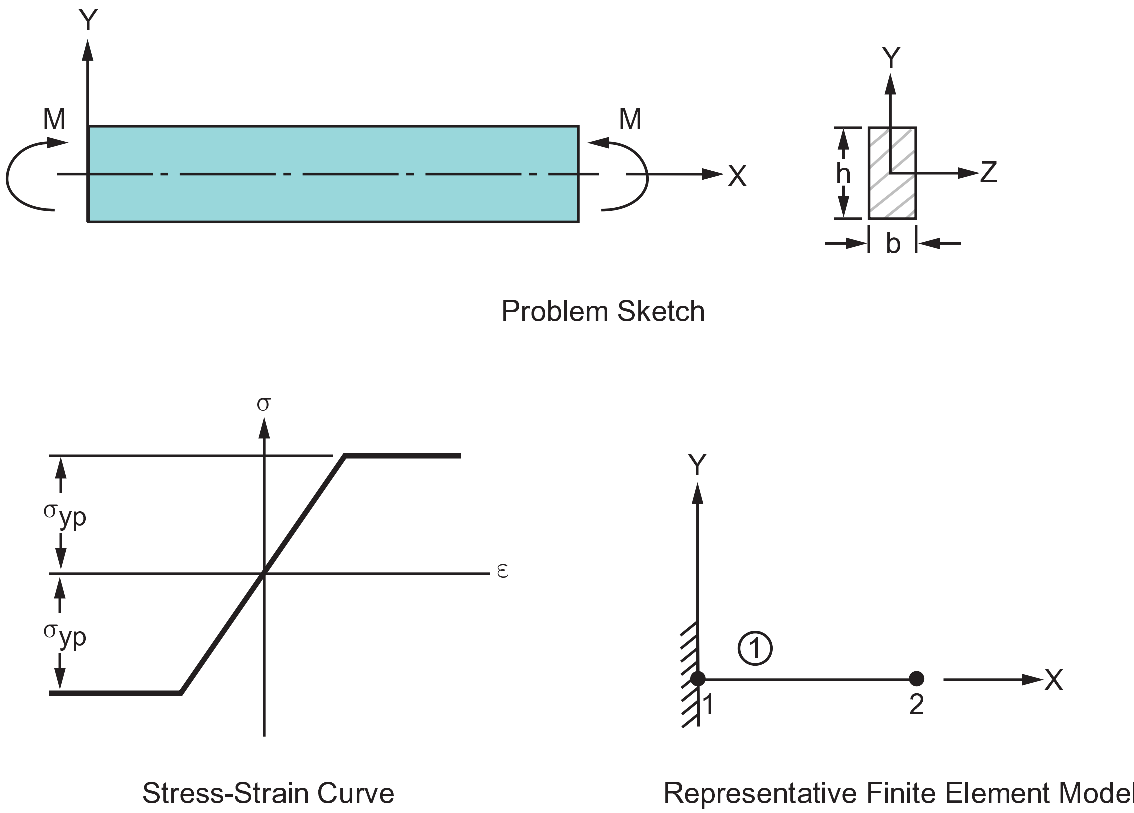
Overview

Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pg. 349, article 64.
Analysis Type(s):	Static, Plastic Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Plastic Beam Element (BEAM188)
Input Listing:	vm24.dat

Test Case

A rectangular beam is loaded in pure bending. For an elastic-perfectly-plastic stress-strain behavior, show that the beam remains elastic at $M = M_{yp} = \sigma_{yp}\ bh^2/6$ and becomes completely plastic at $M = M_{ult} = 1.5\ M_{yp}$.

Figure 24.1: Plastic Hinge Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.3$ $\sigma_{yp} = 36000$ psi	b = 1 in h = 2 in $I_z = b\ h^3/12 = 0.6667$ in^4	$M = 1.0\ M_{yp}$ to $1.5\ M_{yp}$ (M_{yp} = 24000 in-lb)

Analysis Assumptions and Modeling Notes

Bilinear kinematic hardening (BKIN) and 6 cells are used through the thickness

An arbitrary beam length is chosen. Because of symmetry, only half of the structure is modeled (since length is arbitrary, this means only that boundary conditions are changed). The load is applied in four increments using a do-loop, and convergence status is determined from the axial plastic strain for each load step in POST26.

Results Comparison (for both analyses)

M/M_{yp}	Target Rotation	Mechanical APDL	Ratio
1.0	0.01200	0.01200	1.000
1.1666	0.01469	0.01459	0.993
1.3333	0.02078	0.02027	0.975
1.5	∞	0.11850	NA

VM25: Stresses in a Long Cylinder

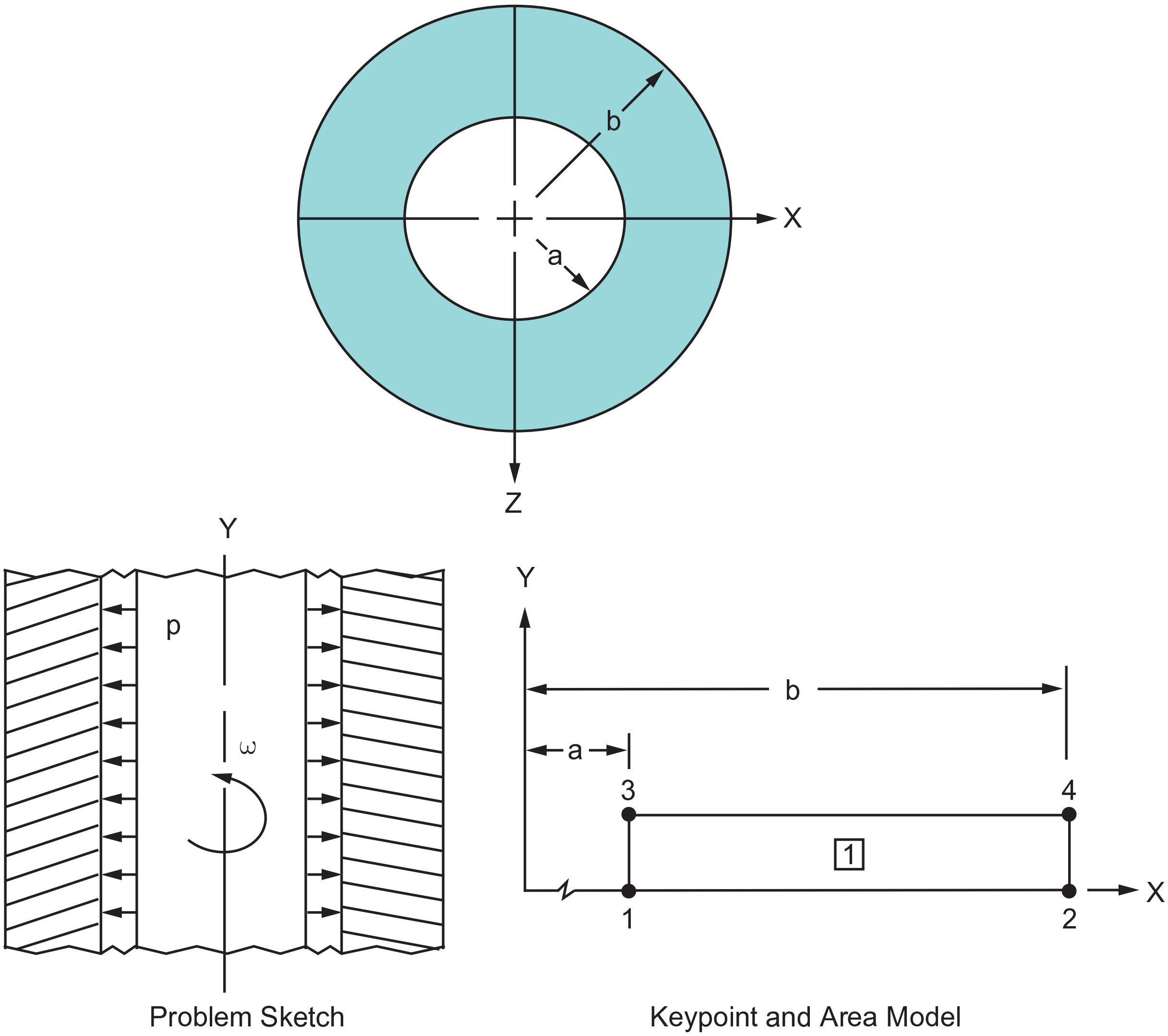
Overview

Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pg. 213, problem 1 and pg. 213, article 42.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 8-Node Structural Solid Elements (PLANE183)
Input Listing:	vm25.dat

Test Case

A long thick-walled cylinder is initially subjected to an internal pressure p. Determine the radial displacement δ_r at the inner surface, the radial stress σ_r, and tangential stress σ_t, at the inner and outer surfaces and at the middle wall thickness. Internal pressure is then removed and the cylinder is subjected to a rotation ω about its center line. Determine the radial σ_r and tangential σ_t stresses at the inner wall and at an interior point located at $r = X_i$.

Figure 25.1: Long Cylinder Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.3$ $\rho = 0.00073$ lb-sec^2/in^4	a = 4 inches b = 8 inches $X_i = 5.43$ inches	p = 30,000 psi $\omega = 1000$ rad/sec

Analysis Assumptions and Modeling Notes

The axial length is arbitrarily selected. Elements are oriented such that surface stresses may be obtained at the inner and outer cylinder surfaces.

POST1 is used to display linearized stresses through the thickness of the cylinder when it is subjected to an internal pressure.

Results Comparison

		Target	Mechanical APDL	Ratio
p = 30,000 psi	Displacement$_r$, in (r = 4 in)	0.0078666	0.0078667	1.000
	Stress$_r$, psi (r = 4 in)	-30000.	-29908.046875	0.997
	Stress$_r$, psi (r = 6 in)	-7778.	-7757.541	0.997
	Stress$_r$, psi (r = 8 in)	0.	6.734	--
	Stress$_t$, psi (r = 4 in)	50000.	49908.046875	0.998
	Stress$_t$, psi (r = 6 in)	27778.	27757.541	0.999
	Stress$_t$, psi (r = 8 in)	20000.	19993.265	1.000
Rotation = 1000 rad/sec	Stress$_r$, psi (r = 4 in)	0.0	49.307	--
	Stress$_t$, psi (r = 4 in)	40588.	40526.285	0.998
	Stress$_r$, psi (r = 5.43 in)	4753.	4745.722	0.998
	Stress$_t$, psi (r = 5.43 in)	29436.	29406.567	0.999

Figure 25.2: SZ Stresses Along a Section (Internal Pressure)

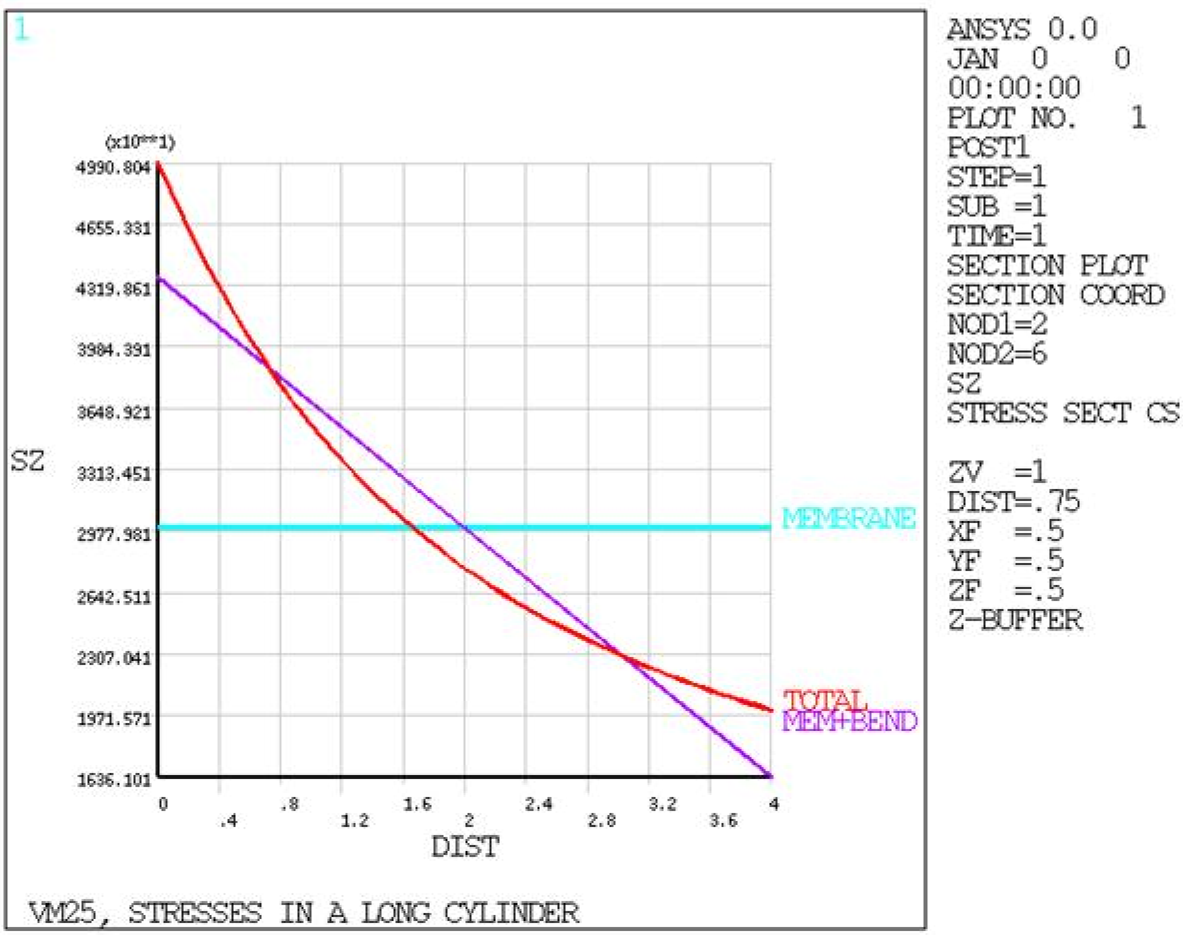
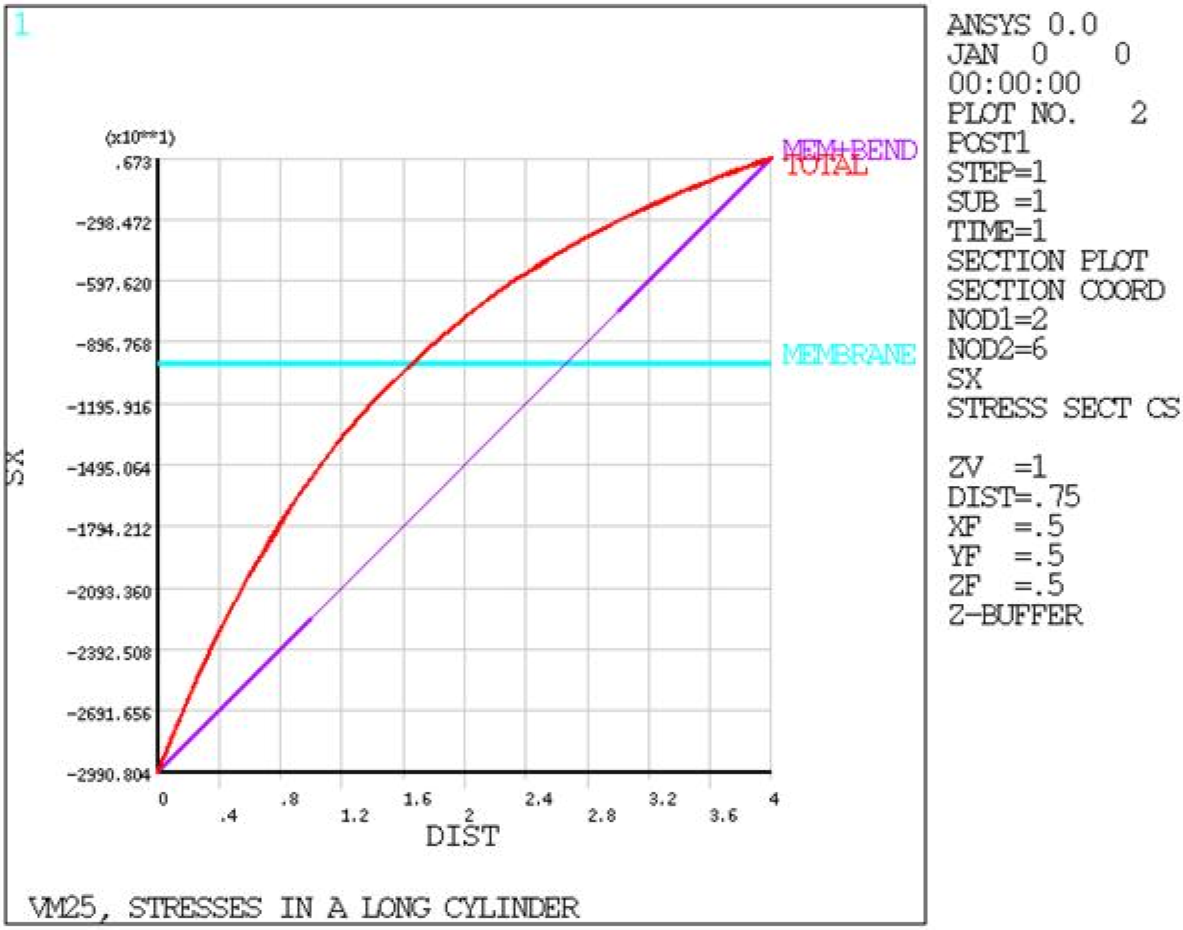


Figure 25.3: SX Stresses Along a Section (Internal Pressure)



VM26: Large Deflection of a Cantilever

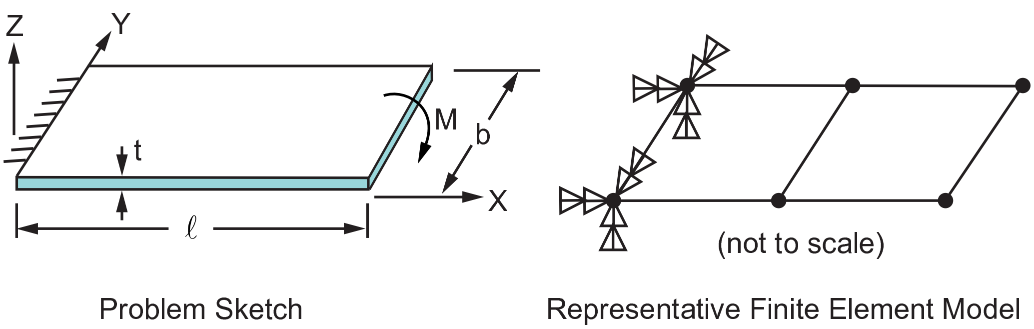
Overview

Reference:	K. J. Bathe, E. N. Dvorkin, "A Formulation of General Shell Elements - The Use of Mixed Interpolation of Tensorial Components", *Int. Journal for Numerical Methods in Engineering*, Vol. 22 No. 3, 1986, pg. 720.
Analysis Type(s):	Static, Large Deflection Analysis (**ANTYPE** = 0)
Element Type(s):	4-Node Finite Strain Shell (SHELL181) 8-Node Finite Strain Shell (SHELL281)
Input Listing:	vm26.dat

Test Case

A cantilevered plate of length ℓ, width b, and thickness t is fixed at one end and subjected to a pure bending moment M at the free end. Determine the true (large deflection) free-end displacements and rotation, and the top surface stress at the fixed end, using shell elements.

Figure 26.1: Cantilever Problem Sketch



Material Properties	Geometric Properties	Loading
E = 1800 N/mm^2 υ = 0.0	ℓ = 12 mm b = 1 mm t = 1 mm	M = 15.708 N-mm

Analysis Assumptions and Modeling Notes

The large deflection option is chosen (**NLGEOM**,ON) and shell elements are used to match the reference's assumptions and test case definition. Since the geometry is closer to that of a beam, a shell element is not the usual element type to solve problems of this geometry.

The free-end nodes are coupled in y-rotations so that the bending moment M can be applied to only one end node. The load is applied in two equal increments, using the analysis restart option (solely for validation and demonstration of **ANTYPE**,,REST).

Results Comparison

		Target[1]	Mechanical APDL	Ratio
SHELL181	UX, node 4 (mm)	-2.90	-2.77	0.95
	UZ, node 4 (mm)	-6.50	-6.71	1.03
	ROTY, node 4 (rad)	1.26	1.26	1.00
	$Stress_x$, node 1 (N/mm^2)	94.25	94.25	1.00
SHELL281	UX, node 4 (mm)	-2.90	-2.92	1.01
	UZ, node 4 (mm)	-6.50	-6.60	1.02
	ROTY, node 4 (rad)	1.26	1.26	1.00
	$Stress_x$, node 1 (N/mm^2)	94.25	94.31	1.00

1. to accuracy of graphical readout

VM27: Thermal Expansion to Close a Gap

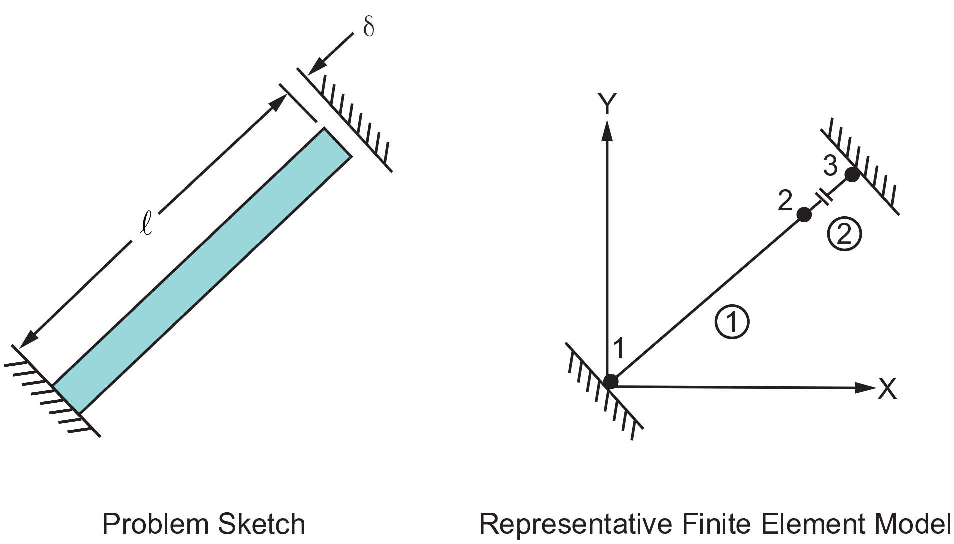
Overview

Reference:	C. O. Harris, *Introduction to Stress Analysis*, The Macmillan Co., New York, NY, 1959, pg. 58, problem 8.
Analysis Type(s):	Static, Thermal-stress Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Spar (or Truss) Elements (LINK180) 3-D Node-to-Node Contact Elements (CONTA178)
Input Listing:	vm27.dat

Test Case

An aluminum-alloy bar is fixed at one end and has a gap δ between its other end and a rigid wall when at ambient temperature T_a. Calculate the stress σ, and the thermal strain $\varepsilon_{Thermal}$ in the bar after it has been heated to temperature T.

Figure 27.1: Gap Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 10.5 \times 10^6$ psi $\alpha = 12.5 \times 10^{-6}$ in/in-°F	ℓ = 3 in δ = 0.002 in	T_a = 70°F T = 170°F

Analysis Assumptions and Modeling Notes

The problem is solved in 3-D using LINK180 and CONTA178 elements. Models are created at arbitrary angles. The gap stiffness is arbitrarily selected at a high value (10×10^{10} psi) to approximate the rigid wall. The automatic load stepping procedure (**AUTOTS**,ON) is used.

Results Comparison

		Target	Mechanical APDL	Ratio
3-D Analysis	Stress, psi	-6125.	-6124.785	1.000
	$Strain_{Thermal}$	0.00125	0.00125	1.000

VM28: Transient Heat Transfer in an Infinite Slab

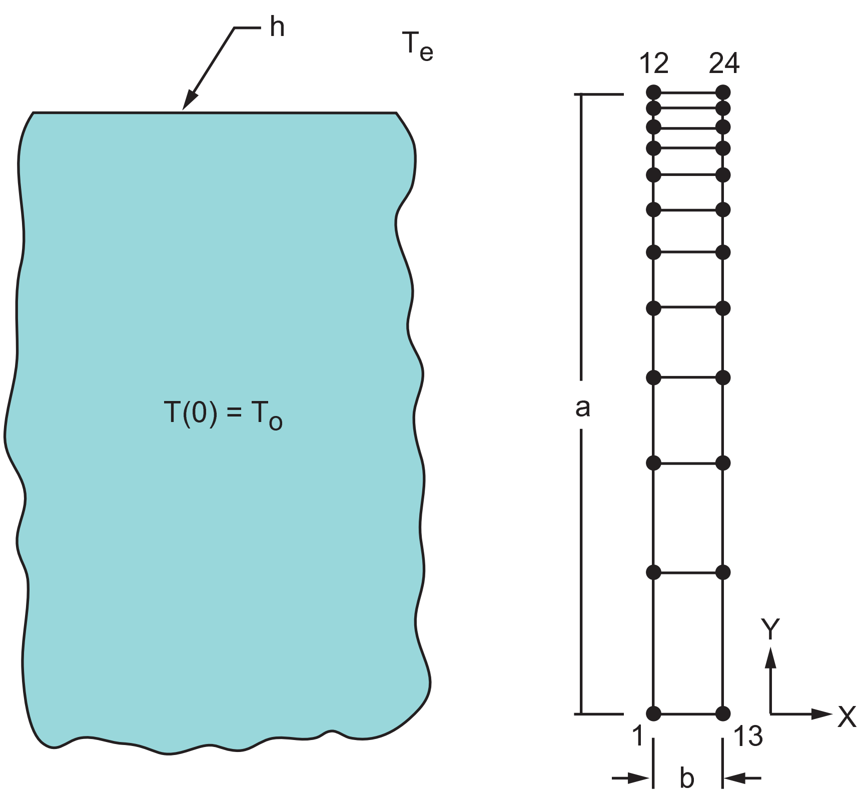
Overview

Reference:	J. P. Holman, *Heat Transfer*, 4th Edition, McGraw-Hill Book Co., Inc., New York, NY, 1976, pg. 106.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 4)
Element Type(s):	2-D 8-Node Thermal Solid Element (PLANE77)
Input Listing:	vm28.dat

Test Case

A semi-infinite solid is initially at temperature T_o. The solid is then suddenly exposed to an environment having a temperature T_e and a surface convection coefficient h. Determine the temperature distribution through the solid after 2000 seconds.

Figure 28.1: Infinite Slab Problem Sketch



Problem Sketch Representative Finite Element Model

Material Properties	Geometric Properties	Loading
k = 54 W/m°C ρ = 7833 kg/m^3 c = 465 J/kg-°C	a = 1 m b = 0.1 m	T_o = 0°C T_e = 1000°C h = 50 W/m^2-°C

Analysis Assumptions and Modeling Notes

The width b of 0.1 m is arbitrarily selected for the elements. The model length a (1 meter) is selected to model the infinite boundary such that no significant temperature change occurs at the inside end points (nodes 1, 13) for the time period of interest. The node locations are selected with a higher density near the surface to better model the transient behavior. The automatic time stepping procedure (**AUTOTS**,ON) is used with an initial integration time step of 10 sec (2000 sec/200 max. iterations = 10) to more closely model the thermal shock at the surface.

Results Comparison

Temperature °C	Target	Mechanical APDL	Ratio
@ Y = .9777 (Node 11)	140.0	140.7	1.005
@ Y = .9141 (Node9)	98.9	99.1	1.00
@ Y = .8134 (Node 7)	51.8	51.7	0.997
@ Y = .6538 (Node 5)	14.5	14.0	0.968

VM29: Friction on a Support Block

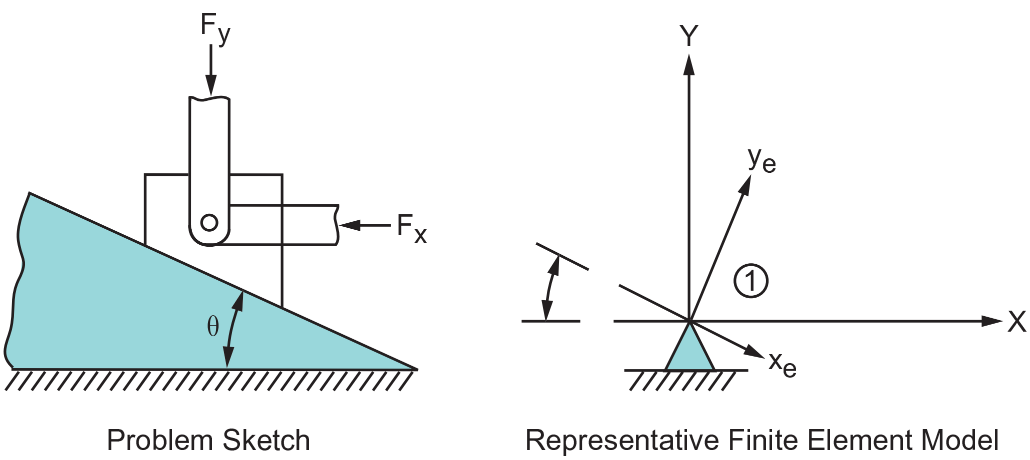
Overview

Reference:	F. P. Beer, E. R. Johnston, Jr., *Vector Mechanics for Engineers, Statics and Dynamics*, McGraw-Hill Book Co., Inc., New York, NY, 1962, pg. 283, problem 8.2.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Point-to-Point Contact Elements (CONTAC12) 3-D Node-to-Node Contact Elements (CONTA178)
Input Listing:	vm29.dat

Test Case

A support block is acted upon by forces F_x and F_y. For a given value of F_y determine the smallest value of F_x which will prevent the support block from sliding down the plane. Also determine the normal force F_n and sliding force F_s at the interface.

Figure 29.1: Support Block Problem Sketch



Material Properties	Geometric Properties	Loading
μ = 0.3	Θ = 20	F_y = 100 lb

Analysis Assumptions and Modeling Notes

A real problem of this nature would be solved in a trial-and-error, iterative fashion. In this case the theoretical answer is known, so the solution is verified by the "backward" process described below.

The normal stiffness of the sticking interface is arbitrarily selected at a high value. A value slightly greater than the calculated F_x value of 5.76728 lb is input in the first load step. A slightly lesser value is input in the second load step. The number of sub-steps is limited to one to prevent divergence due to the free motion of the block. The problem is first solved using CONTAC12 elements and then using CONTA178 elements. For CONTA178 elements the contact normals are defined using real constants NX, NY and NZ.

Results Comparison

Status	Target	Mechanical APDL	Ratio
F_x = 5.7674 lb.	**Sticking**	**Sticking**	--
F_n , lb	-95.942	-95.942	1.000
F_s , lb	28.783	28.782	1.000
F_x = 5.76720 lb.	**Sliding**	**Sliding**	--
F_n , lb	-95.942	-95.942	1.000
F_s , lb	28.783	28.783	1.000
CONTA178 elements			
F_x = 5.76724 lb.	**Sticking**	**Sticking**	--
F_n , lb	-95.942	-95.942	1.000
F_s , lb	28.783	28.782	1.000
F_x = 5.76720 lb.	**Sliding**	**Sliding**	--
F_n , lb	-95.942	-95.942	1.000
F_s , lb	28.783	28.783	1.000

VM30: Solid Model of Surface Fillet

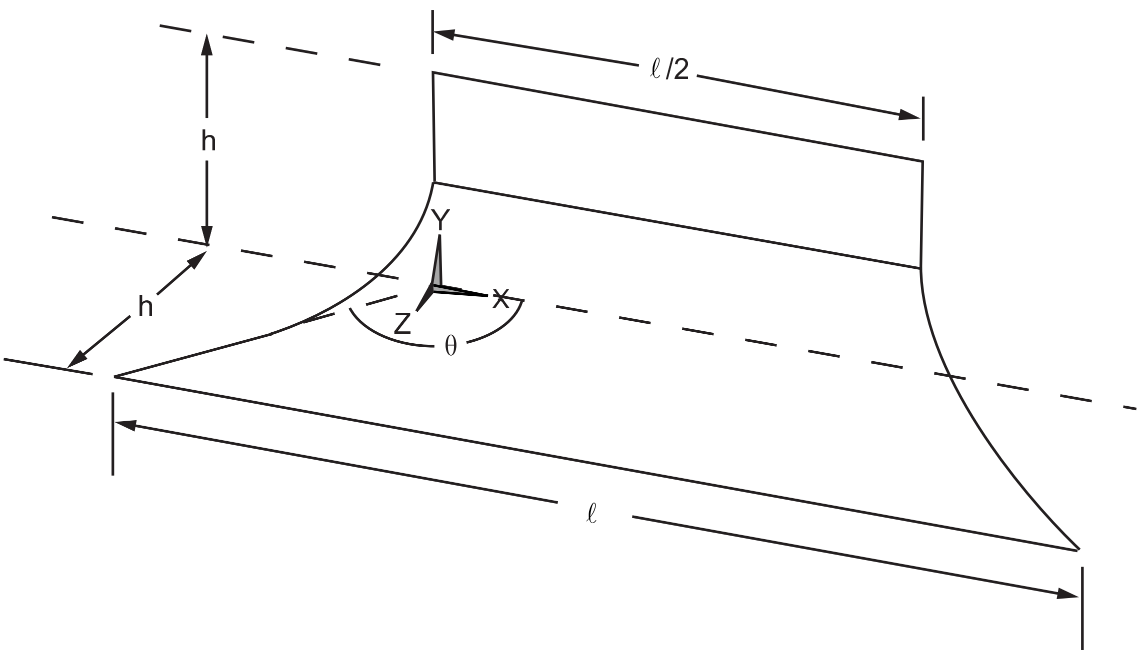
Overview

Reference:	D. R. Hose, I. A. Rutherford, "Benchmarks for Finite Element Pre-processors", *NAFEMS Ref: R0001*, December 1993, pg. 23.
Analysis Type(s):	Solid Modeling Boolean Operations
Element Type(s):	Not Applicable
Input Listing:	vm30.dat

Test Case

A rectangular plate and a trapezoidal plate intersect at an angle of 90° with a common radius fillet of 1 mm. The edge of the fillet lies in a plane. From solid model construction, determine the accuracy of the fillet operation by measuring the out-of-plane deviation of subsequent meshed node locations.

Figure 30.1: Surface Fillet Problem Sketch



Problem Sketch

Geometric Properties
ℓ = 8 mm h = 2 mm Θ = 1355

Analysis Assumptions and Modeling Notes

The model is created using geometric primitives. The fillet is created using an area fillet operation. A glue operation is used to provide continuity for creating the fillet. An arbitrary element type (SHELL281) is defined for meshing purposes. A local coordinate system is created in the plane of the weld. The nodes are listed in that coordinate system to access the maximum out-of-plane deviation. The maximum absolute deviation is reported.

Results Comparison

	Target	Mechanical APDL	Ratio
Maximum Deviation (mm)	0	2.91×10^{-7}	--

Figure 30.2: Area Plot

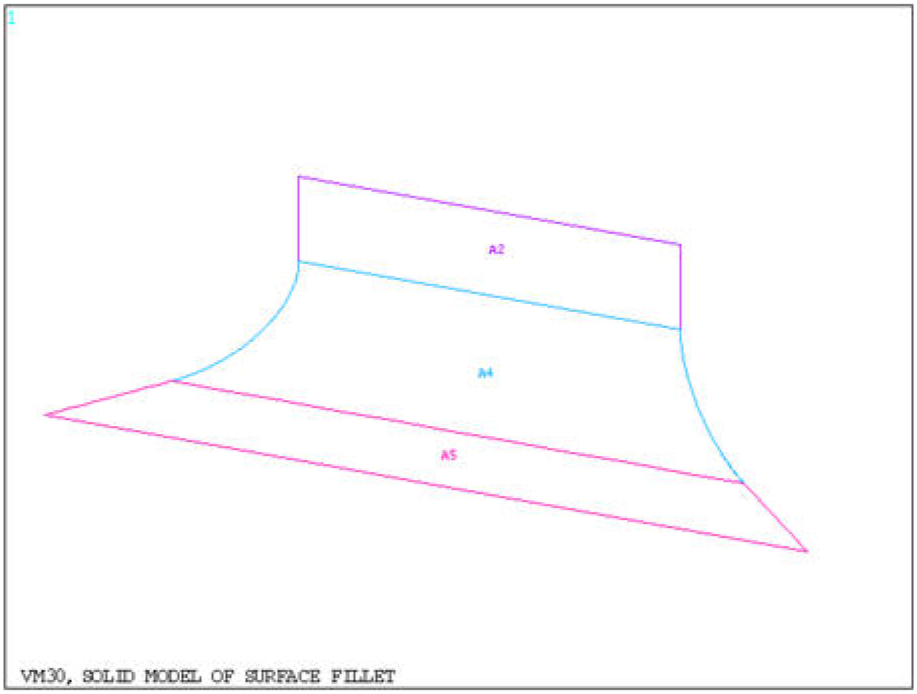
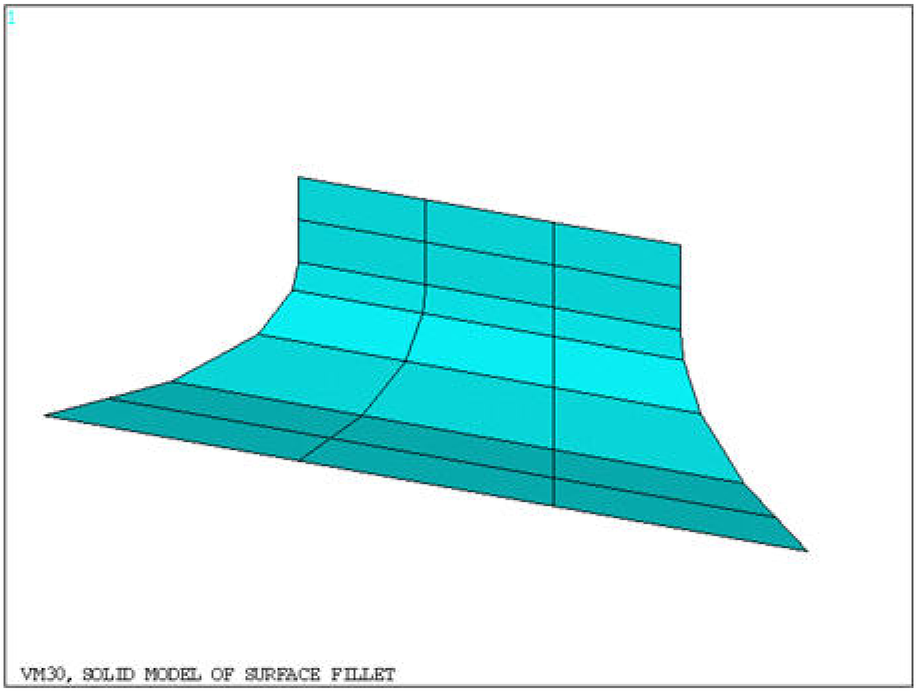


Figure 30.3: Element Plot



VM31: Cable Supporting Hanging Loads

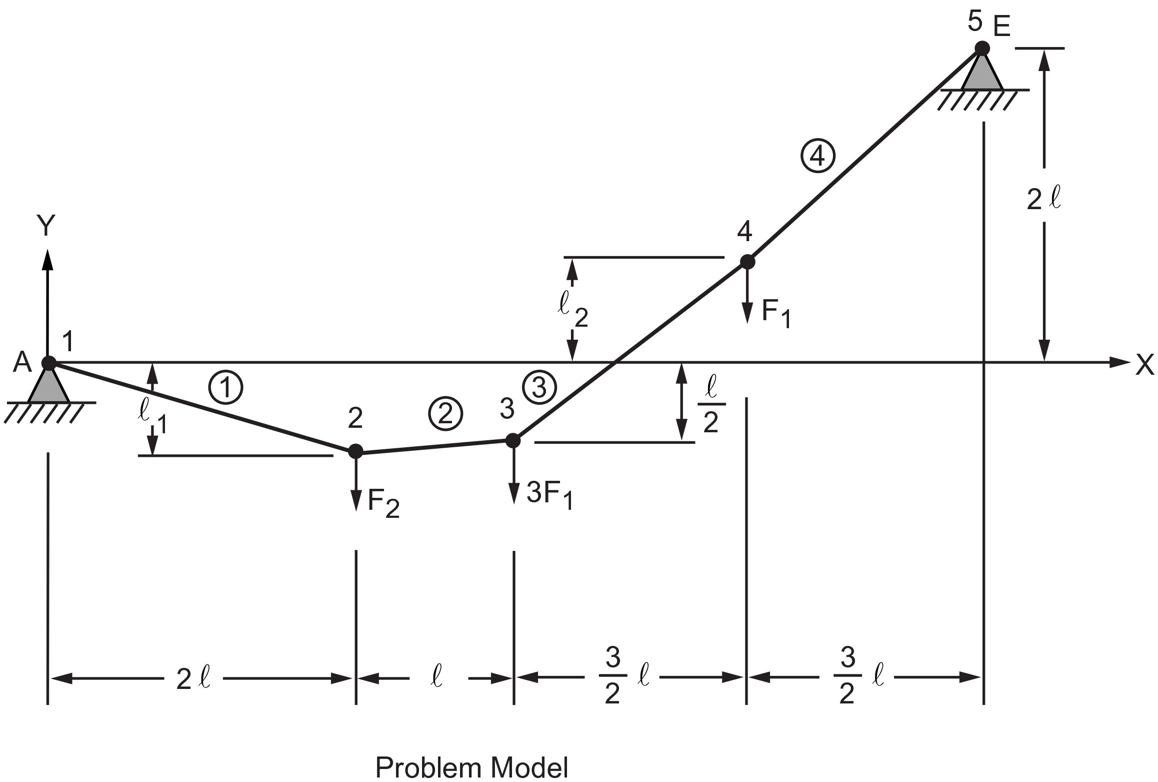
Overview

Reference:	F. P. Beer, E. R. Johnston, Jr., *Vector Mechanics for Engineers, Statics and Dynamics*, McGraw-Hill Book Co., Inc., New York, NY, 1962, pg. 260, problem 7.8.
Analysis Type(s):	Static, Stress Stiffening Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Spar (or Truss) Elements (LINK180)
Input Listing:	vm31.dat

Test Case

The cable AE supports three vertical loads from the points indicated. For the equilibrium position shown, determine the horizontal A_x and vertical A_y reaction forces at point A and the maximum tension T in the cable.

Figure 31.1: Hanging Load Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 20 \times 10^6$ ksi	Area of cable = 0.1 ft^2 ℓ = 10 ft ℓ_1 = 5.56 ft ℓ_2 = 5.83 ft	F_1 = 4 kips F_2 = 6 kips

Analysis Assumptions and Modeling Notes

An iterative solution is required. A small initial strain (1 x 10^{-7}) is input to give some initial stiffness to the cable.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
A_x , Kips	-18.000	-17.997	1.000
A_y , Kips	5.0000	5.0009	1.000
T, Kips	24.762	24.755[2]	1.000

1. Solution recalculated
2. Corresponds to MFORX for element 4 in element solution output

VM32: Thermal Stresses in a Long Cylinder

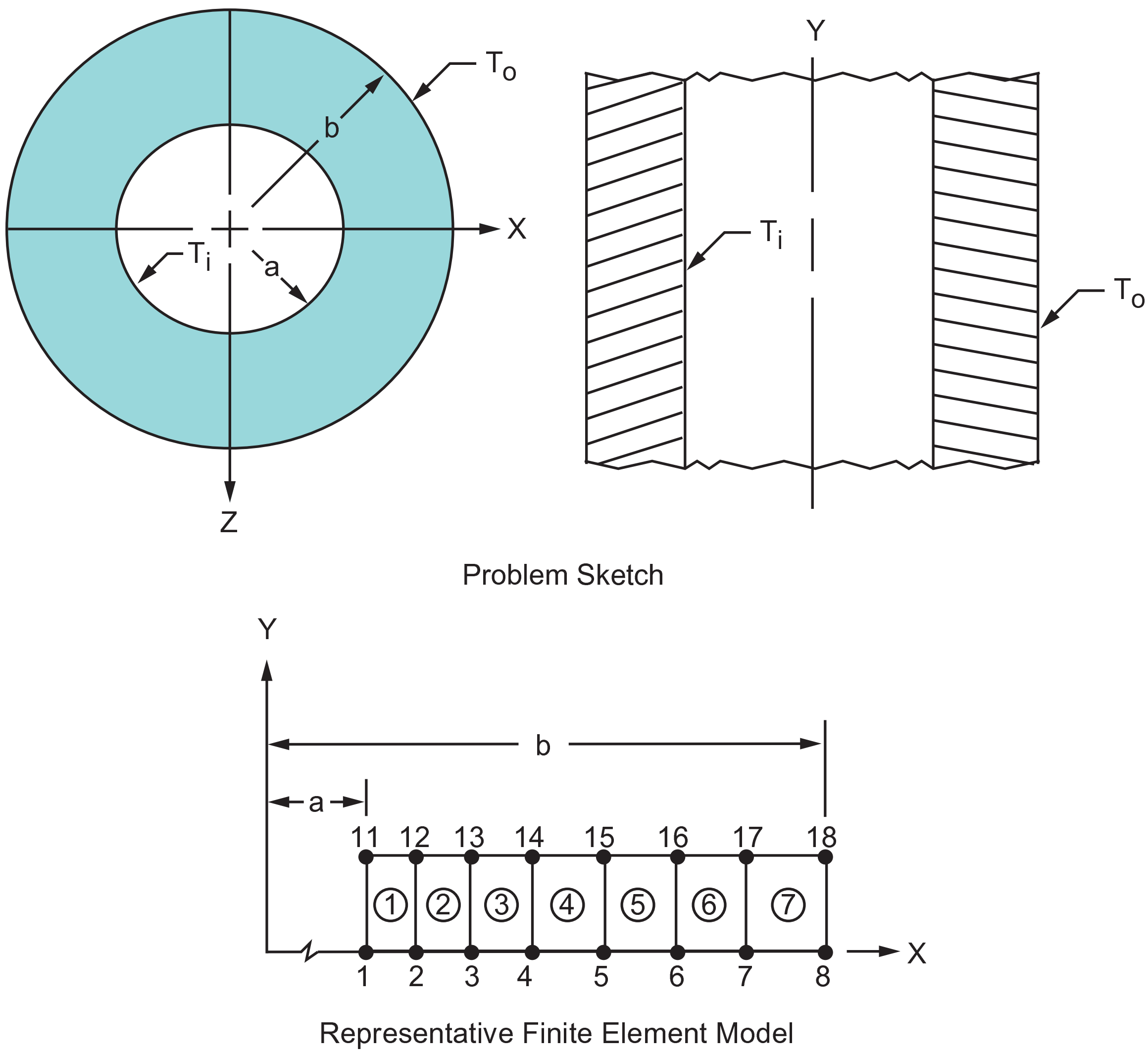
Overview

Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pg. 234, problem 1.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Thermal Solid Elements (PLANE55) 2-D Structural Solid Elements (PLANE42)
Input Listing:	vm32.dat

Test Case

A long thick-walled cylinder is maintained at a temperature T_i on the inner surface and T_o on the outer surface. Determine the temperature distribution through the wall thickness. Also determine the axial stress σ_a and the tangential (hoop) stress σ_t at the inner and outer surfaces.

Figure 32.1: Long Cylinder Problem Sketch



Material Properties	Geometric Properties	Loading
E = 30 x 10^6 psi α = 1.435 x 10^{-5} in/in-°C υ = 0.3 k = 3Btu/hr-in-°C	a = 0.1875 inches b = 0.625 inches	T_i = -1°C T_o = 0°C

Analysis Assumptions and Modeling Notes

The axial length is arbitrary. Two element types are defined so that the same model can be used for the thermal and stress solutions. A radial grid with nonuniform spacing ratio (1:2) is used since the largest rate of change of the thermal gradient occurs at the inner surface. Surface stresses are requested on element 1 and 7 to obtain more accurate axial and hoop stresses at the inner and outer radii. Nodal coupling is used in the static stress analysis.

Results Comparison

Thermal Analysis	Target	Mechanical APDL	Ratio
T,°C (at X = 0.1875 in)	-1.0000	-1.0000	1.000
T,°C (at X = 0.2788 in)	-0.67037	-0.67061	1.000
T,°C (at X = 0.625 in)	0.0000	0.0000	-

Static Analysis	Target	Mechanical APDL	Ratio
$Stress_a$, psi (at X = 0.1875 in)	420.42	432.59	1.029
$Stress_t$, psi (at X = 0.1875 in)	420.42	426.49	1.014
$Stress_a$, psi (at X = 0.625 in)	-194.58	-190.05	0.977
$Stress_t$, psi (at X = 0.625 in)	-194.58	-189.76	0.975

VM33: Transient Thermal Stress in a Cylinder

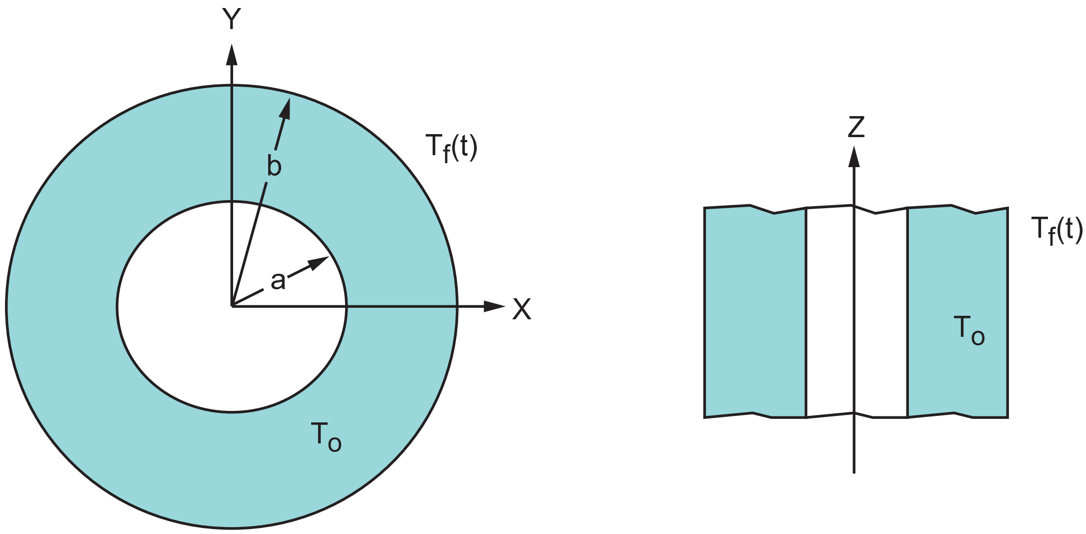
Overview

Reference:	R. J. Roark, W. C. Young, *Formulas for Stress and Strain*, 5th Edition, McGraw-Hill Book Co., Inc., New York, NY, 1975, pg. 585.
Analysis Type(s):	Coupled-field Analysis (**ANTYPE** = 4)
Element Type(s):	3-D Coupled-field Solid Element (SOLID5) 3-D 20-Node Coupled-Field Solid (SOLID226)
Input Listing:	vm33.dat

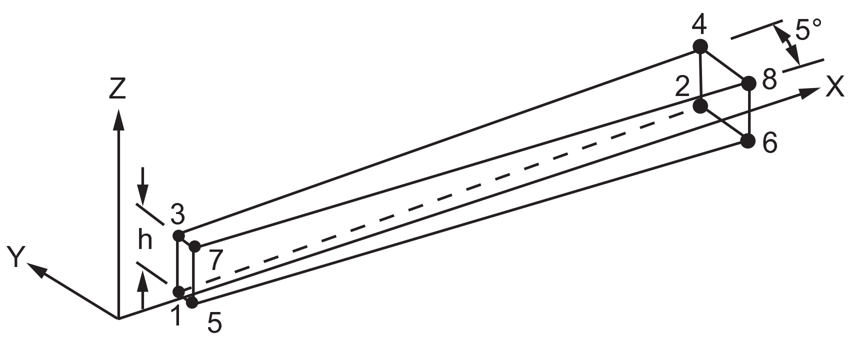
Test Case

A long thick-walled cylinder, initially at a uniform temperature T_o, has its outer radius temperature raised at a constant rate of 1.0°/sec to temperature T_f. After a steady state of heat flow has been reached, determine the tangential stress at the inner and outer surfaces. Display the outer-to-inner surface temperature difference and the tangential stress as a function of time.

Figure 33.1: Cylinder Problem Sketch



Problem Sketch



Keypoint and Line Segment Model

Material Properties	Geometric Properties	Loading
E = 30 x 10^6 psi υ = 0.3 α = 8.4 x 10^{-6} in/in-°F k = .000625 BTU/sec in-°F ρ = 0.284 lb-sec^2/in^4 c = .10 BTU/lb-°F	a = 1.0 in b = 3.0 in h = .20 in	T_b = 500°F T_o = 70°F

Analysis Assumptions and Modeling Notes

Due to symmetry, only a wedge of arbitrary height is required for modeling. A 5° wedge is selected to minimize curved geometry effects when using a lower order element. The thermal steady state condition is satisfied when the inner and outer wall temperature difference is constant. A transient thermal-stress analysis is required with a sufficient time period to allow the steady-state condition to be obtained. A time period of t = 430 sec is selected. The temperature T_f is assigned a value of T = 500°F such that, for a ramped load condition, the constant temperature rise of: T_f-T_o/Δt = 500-70/430 = 1°F/sec is obtained.

Since the structural dynamic effects are not of concern, inertial and damping structural effects can be ignored, by specifying time integration for the temperature degree of freedom only. A sufficient number of elements (15) is modeled through the thickness such that an accurate thermal transient and nodal stress results are obtained.

Symmetric structural boundary conditions are used at the radial and bottom planes. Since the cylinder being modeled is long, nodes at z = h are coupled in UZ to enforce a constant axial strain condition. The reported values at t = 430 sec. should be fairly accurate since thermal steady state is achieved.

Results Comparison

Tangential Stress	Target	Mechanical APDL	Ratio
SOLID5			
$Stress_y$psi(r=b)	-13396	-13097	0.978
$Stress_y$psi(r=a)	10342	10425	1.008
SOLID226			
$Stress_y$psi(r=b)	-13396	-13360	0.997
$Stress_y$psi(r=a)	10342	10325	0.998

Figure 33.2: Outer-to-inner Surface Temperature Difference

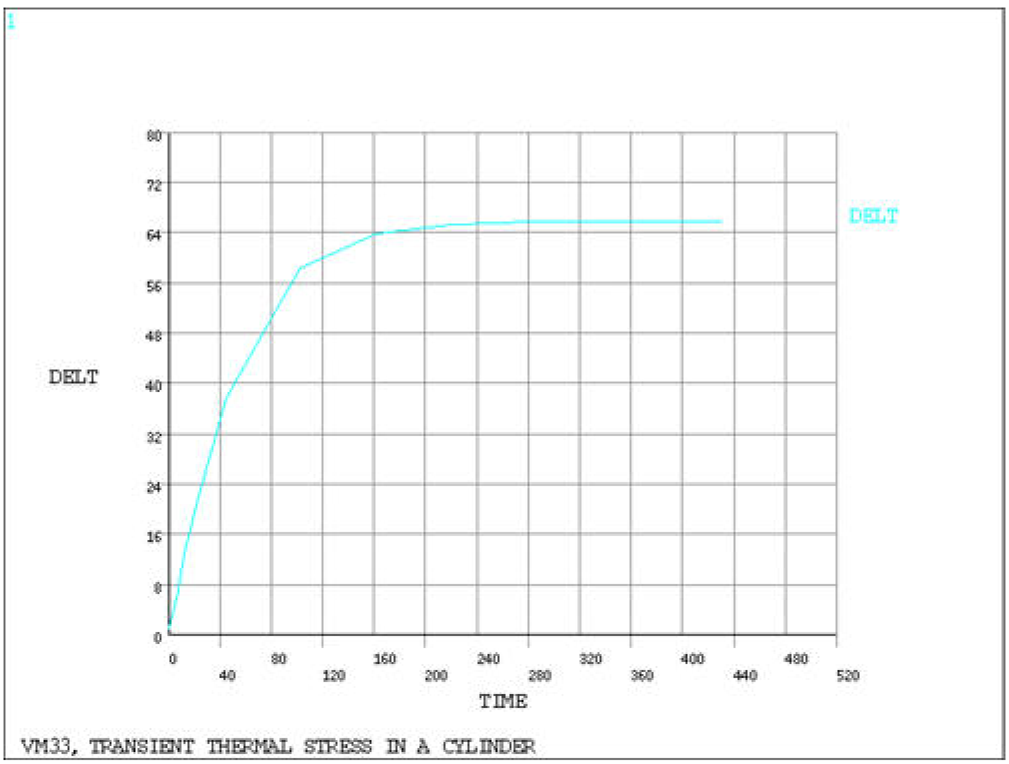
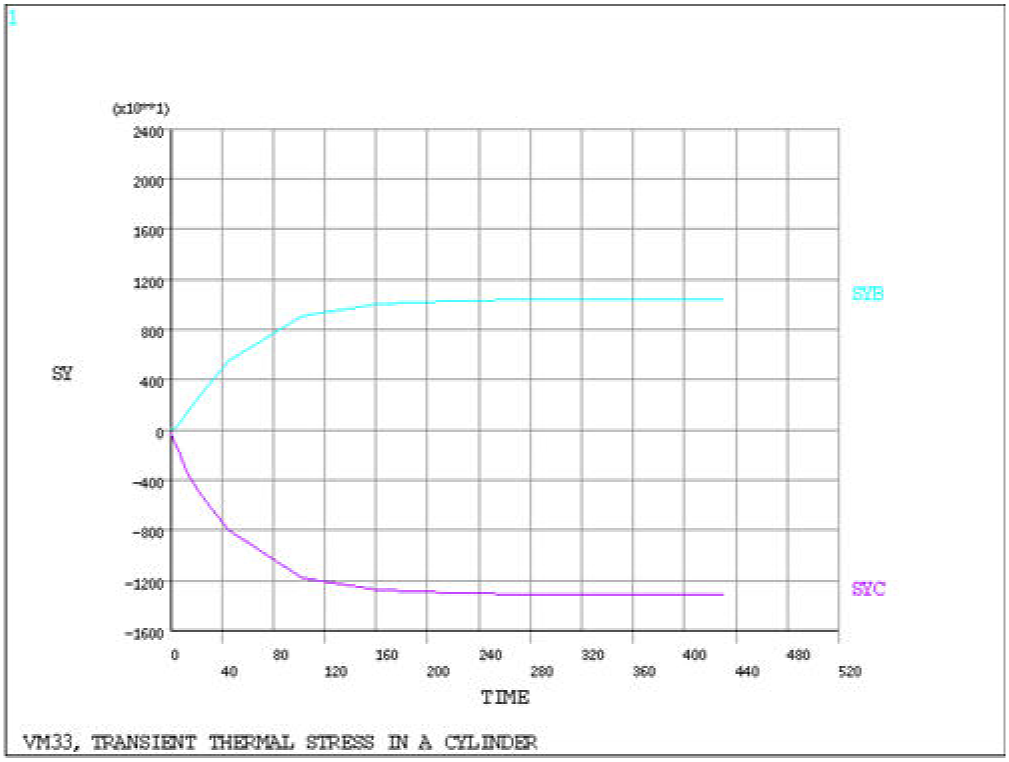


Figure 33.3: Tangential Stress as a Function of Time



VM34: Bending of a Tapered Plate (Beam)

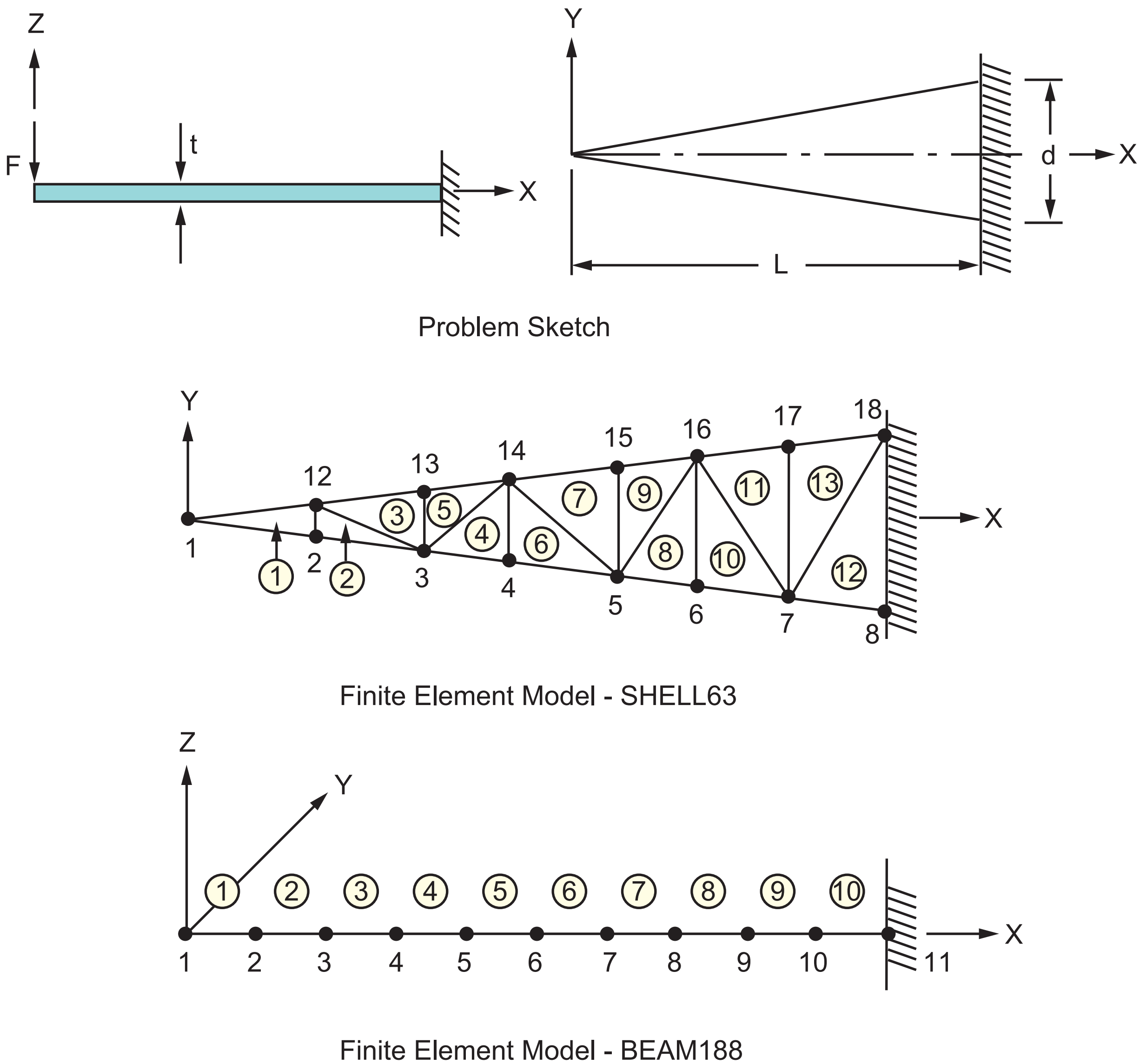
Overview

Reference:	C. O. Harris, *Introduction to Stress Analysis*, The Macmillan Co., New York, NY, 1959, pg. 114, problem 61.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Elastic Shell Elements (SHELL63) 3-D Elastic Tapered Unsymmetric Beam Element (BEAM188) 4-Node Finite Strain Shell Elements (SHELL181) 8-Node Structural Shell (SHELL281)
Input Listing:	vm34.dat

Test Case

A tapered cantilever plate of rectangular cross-section is subjected to a load F at its tip. Find the maximum deflection δ and the maximum principal stress σ_1 in the plate.

Figure 34.1: Beam Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.0$	L = 20 in d = 3 in t = 0.5 in	F = 10 lbs

Analysis Assumptions and Modeling Notes

The problem is solved first using quadrilateral shell elements (SHELL63) and then using tapered beam elements (BEAM188). For the quadrilateral shell elements (used in triangular form), nodal coupling is used to ensure symmetry. Node 10 is arbitrarily located at Z = 1.0 in order to define the orientation of the beam. The problem is also solved using quadrilateral finite strain shell elements (SHELL181 and SHELL281).

Results Comparison

		Target	Mechanical APDL	Ratio
SHELL63	Deflection, in	-0.042667	-0.042667	1.000
	$(Stress_1)_{max}$, psi	1600.00	1600.4496	1.000
BEAM188	Deflection, in	-0.042667	-0.042792	1.003
	$(Stress_1)_{max}$, psi	1600.00	1599.99995	1.000
SHELL181	Deflection, in	-0.042667	-0.042707	1.001
	$(Stress_1)_{max}$, psi	1600.000000	1600.000006	1.000
SHELL281	Deflection, in	-0.042667	-0.042732	1.002
	$(Stress_1)_{max}$, psi	1600.00	1604.375880	1.003

VM35: Bimetallic Layered Cantilever Plate with Thermal Loading

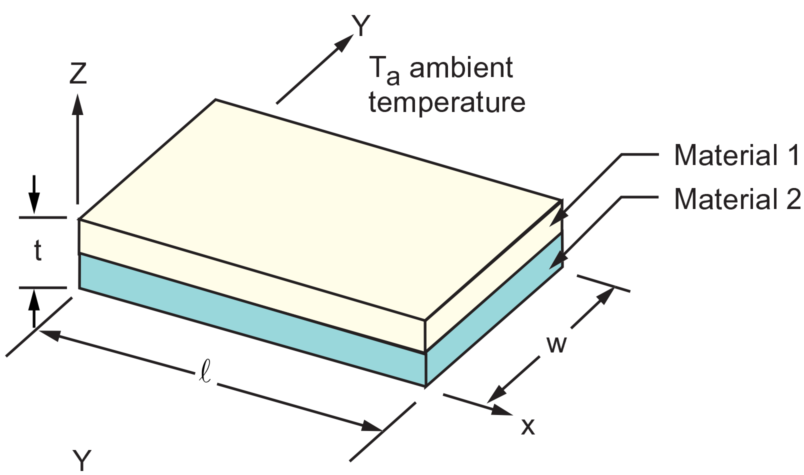
Overview

Reference:	R. J. Roark, W. C. Young, *Formulas for Stress and Strain*, 5th Edition, McGraw-Hill Book Co., Inc., New York, NY, 1975, pp. 113-114.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	8-Node Finite Strain Shell Elements (SHELL281)
Input Listing:	vm35.dat

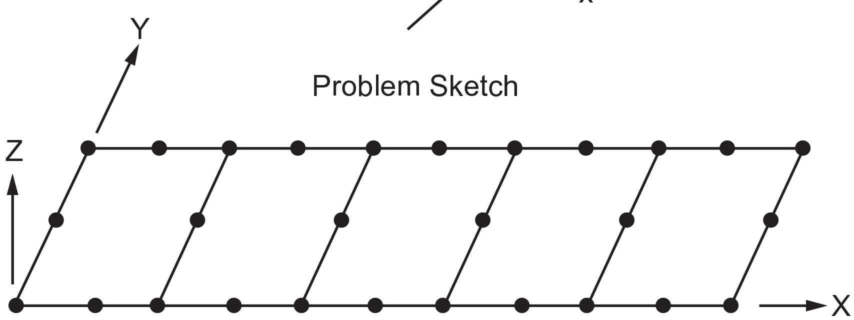
Test Case

A cantilever beam of length ℓ, width w, and thickness t is built from two equal thickness layers of different metals. The beam is stress free at $T_{ref.}$ The beam is fixed at the centerline of one end (X = 0, Y = w/2), and subjected to a uniform temperature T_a. Determine the deflection at the centerline of the free end (X = ℓ) of the cantilever and the outer fiber bending stress at the fixed end.

Figure 35.1: Cantilever Plate Problem Sketch



Problem Sketch



Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E_1 = E_2 = 3 \times 10^7$ psi $\upsilon_1 = \upsilon_2 = 0.0$	ℓ = 10 in t = 0.1 in	T_{ref} = 70°F T_a = 170°F

Material Properties	Geometric Properties	Loading
α_1 = 1 x 10^{-5} in/in-°F α_2 = 2 x 10^{-5} in/in-°F		

Analysis Assumptions and Modeling Notes

The width w is arbitrary for the solution of this problem and is chosen as 1 to produce reasonably-shaped elements. At the "fixed" end, only the center node is constrained to match the simple beam theory used in the reference, and allow unrestrained bending in the Y-Z plane.

The model is solved using layered finite strain shell elements (SHELL281).

Results Comparison

	Target	Mechanical APDL	Ratio
SHELL281			
free-end deflection$_z$, in	0.750	0.750	1.000
free-end deflection$_x$, in	0.015	0.015	1.000
fixed-end top stress$_x$, psi	7500	7500	1.000

VM36: Limit Moment Analysis

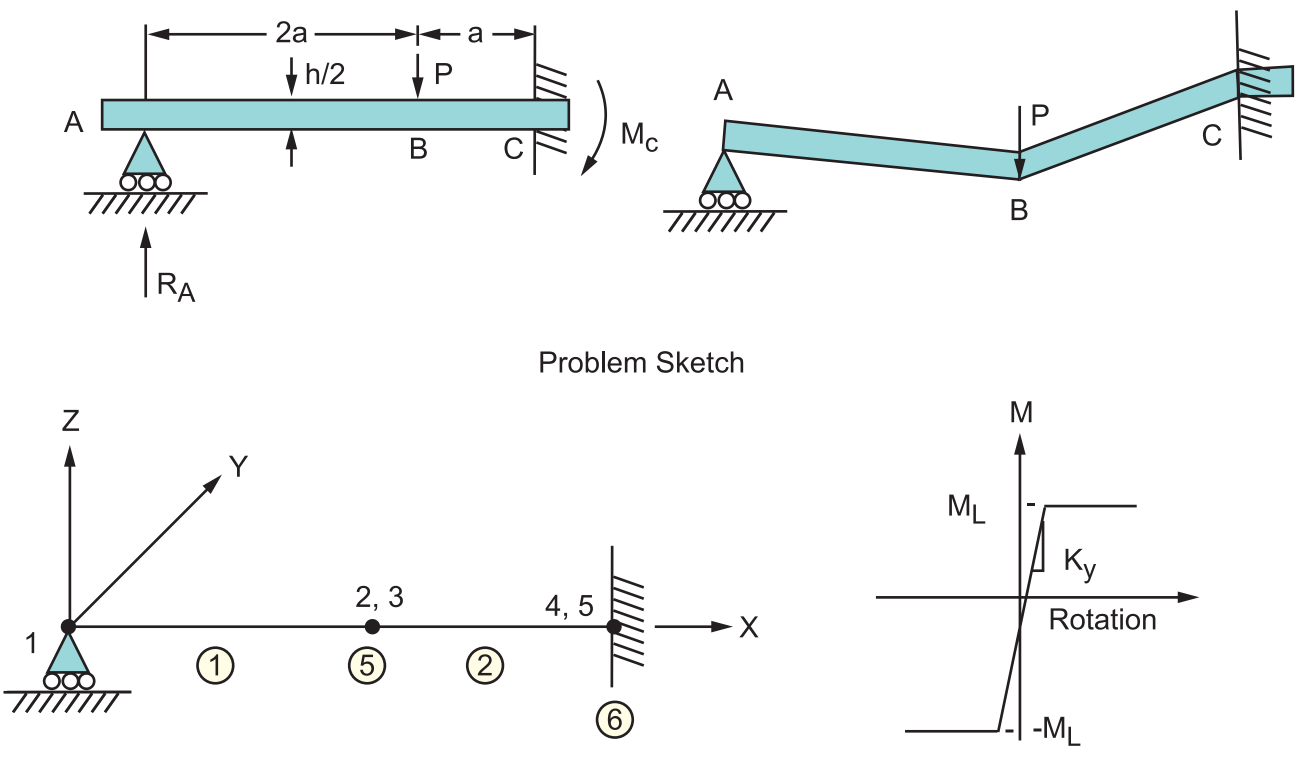
Overview

Reference:	S. H. Crandall, N. C. Dahl, *An Introduction to the Mechanics of Solids*, McGraw-Hill Book Co., Inc., New York, NY, 1959, pg. 389, ex. 8.9.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Combination Elements (COMBIN40) 3-D 2 Node Beam (BEAM188)
Input Listing:	vm36.dat

Test Case

A symmetric cross-section beam of bending stiffness EI_y, and height h, totally fixed at C, simply supported at A, is subjected to a concentrated load P at point B. Verify that a load P which is slightly smaller than the theoretical load limit P_L will cause elastic deformation and that a load which is slightly larger than P_L will cause plastic deformation. Also determine the maximum deflection δ, the reaction force at the left end R_A, and the reaction moment at the right end M_c just prior to the development of a plastic hinge.

Figure 36.1: Limit Moment Problem Sketch



Representative Finite Element Model

Force-Deflection Diagram for Hinges

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = .3$ $M_L = 27,777.77$ in-lb $K_y = 1 \times 10^{12}$ lb/in	a = 50 in $I_y = 20$ in^4 h/2 = 3.93597 in	P = -1000.0 lb (Load Step #1) P = -1388.8 lb (Load Step #2) P = -1390.0 lb (Load Step #3)

Analysis Assumptions and Modeling Notes

The load required for M_c=M_L (the limiting, or fully plastic bending moment) is calculated to be 1000 lbs. From the reference, the second plastic hinge develops at B when $P_L = 2.5M_L/a = 1388.88$ lb. The beam area is not necessary for this loading and is assumed to be 1.0. The beam half height (h/2) is input as a section data using the **SECDATA** command. K_y is arbitrarily selected to be a large value (1×10^{12}) to minimize the elastic effect of the hinge.

Combination elements are used as breakaway hinge connections, which slide above the M_L value. An extra set of these elements are defined in parallel with an arbitrary low stiffness and a large value of real constant FSLIDE to maintain solution stability after collapse. Sliding status of the combination elements indicates that a plastic hinge has formed.

The status of the COMBIN40 is denoted by integers. If STAT = 1, the gap is closed (elastic behavior). STAT = 2 and STAT = -2 indicate positive slide and negative slide respectively (plastic behavior).

Results Comparison

		Target	Mechanical APDL	Ratio
P = 1000 lbs (elastic)	Deflection, in	-0.02829	-0.02855	1.009
	R_A lb	148.15	148.25	1.001
	M_c in-lb	27778	27762.817	0.999
P = 1388.8 lbs	Hinge @ B	1 (Elastic)	1 (Elastic)	1.000
	Hinge @ C	2 (Plastic)	2 (Sliding)	1.000
P = 1390 lbs	Hinge @ B	-2 (Plastic)	-2 (Sliding)	1.000
	Hinge @ C	2 (Plastic)	2 (Sliding)	1.000

VM37: Elongation of a Solid Bar

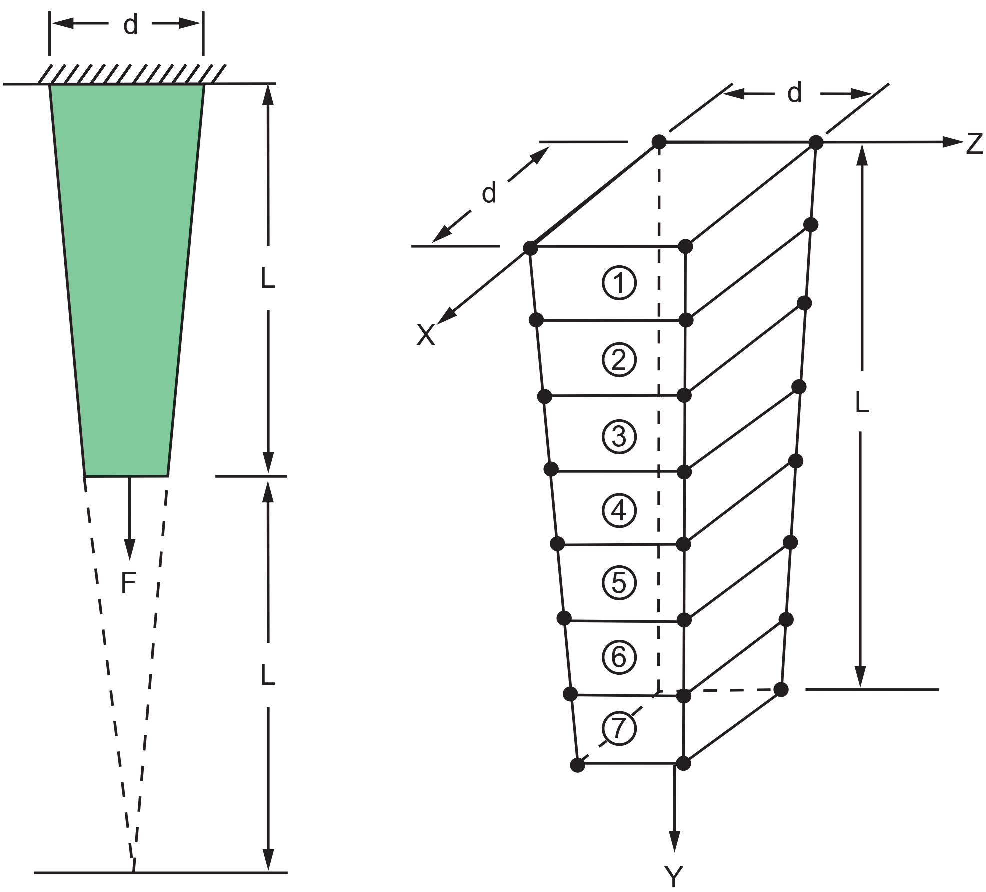
Overview

Reference:	C. O. Harris, *Introduction to Stress Analysis*, The Macmillan Co., New York, NY, 1959, pg. 237, problem 4.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Structural Solid Elements (SOLID45) 3-D Structural Solid Elements (SOLID185) 3-D Structural Solid Shell Elements (SOLSH190)
Input Listing:	vm37.dat

Test Case

A tapered aluminum alloy bar of square cross-section and length L is suspended from a ceiling. An axial load F is applied to the free end of the bar. Determine the maximum axial deflection δ in the bar and the axial stress σ_y at mid-length (Y = L/2).

Figure 37.1: Solid Bar Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 10.4 \times 10^6$ psi $\upsilon = .3$	L = 10 in d = 2 in	F = 10,000 lb

Analysis Assumptions and Modeling Notes

The problem is solved in three different ways:

- Using 3-D Structural Solid Elements (SOLID95)
- Using 3-D Structural Solid Elements (SOLID186)
- Using 3-D Structural Solid Shell Elements (SOLSH190)

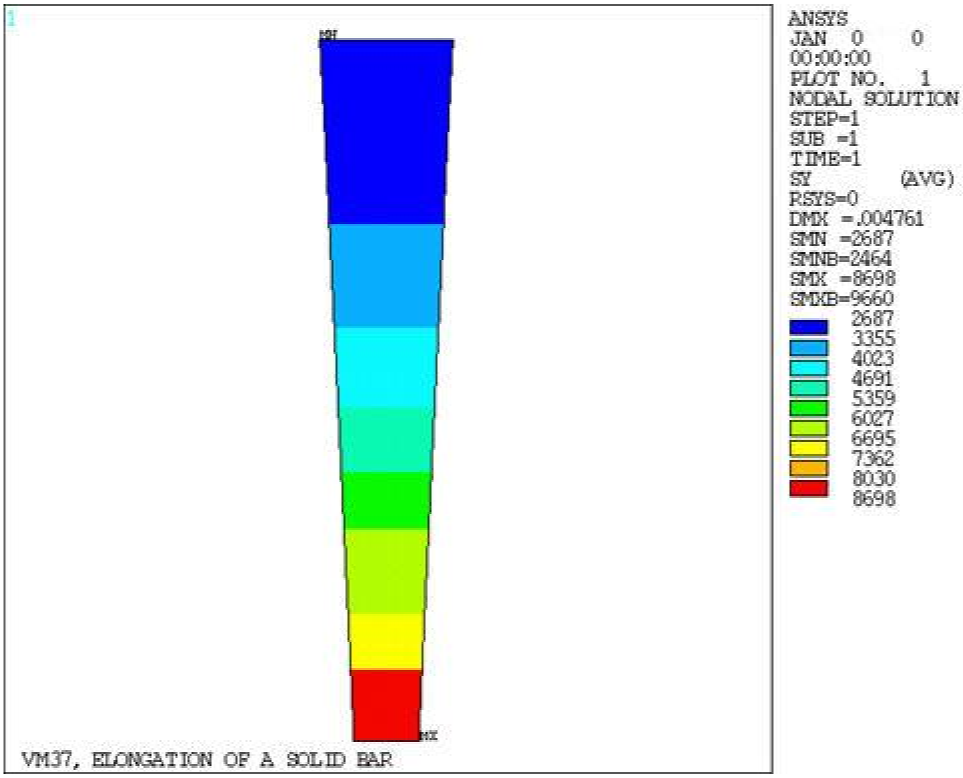
A single tapered volume is mapped-meshed with seven brick-shaped elements along the length of the bar.

POST1 is used to get the nodal displacements at the free end and the axial stress at mid-length of the bar.

Results Comparison

	Target	Mechanical APDL	Ratio
SOLID45			
d , in	0.0048077	.0047570	0.989
$Stress_y$, psi (elem. 4)	4444.	4441.088	0.999
SOLID185			
d , in	0.0048077	.0047570	0.989
$Stress_y$, psi (elem. 4)	4444.	4441.088	0.999
SOLSH190			
d , in	0.0048077	.0047801	0.994
$Stress_y$, psi (elem. 4)	4444.	4463.29	1.004

Figure 37.2: Elongation of a Solid-Bar-Axial Stress Contour Display (SOLID45 Model)



VM38: Internal Pressure Loading of a Thick-Walled Cylinder

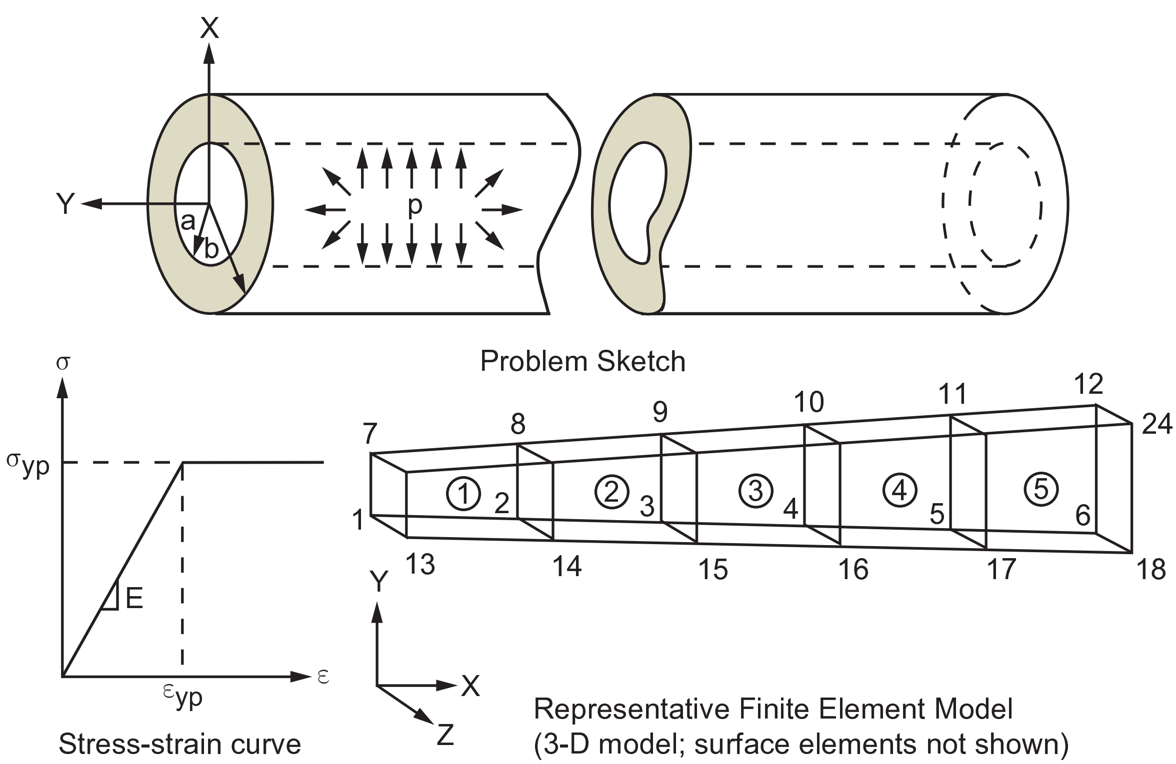
Overview

Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pg. 388, article 70.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Structural Solid Elements (PLANE182) 2-D Structural Surface Effect Elements (SURF153) 3-D Structural Solid Elements (SOLID185) 3-D Structural Surface Effect Elements (SURF154)
Input Listing:	vm38.dat

Test Case

A long thick-walled cylinder is subjected to an internal pressure p (with no end cap load). Determine the radial stress, σ_r, and the tangential (hoop) stress, σ_t, at locations near the inner and outer surfaces of the cylinder for a pressure, p_{el}, just below the yield strength of the material, a fully elastic material condition.

Figure 38.1: Thick-Walled Cylinder Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi σ_{yp} = 30,000 psi υ = 0.3	a = 4 in b = 8 in	p_{el} = 12,990 psi

Analysis Assumptions and Modeling Notes

The theory available for this problem is based on the Tresca (maximum shear) yield criterion while Mechanical APDL uses the von Mises yield criterion. The applied p_{ult} pressure is calculated from the Tresca theory by using $T_y = \sigma_{yp} \sqrt{3}$. This procedure is sufficient to calculate approximate loads but the resulting nonlinear stress components should not be compared directly.

The problem is solved first using axisymmetric solid elements (PLANE182) and then using 3-D solid elements (SOLID185). Since the problem is axisymmetric, only a small sector (5°) is modeled with SOLID185. In order to ensure constant axial strain (implied by the "long" cylinder definition), nodal coupling is used with PLANE182 and SOLID185. To illustrate the use of surface effect elements, the internal pressure P is applied using 2-D structural surface effect elements (SURF153) in the first analysis, whereas 3-D structural surface effect elements (SURF154) are used in the second analysis. Results are obtained from the solution phase and from the element centroid data.

Results Comparison

		Target	Mechanical APDL	Ratio
PLANE182: Fully Elastic	$Stress_r$, psi (X=4.4 in)	-9,984.	-9,986.	1.000
	$Stress_t$, psi (X=4.4 in)	18,645.	18,809.	1.009
	$Stress_r$, psi (X=7.6 in)	-468.	-467.	0.999
	$Stress_t$, psi (X=7.6 in)	9,128.	9,120.	0.999
SOLID185: Fully Elastic	$Stress_r$, psi (X=4.4 in)	-9,984.	-9,986.	1.000
	$Stress_t$, psi (X=4.4 in)	18,645.	18,809.	1.009
	$Stress_r$, psi (X=7.6 in)	-468.	-467.	0.999
	$Stress_t$, psi (X=7.6 in)	9,128.	9,120.	0.999

1. Output quantity SEQV

VM39: Bending of a Circular Plate with a Center Hole

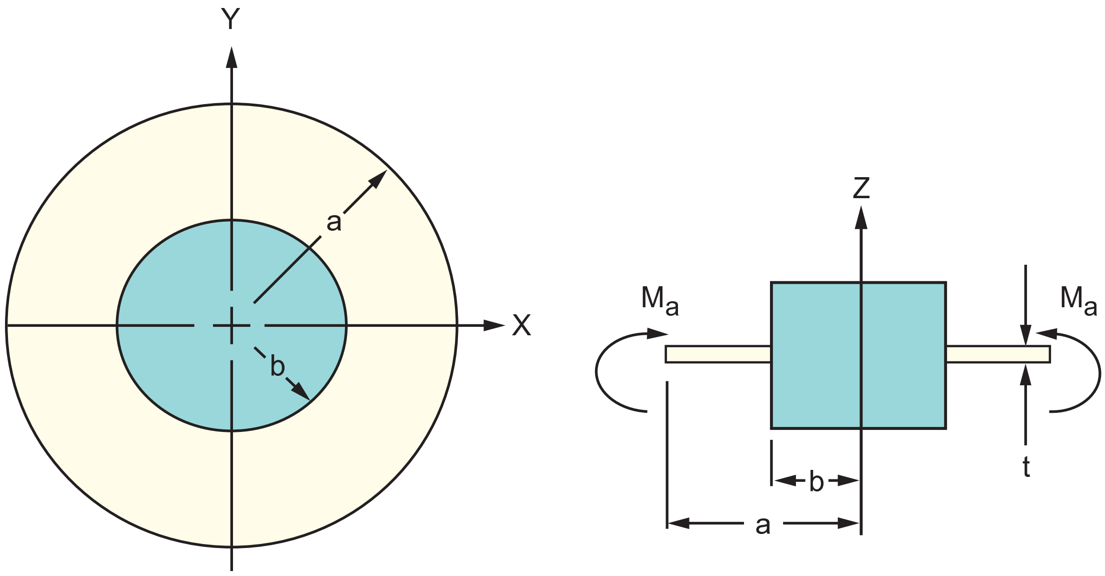
Overview

Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pg. 111, eq. E and F.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Elastic Shell Elements (SHELL63) 4-Node Finite Strain Shell Elements (SHELL181)
Input Listing:	vm39.dat

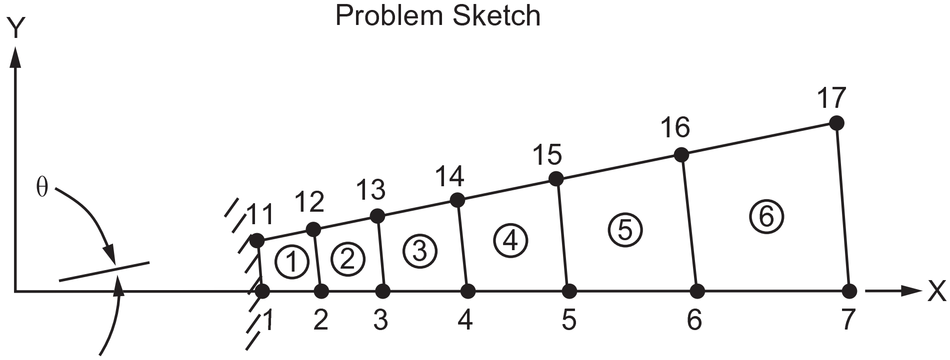
Test Case

A circular plate of thickness t with a center hole is rigidly attached along the inner edge and unsupported along the outer edge. The plate is subjected to bending by a moment M_a applied uniformly along the outer edge. Determine the maximum deflection δ and the maximum slope Φ of the plate. In addition, determine the moment M and stress σ_x at the top centroidal locations of element 1 (near inner edge) and element 6 (near outer edge).

Figure 39.1: Circular Plate Problem Sketch



Problem Sketch



Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = .3$	a = 30 in b = 10 in t = .25 in $\Theta = 105$	M_a = 10 in-lb/in = 52.360 in-lb/10° segment

Analysis Assumptions and Modeling Notes

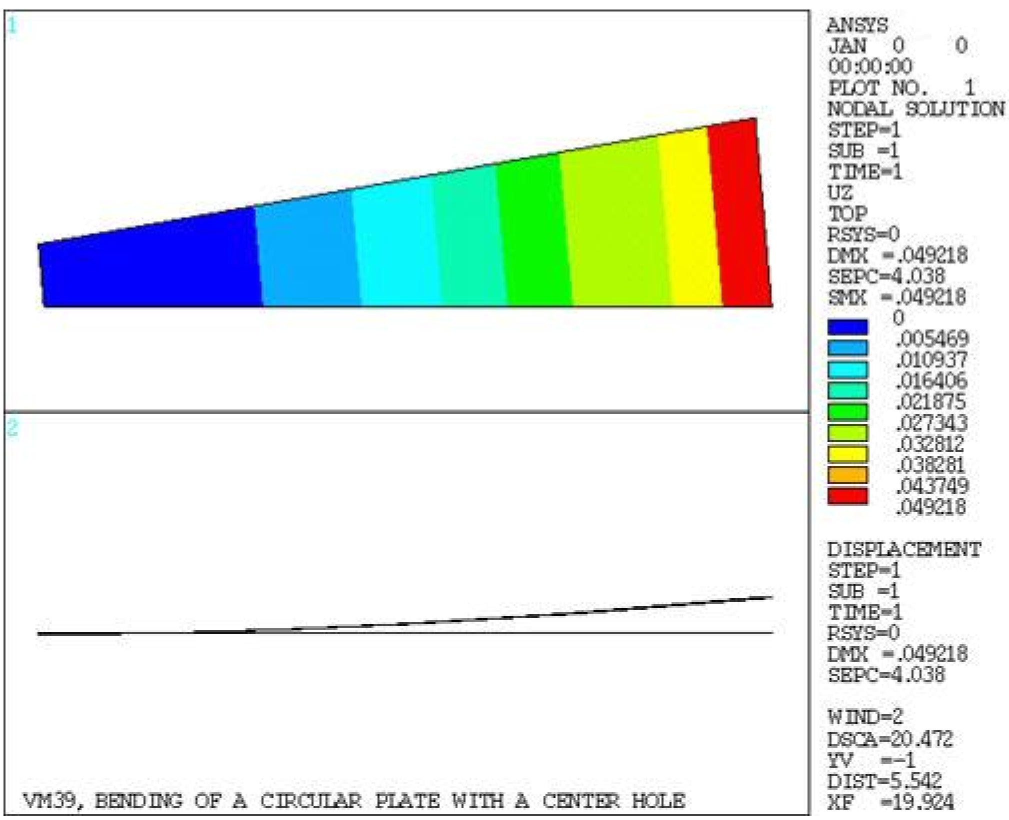
Since the problem is axisymmetric only a small sector of elements is needed. A small angle Θ = 10° is used for approximating the circular boundary with a straight-edged element. A radial grid with nonuniform (3:1) spacing is used. The calculated load is equally divided and applied to the outer nodes.

The model is first solved using SHELL63 elements and then using SHELL181 elements.

Results Comparison

		Target	Mechanical APDL	Ratio
SHELL63				
Deflection, in		.049064	.049218	1.003
Slope, rad		-.0045089	-.0045249	1.004
@ x = 10.81 in.	M, in-lb/in	-13.783	-13.675	0.992
	$Stress_x$, psi	-1323.2	-1312.732	0.992
@ x = 27.1 in.	M, in-lb/in	-10.127	-10.133	1.001
	$Stress_x$, psi	-972.22	-972.742	1.001
SHELL181				
Deflection, in		.049064	.0491780	1.002
Slope, rad		-.0045089	-.0045293	1.005
@ x = 10.81 in.	M, in-lb/in	-13.783	-13.801	1.001
	$Stress_x$, psi	-1323.2	-1318.609	0.997
@ x = 27.1 in.	M, in-lb/in	-10.127	-10.166	1.004
	$Stress_x$, psi	-972.22	-974.959	1.003

Figure 39.2: Window 1: UZ Displacement Contours; Window 2: Displaced Shape - Edge View



VM40: Large Deflection and Rotation of a Beam Pinned at One End

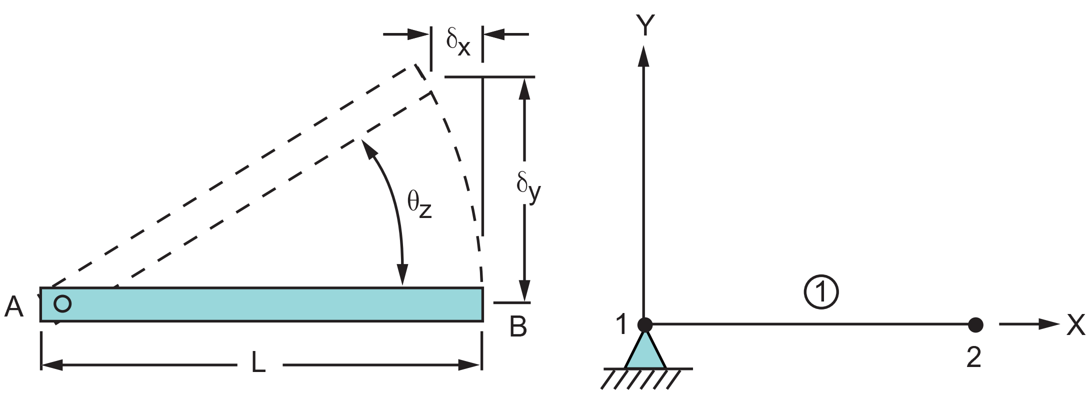
Overview

Reference:	Any basic mathematics book
Analysis Type(s):	Nonlinear Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	3-D 2 Node Beam (BEAM188)
Input Listing:	vm40.dat

Test Case

A massless beam of length L is initially at position AB on a horizontal frictionless table. Point A is pinned to the table and given a large rotation Θ_z through a full revolution at speed ω_z. Determine the position of the beam in terms of δ, and Θ at various angular locations. Show that the beam has no axial stress σ at any position.

Figure 40.1: Beam Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\rho = 1 \times 10^{-10}$ lb-sec^2/in^4	L = 10 in	ω_z = 400 rpm (ccw)

Analysis Assumptions and Modeling Notes

The beam area, moment of inertia, and thickness have no effect on the solution and are assumed equal to 1.0. Density (ρ) is assigned as nearly zero (1×10^{-10}) to avoid centrifugal effects in the problem. Since this is rigid body motion, the time step is chosen to obtain the solution at discrete locations. The speed of 400 rpm is obtained by rotating one revolution in 0.15 sec (1/400th of a minute).

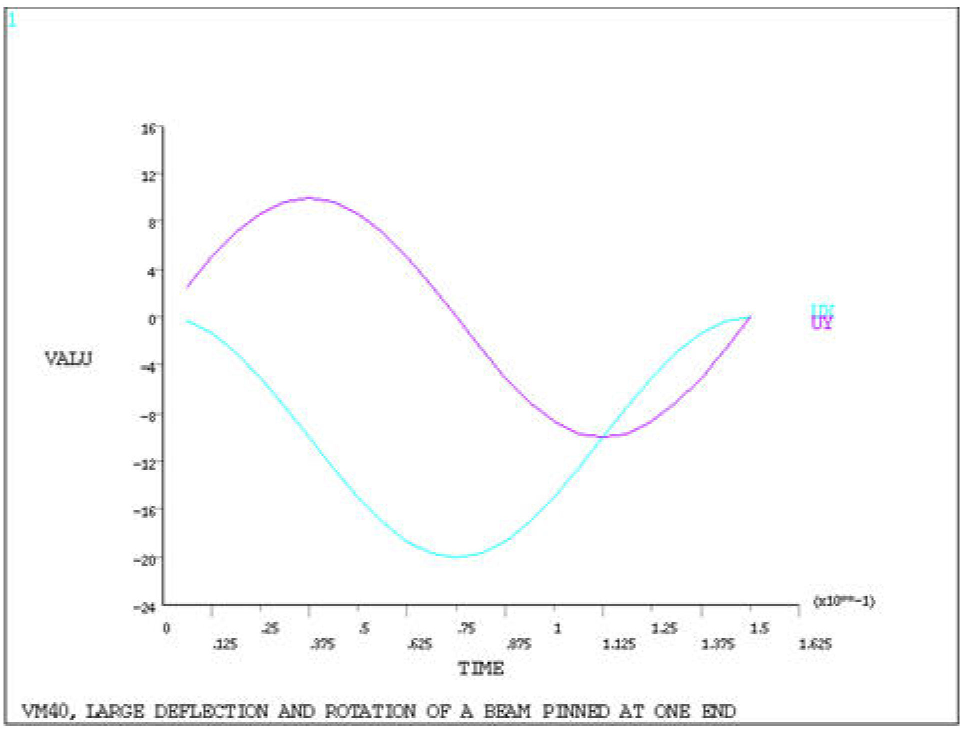
Results Comparison

Rotation$_{z,}$ deg	Deflection	Target	Mechanical APDL	Ratio
60	Deflection$_x$ (in)	-5.0	-5.0	1.00
90	Deflection$_y$ (in)	10.0	10.0	1.00
180	Deflection$_x$ (in)	-20.0	-20.0	1.00
210	Deflection$_y$ (in)	-5.0	-5.0	1.00
315	Deflection$_x$ (in)	-2.93	-2.93	1.00
360	Deflection$_y$ (in)	0.0	0.0	-

Note

Axial stress, $\sigma \approx$ 0, at each position.

Figure 40.2: Displacement of the Free End



VM41: Small Deflection of a Rigid Beam

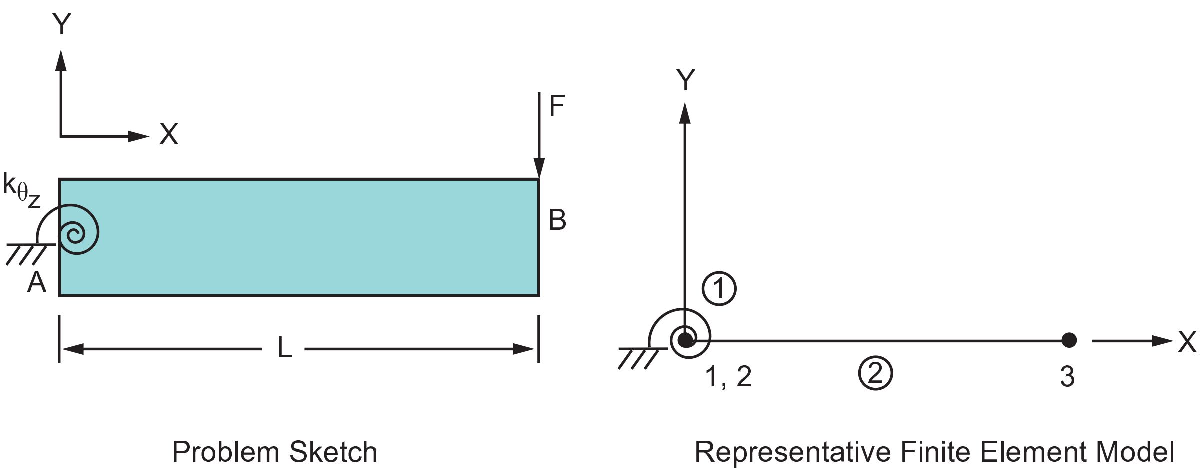
Overview

Reference:	Any Basic Statics and Strength of Material Book
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Stiffness, Damping, or Mass Matrix Element (MATRIX27) 3-D 2 Node Beam (BEAM188)
Input Listing:	vm41.dat

Test Case

A very stiff beam of length L, subjected to a lateral load F, is initially at position AB on a horizontal table. Point A is pinned to the table and restrained from rotation by a relatively weak torsion spring. Determine the final position of the beam in terms of δ_x, δ_y, and Θ. Show that the bending stress in the beam σ_{bend} is negligible.

Figure 41.1: Rigid Beam Problem Sketch



Material Properties	Geometric Properties	Loading
$K_{\theta z}$ = 10,000 in-lb/rad E = 30 x 10^6 psi	L = 10 in	F= 10 lb

Analysis Assumptions and Modeling Notes

The problem is solved using two approaches:

- thick beam geometry approach
- constraint equation approach

In the thick beam approach, the "rigid" beam properties are arbitrarily selected as area = 100 in^2, I = 1000 in^4, thickness = 10 in.

In the constraint equation approach, a constraint equation is used to enforce the assumption of a rigid beam. The constraint equation is of the form: $\delta_y = (L)(\Theta)$. The beam properties are arbitrarily based on a 0.25 square inch cross-section.

Results Comparison

		Target	Mechanical APDL	Ratio
Thick Beam	Deflection$_x$, in	0.0	0.0	-
	Deflection$_y$, in	-0.1	-0.1	1.000
	Angle, rad	-0.01	-0.01	1.000
	Stress$_{bend}$, psi	0.0	0.03[1]	-
Constraint Equation	Deflection$_x$, in	0.0	0.0	-
	Deflection$_y$, in	-0.1	-0.1	1.000
	Angle, rad	-0.01	-0.01	1.000
	Stress$_{bend}$, psi	0.0	0.0	-

1. Small but negligible stress.

VM42: Barrel Vault Roof Under Self Weight

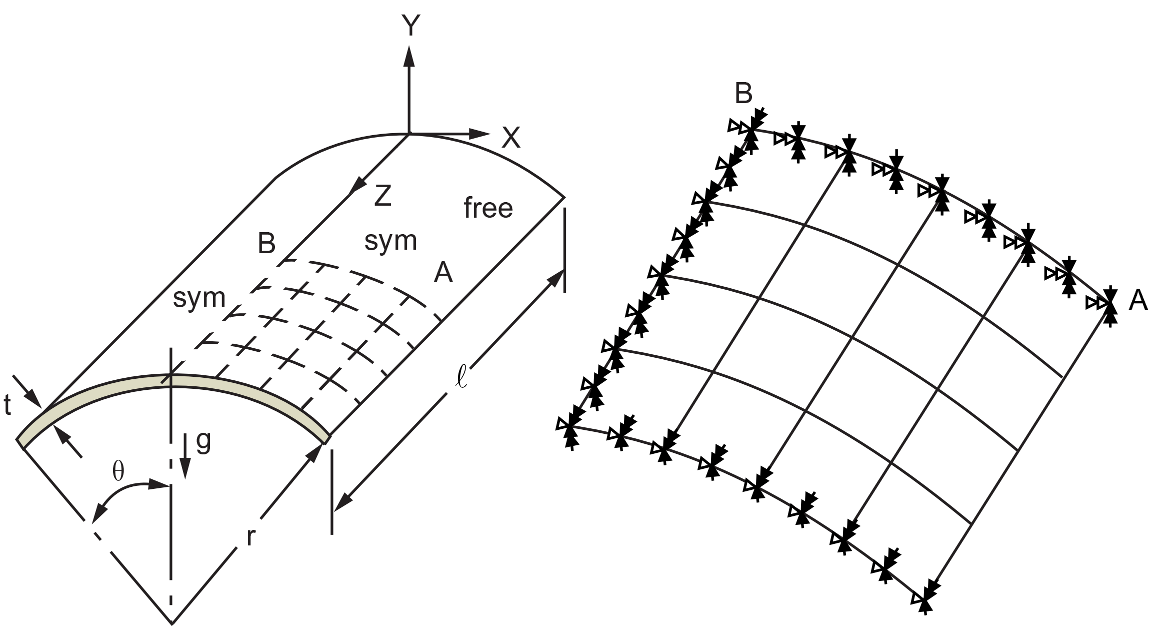
Overview

Reference:	R. D. Cook, *Concepts and Applications of Finite Element Analysis*, 2nd Edition, John Wiley and Sons, Inc., New York, NY, 1981, pp. 284-287.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	4-Node Finite Strain Shell Elements (SHELL181) 8-Node Finite Strain Shell Elements (SHELL281)
Input Listing:	vm42.dat

Test Case

A cylindrical shell roof of density ρ is subjected to a loading of its own weight. The roof is supported by walls at each end and is free along the sides. Find the x and y displacements at point A and the top and bottom stresses at points A and B. Express stresses in the cylindrical coordinate system.

Figure 42.1: Barrel Vault Roof Problem Sketch



Problem Sketch Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 4.32 \times 10^8$ N/m^2 $\upsilon = 0.0$ $\rho = 36.7347$ kg/m^3	t = 0.25 m r = 25 m ℓ = 50 m Θ = 40°	g = 9.8 m/s^2

Analysis Assumptions and Modeling Notes

A one-fourth symmetry model is used. Displacements, UX and UY, and the longitudinal rotation, ROTZ, are constrained at the roof end to model the support wall.

Results Comparison

	Target	Mechanical APDL	Ratio
SHELL181			
UY_A, m	-.3019	-.316	1.047
UX_A, m	-.1593	-.1661	1.042
$Stress_z$, Top @ A, Pa	215570	205333.2869	0.953
$Stress_z$, Bot @ A, Pa	340700	336983.6777	0.989
$Stress_{angle}$, Top @ B, Pa	191230	182418.8632	0.954
$Stress_{angle}$, Bot @ B, Pa	-218740	-209768.5422	0.959
SHELL281			
UY_A, m	-.3019	-.3028	1.003
UX_A, m	-.1593	-.1598	1.003
$Stress_z$, Top @ A, Pa	215570	215624.9892	1
$Stress_z$, Bot @ A, Pa	340700	341504.3073	1.002
$Stress_{angle}$, Top @ B, Pa	191230	191007.4670	0.999
$Stress_{angle}$, Bot @ B, Pa	-218740	-218511.8878	0.999

VM43: Bending of an Axisymmetric Thick Pipe

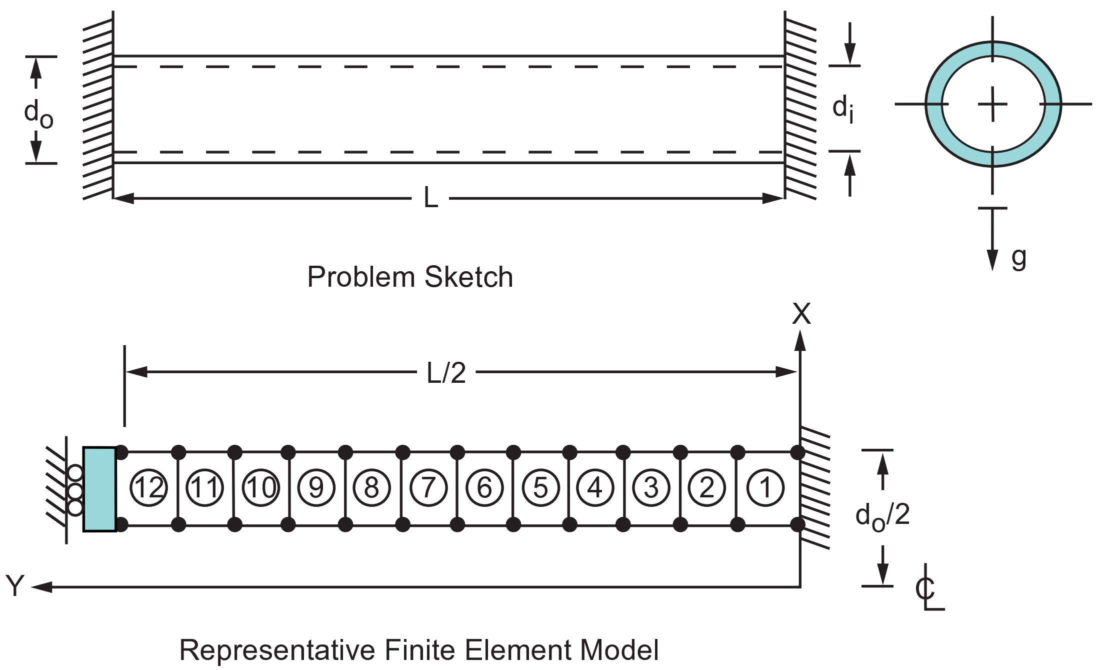
Overview

Reference:	R. J. Roark, *Formulas for Stress and Strain*, 4th Edition, McGraw-Hill Book Co., Inc., New York, NY, 1965, pg. 112, no. 33.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Axisymmetric-Harmonic 4-Node Structural Solid Elements (PLANE25)
Input Listing:	vm43.dat

Test Case

A long thick-walled pipe is rigidly supported at its ends between two walls. Determine the maximum deflection in the pipe due to gravity loading. Determine the maximum tensile stress σ_{max} at the outer surface of the pipe at Y = 4.16666 in.

Figure 43.1: Axisymmetric Thick Pipe Sketch Problem



Material Properties	Geometric Properties	Loading
E = 30 x 10^6 ρ = .00073 lb-sec^2/in^4 υ = 0.0	L = 200 in d_o = 2 in d_i = 1 in	g = 386 in/sec^2

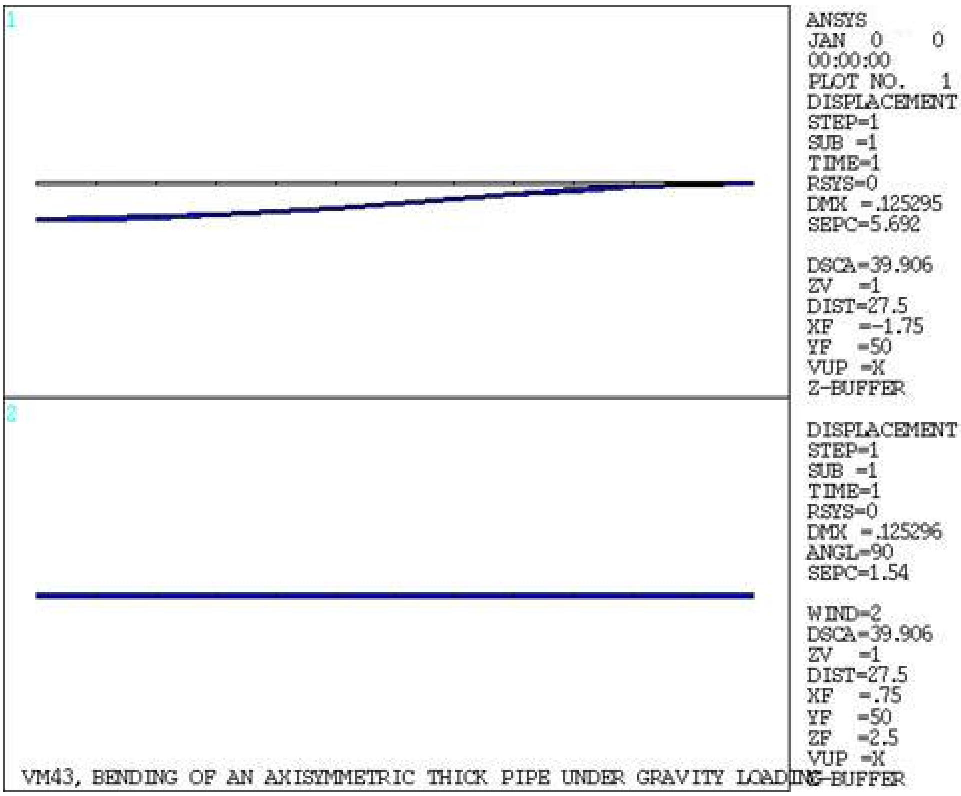
Analysis Assumptions and Modeling Notes

The loading g, which is constant in magnitude and direction around the circumference of the pipe, is applied as the sum of two harmonically varying loads. Each load has one wave around the circumference and is 90° out of phase with the other.

Results Comparison

	Target	Mechanical APDL	Ratio
$Deflection_x$, in (angle = 0°)	-0.12524	-0.12529	1.000
$Deflection_z$, in (angle = 90°)	0.12524	0.12530	1.000
$Stress_{max}$, psi (angle = 0°)	2637.8	2652.4	1.006

Figure 43.2: Displacement Displays



Window 1 Shows a Circumferential Angle of 0°
Window 2 Shows a Circumferential Angle of 90°

VM44: Bending of an Axisymmetric Thin Pipe

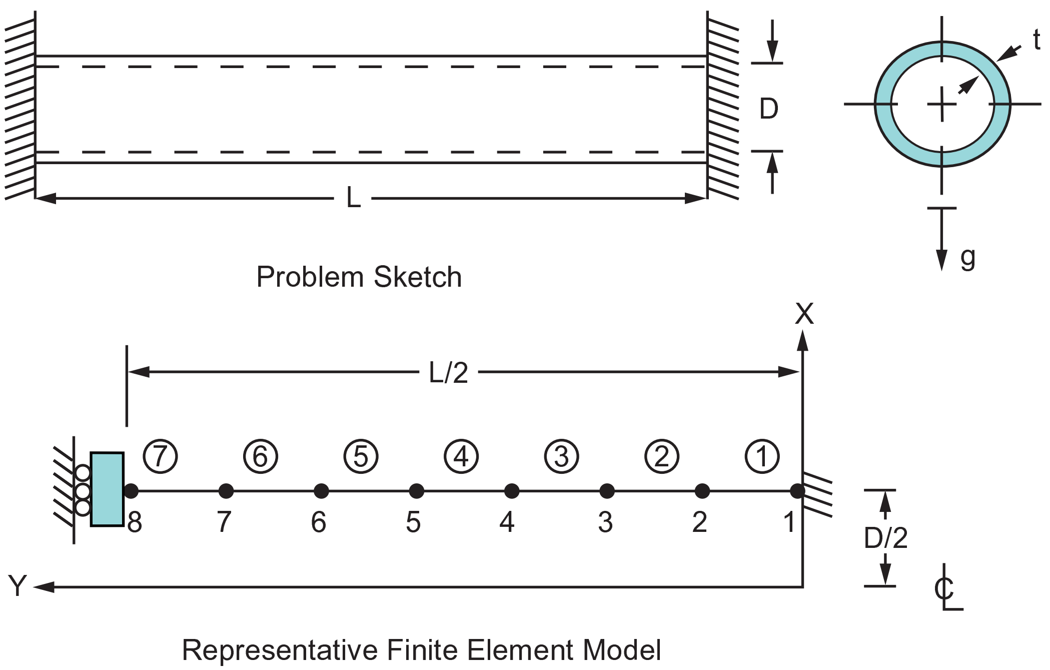
Overview

Reference:	R. J. Roark, *Formulas for Stress and Strain*, 4th Edition, McGraw-Hill Book Co., Inc., New York, NY, 1965, pg. 112, no. 33.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Axisymmetric Harmonic Structural Shell Elements (SHELL61)
Input Listing:	vm44.dat

Test Case

A long thin-walled pipe is rigidly supported at its ends between two walls. Determine the maximum deflection in the pipe due to gravity loading. Determine the maximum tensile stress σ_{max} at the outer surface of the pipe at Y = 0.

Figure 44.1: Axisymmetric Thin Pipe Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\rho = 0.00073$ lb-sec^2/in^4 $\upsilon = 0.0$	L = 250 in D = 2 in t = 0.1 in	g = 386 in/sec^2

Analysis Assumptions and Modeling Notes

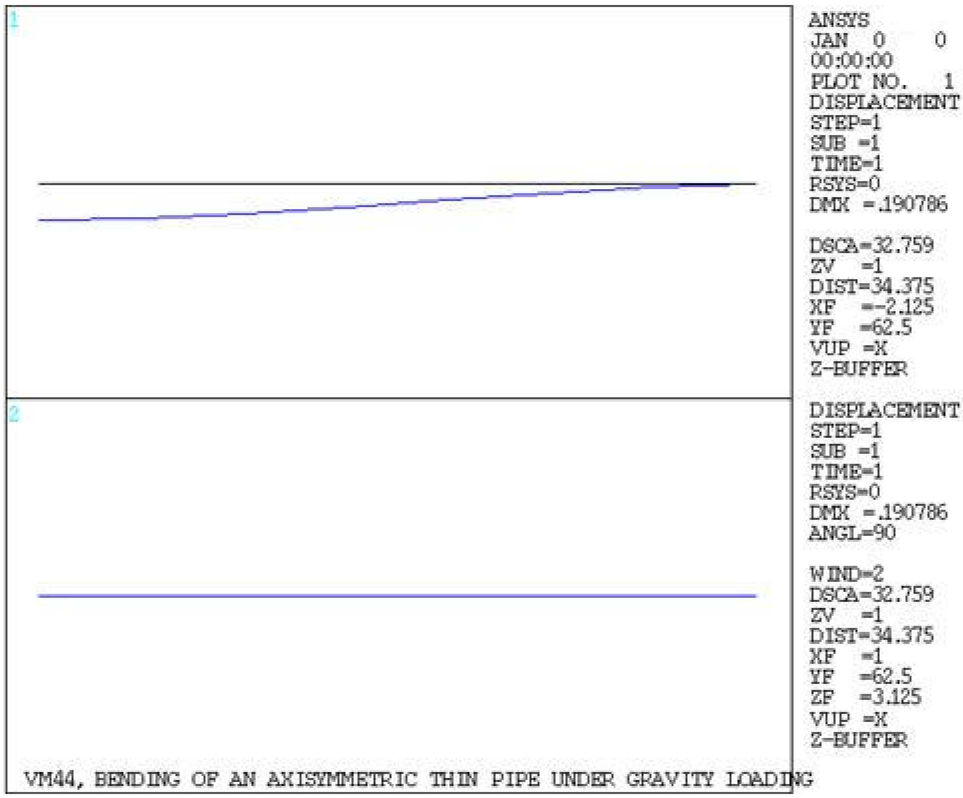
The loading g, which is constant in magnitude and direction around the circumference of the pipe, is applied as the sum of two harmonically varying loads. Each load has one wave around the circumference and is 90° out of phase with the other.

Results Comparison

	Target	Mechanical APDL	Ratio
Deflection$_x$, in (angle = 0°)	-0.19062	-0.19079	1.001
Deflection$_z$, in (angle = 90°)	0.19062	0.19079	1.001
Stress$_{max}$, psi (angle = 0°)	3074.3	3059.115[1]	0.995

1. Corresponds to S1 at BOT of element 1 (section at node I).

Figure 44.2: Displacement Displays



Window 1 Shows a Circumferential Angle of 0°
Window 2 Shows a Circumferential Angle of 90°

VM45: Natural Frequency of a Spring-Mass System

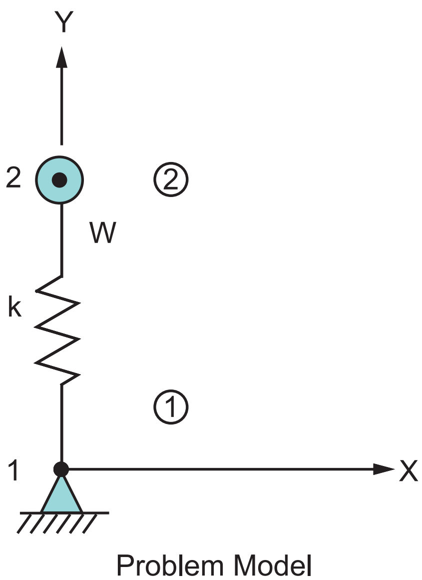
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 6, ex. 1.2-2.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	Spring-Damper Element (COMBIN14) Structural Mass Element (MASS21)
Input Listing:	vm45.dat

Test Case

An instrument of weight W is set on a rubber mount system having a stiffness k. Determine its natural frequency of vibration f.

Figure 45.1: Spring-mass System Problem Sketch



Material Properties	Loading
k = 48 lb/in W = 2.5 lb	g = 386 in/sec^2

Analysis Assumptions and Modeling Notes

The spring length is arbitrarily selected. The weight of the lumped mass element is divided by gravity in order to obtain the mass. Mass = W/g = 2.5/386 = .006477 lb-sec^2/in.

Results Comparison

	Target	Mechanical APDL	Ratio
f, Hz	13.701	13.701	1.000

VM46: 2-D End Notched Flexure Problem

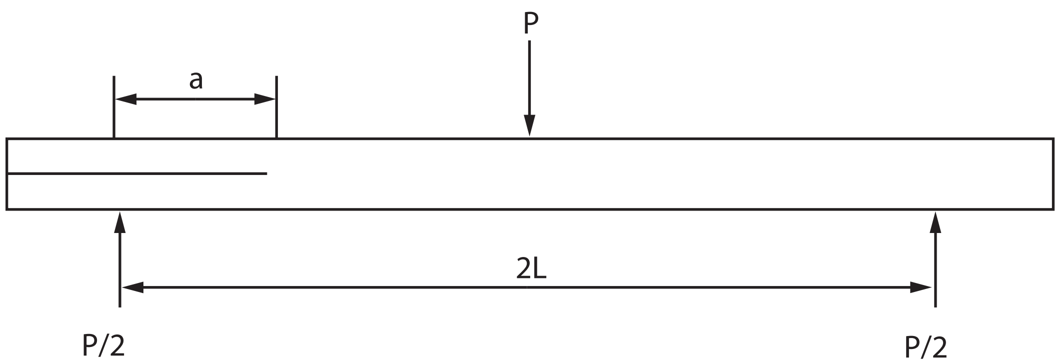
Overview

Reference:	Mandell, J.F. et al. "Prediction of delamination in wind turbine blade structural details". Journal of Solar Energy Engineering. (2003): 522-530.
Analysis Type(s):	Static (**ANTYPE**, 0)
Element Type(s):	2-D Structural Solid Elements (PLANE182)
Input Listing:	vm46.dat

Test Case

A beam is clamped at one end and contains a delamination of length a at the other end. A load P is applied in the middle to cause crack growth. G computation for the cracked tip is conducted for VCCT and compared against the analytical solution (equation (2) in Mandell, J.F. et al. "Prediction of delamination in wind turbine blade structural details").

Figure 46.1: Two-Dimensional End Notched Flexure Problem Sketch



Material Properties	Geometric Properties	Loading
E=210GPa μ=0.3	L=30m a=10m	P=10N

Analysis Assumptions and Modeling Notes

The problem is solved using 2-D PLANE182 element with plain strain element behavior. The contact is defined between the cracks. The crack tip nodes and the number of paths surrounding the crack tip nodes are defined using **CINT** command. The plate is subjected to vertical loading in the middle. G values are computed for the crack tip node.

Results Comparison

	Target	Mechanical APDL	Ratio
G	0.11338	0.11662	1.029

VM47: Torsional Frequency of a Suspended Disk

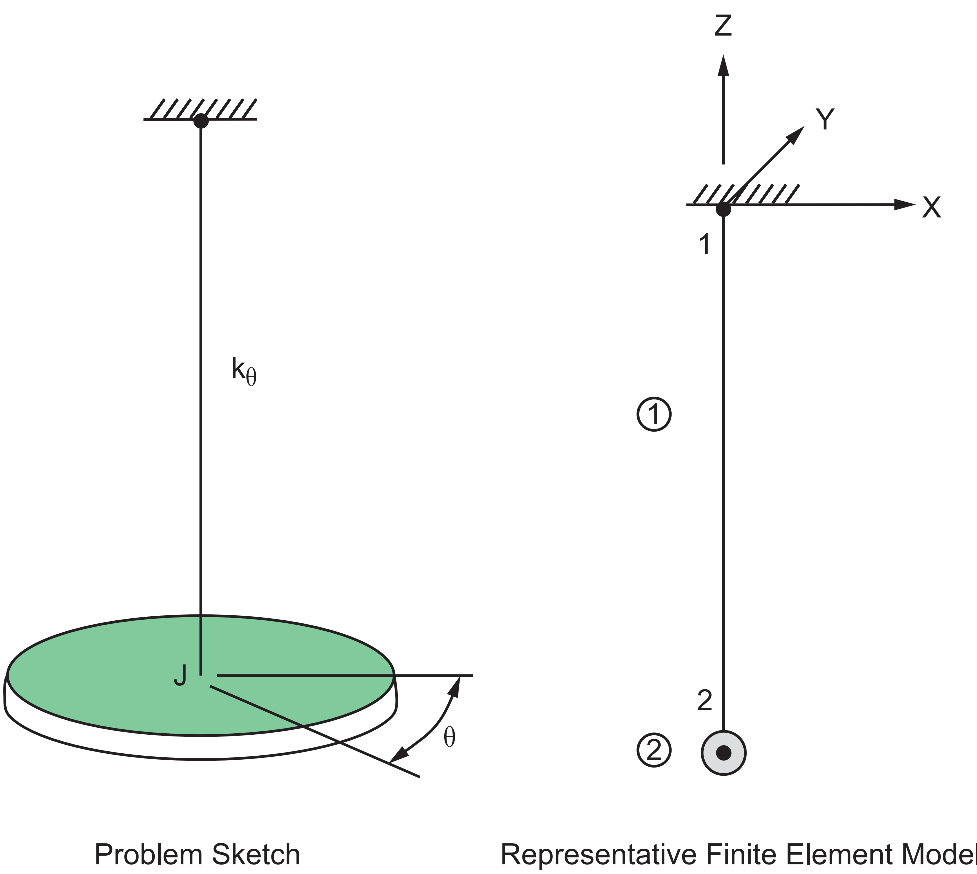
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 10, ex. 1.3-2
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	Spring-Damper Elements (COMBIN14) Structural Mass Elements (MASS21)
Input Listing:	vm47.dat

Test Case

A disk of mass m which has a polar moment of inertia J is suspended at the end of a slender wire. The torsional stiffness of the wire is k_θ. Determine the natural frequency f of the disk in torsion.

Figure 47.1: Suspended Disk Problem Sketch



Material Properties	Geometric Properties
m = 1 lb-sec^2/in k_θ = 4.8 in-lb/rad	J = .30312 lb-in-sec^2

Analysis Assumptions and Modeling Notes

The length of the wire is arbitrarily selected. Modal analysis is performed using Block Lanczos eigensolver.

Results Comparison

	Target	Mechanical APDL	Ratio
f, Hz	0.63333	0.63333	1.00

VM48: Natural Frequency of a Motor-Generator

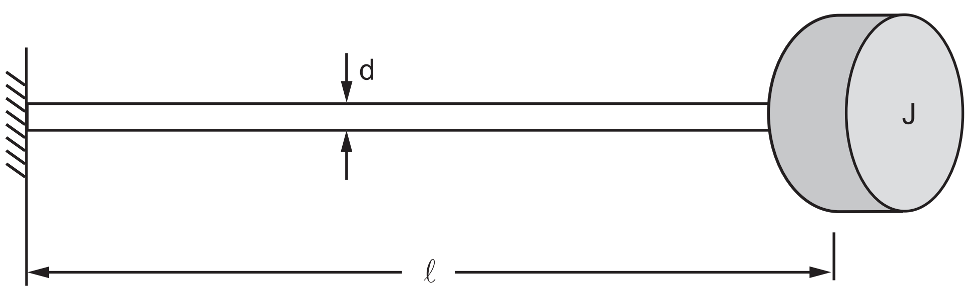
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 10, ex. 1.3-3
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	3-D 2 Node Beam Element (BEAM188) Structural Mass Elements (MASS21)
Input Listing:	vm48.dat

Test Case

A small generator of mass m is driven off a main engine through a solid steel shaft of diameter d. If the polar moment of inertia of the generator rotor is J, determine the natural frequency f in torsion. Assume that the engine is large compared to the rotor so that the engine end of the shaft may be assumed to be fixed. Neglect the mass of the shaft also.

Figure 48.1: Motor-Generator Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties
$E = 31.2 \times 10^6$ psi $m = 1$ lb-sec^2/in	d = .375 in ℓ = 8.00 in J = .031 lb-in-sec^2

Analysis Assumptions and Modeling Notes

The motor is modeled as a circular solid using **SECTYPE** and **SECDATA** commands. All degrees of freedom are constrained, except for the rotational degree of freedom along the x direction at mode 2.

Results Comparison

	Target	Mechanical APDL	Ratio
f, Hz	48.781	48.779	1.00

VM49: Electrostatic Field Analysis of Quadpole Wires

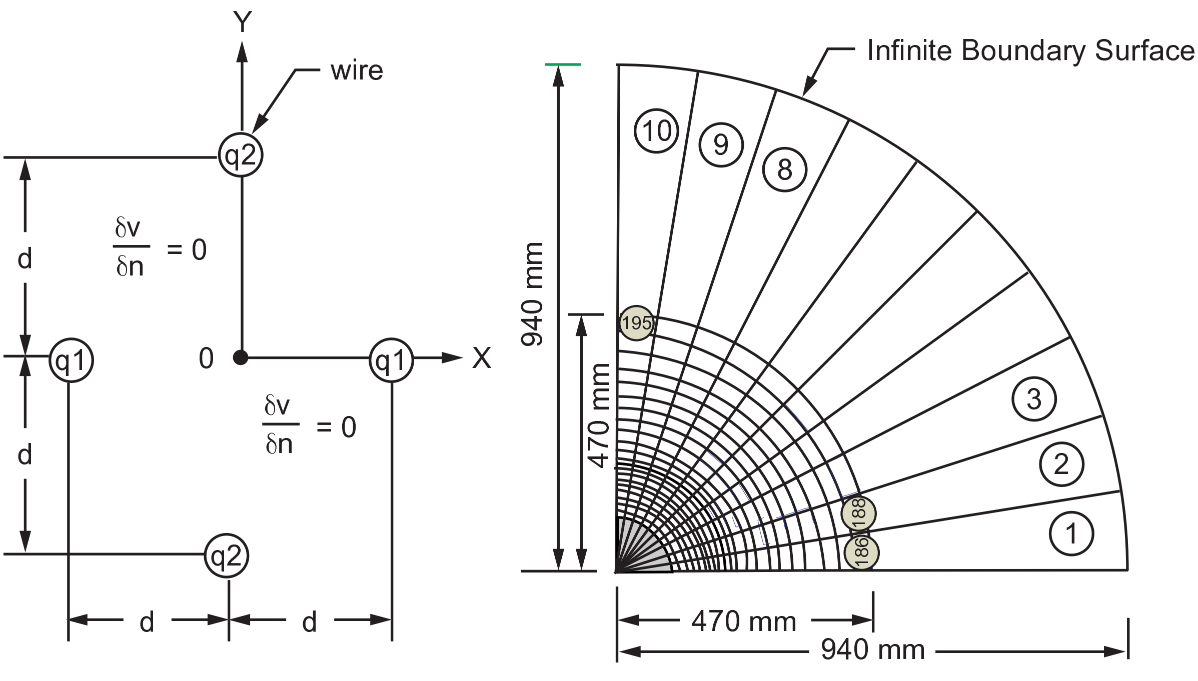
Overview

Reference:	Any Basic Static and Dynamic Electricity Book
Analysis Type(s):	Static, Electrostatic Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 8-Node Electrostatic Solid Element (PLANE121) 2-D Infinite Solid Element (INFIN110)
Input Listing:	vm49.dat

Test Case

Two wires of quadpole device system of zero radius, carrying positive charge, q_1 are placed along the X-axis with their centers located at positive and negative distances, d from the origin, O. Two wires of the same radius carrying negative charge, $q_{2,}$ are placed along the Y-axis with their centers at positive and negative distances, d from the origin, O. All wires are extended in the Z direction. Determine the electric potential, V, produced out to a radius of 470 mm measured from the origin, O.

Figure 49.1: Quadpole Wires Problem Sketch



Problem Sketch   Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$\varepsilon_o = 8.85 \times 10^{-12}$ F/m	d = 25.4 mm	$q_1 = +10^{-6}$ C/m $q_2 = -10^{-6}$ C/m

Analysis Assumptions and Modeling Notes

Two dimensional quad elements of PLANE121 are used out to the radius of 470 mm. At this radius the INFIN110 (quad elements) with length equal to two times the 470 mm are used. Due to symmetry only one quadrant (positive X and positive Y), containing one half of each of two wires (carrying half of positive and negative charge magnitude), is modeled with flux-normal boundary conditions at X = 0.0 and Y = 0.0 axes. Note, since 4-node INFIN110 elements are used with 8-node PLANE121, the infinite element domain is required to mesh before the finite element domain to drop off automatically the midside nodes from the PLANE121 element faces at the interface of the finite and infinite element domain. SF command with label, INF is used to flag the exterior surface (at infinity) of the INFIN110 elements. The charge is applied as a point load at the center of each of two wires.

In POST1 electric potential V at angles 0 to 90° (with 10 divisions) on the outer surface of radius 470 mm are retrieved and written by ***VWRITE** command.

Results Comparison

V (Volt)	Target	Mechanical APDL	Ratio
@ Angle 0°	105.05	105.79	1.01
@ Angle 9°	99.90	100.62	1.01
@ Angle 18°	84.98	85.59	1.01
@ Angle 27°	61.74	62.18	1.01
@ Angle 36°	32.46	32.69	1.01
@ Angle 45°	0.0000	0.0000	0.0
@ Angle 54°	-32.46	-32.69	1.01
@ Angle 63°	-61.74	-62.18	1.01
@ Angle 72°	-84.98	-85.59	1.01
@ Angle 81°	-99.98	-100.62	1.01
@ Angle 90°	-105.05	-105.79	1.01

VM50: Fundamental Frequency of a Simply Supported Beam

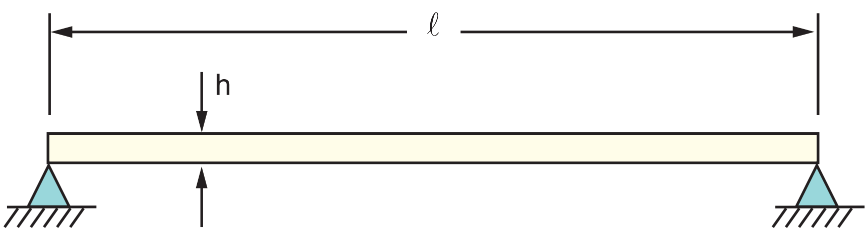
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 18, ex. 1.5-1
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	3-D 3-Node Beam (BEAM189)
Input Listing:	vm50.dat

Test Case

Determine the fundamental frequency f of a simply-supported beam of length ℓ and uniform cross-section as shown below.

Figure 50.1: Simply Supported Beam Problem Sketch



Problem Sketch

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi w = 1.124 lb/in $\rho = w/Ag = .000728$ lb-sec^2/in^4	ℓ = 80 in A = 4 in^2 h = 2 in I = 1.3333 in^4	g = 386 in/sec^2

Analysis Assumptions and Modeling Notes

This beam is modeled with arbitrary cross sections. The problem is solved using Lanczos eigensolver.

Results Comparison

	Target	Mechanical APDL	Ratio
f, Hz	28.766	28.761	1.000

VM51: Electrostatic Forces Between Charged Spheres

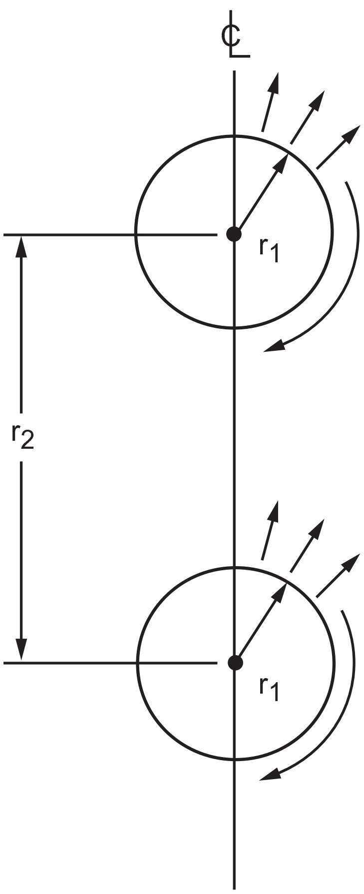
Overview

Reference:	Any General Physics Textbook
Analysis Type(s):	Electrostatic Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 20-Node Electrostatic Solid Element (SOLID122) 3-D 10-Node Tetrahedral Electrostatic Solid Element (SOLID123) 3-D Infinite Solid Element (INFIN111) 2-D 8-Node Electrostatic Solid (PLANE121) Meshing Facet (MESH200)
Input Listing:	vm51.dat

Test Case

Two spheres with radii = 1 m, separated by a distance of 3 m, are subjected to a surface charge. Find the resultant electrostatic force between the spheres.

Figure 51.1: Charged Spheres Problem Sketch



Problem Sketch

Material Properties	Geometric Properties	Loading
ε = 8.854E-12 F/m	r_1 = 1.0 m r_2 = 3.0 m r_3 = 6.0 m r_4 = 1.25 m	Surface charge = 8.854 E-12 C/m^2

Analysis Assumptions and Modeling Notes

The finite element mesh and the infinite element mesh are generated from the solid model. A planar section of the model is meshed with PLANE121 elements and rotated through 30 degrees. The 2-D mesh creates a 3-D mesh of SOLID122 elements. SHELL281 elements are generated over the outer surface of the 3-D mesh and extruded in the radial direction to complete the finite element domain. The process is repeated to extrude the INFIN111 mesh in the radial direction.

It can be assumed that a symmetry plane exists at Y = 0, at which a zero voltage constraint is imposed. Infinite flags are set for the outer surface of the INFIN111 elements.

The same problem is then solved using SOLID123 elements

The theoretical solution is:

$$F = \frac{(q_1 * q_2)}{(4 * \pi * \varepsilon * r_2^2)}$$

where ε = 8.854E-12, $q_1 = q_2 = 4* \pi* \varepsilon$. This charge corresponds to a surface force of ε on the sphere.

surface charge = q/area = $(4* \pi* \varepsilon)/4* \pi*(r_1**2) = \varepsilon$

Results Comparison

SOLID122			
	Target	Mechanical APDL	Ratio
YFORCE	-0.1236E-10	-0.1236E-10	1.000

SOLID123			
	Target	Mechanical APDL	Ratio
YFORCE	-0.1236E-10	-0.1235E-10	0.999

Figure 51.2: Solid Model

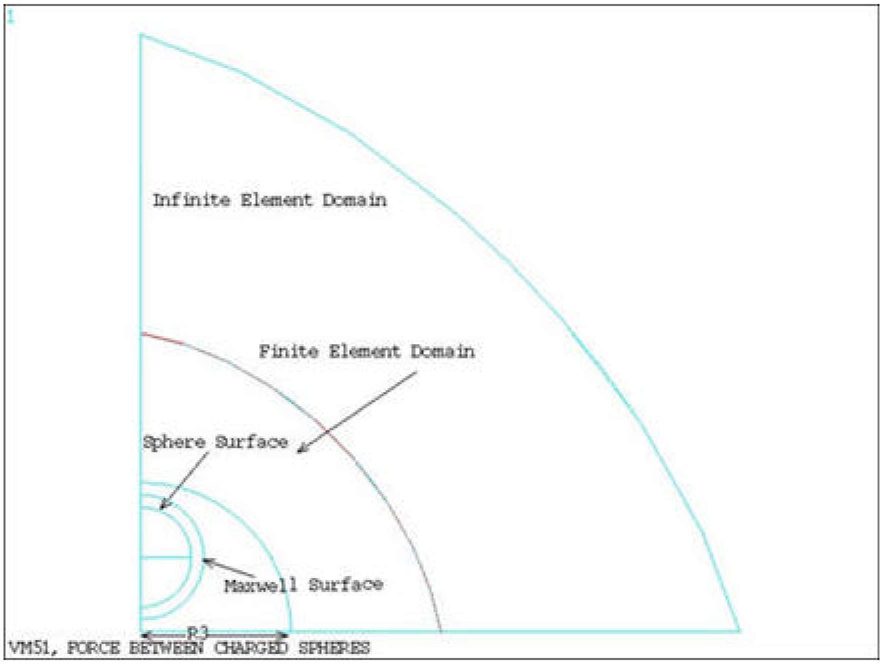


Figure 51.3: FEA Model with SOLID122 and INFIN111 Elements

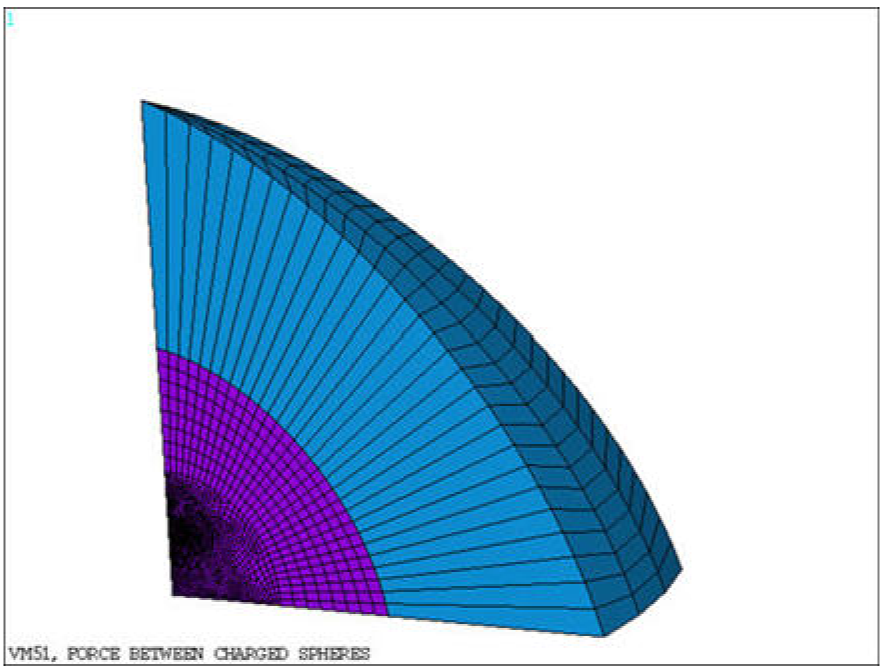


Figure 51.4: Electric Field Plot with SOLID122 and INFIN111 Elements

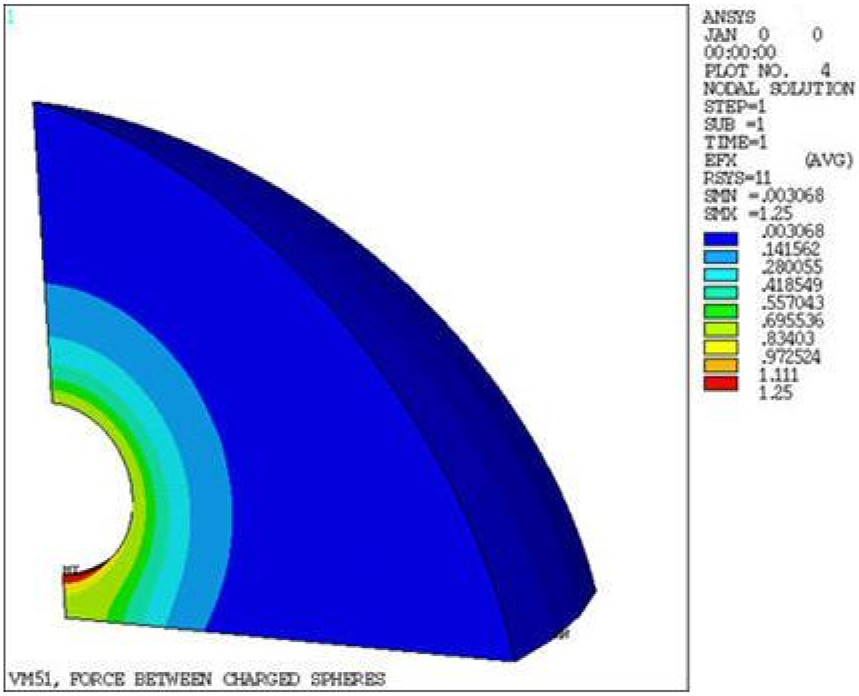


Figure 51.5: Voltage Plot with SOLID122 and INFIN111 Elements

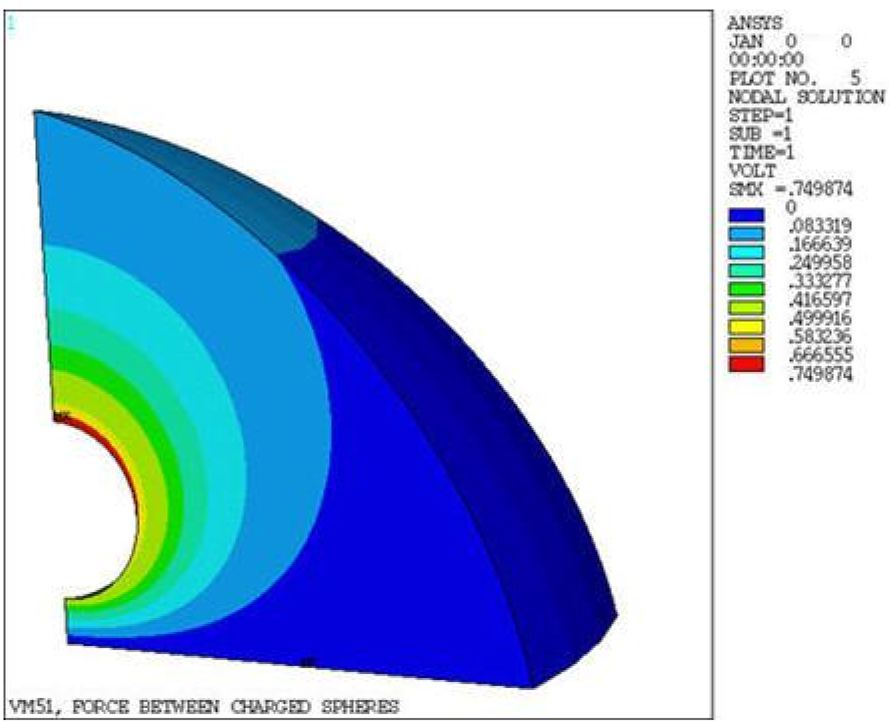


Figure 51.6: FEA Model with SOLID123 and INFIN111 Elements

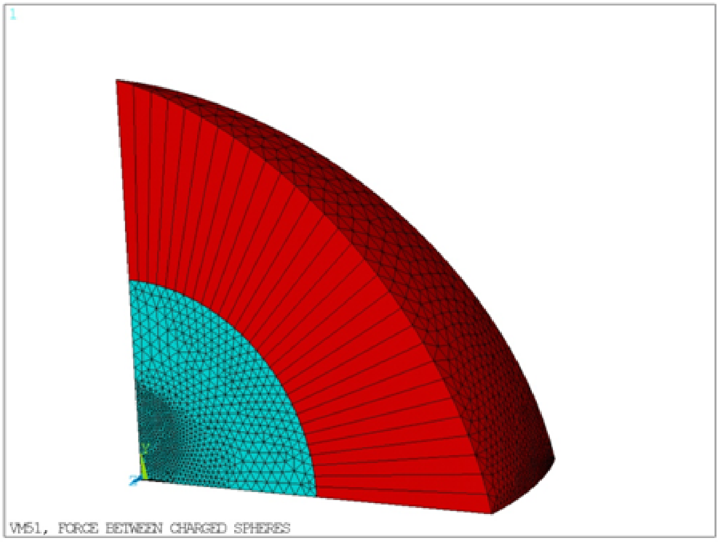


Figure 51.7: Electric Field Plot with SOLID123 and INFIN111 elements

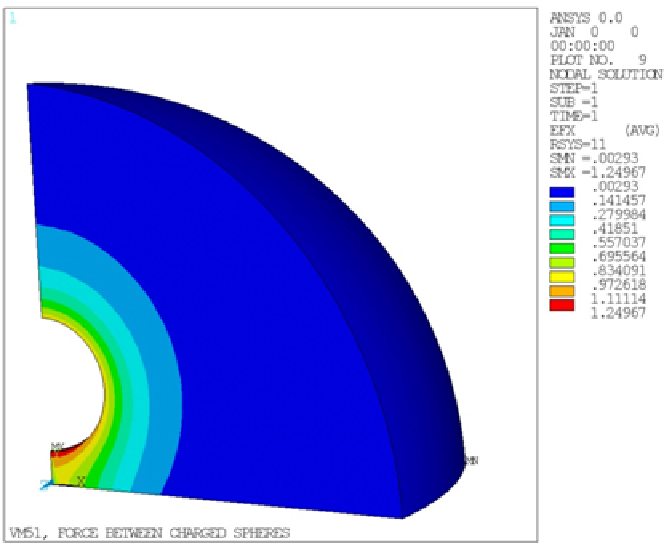
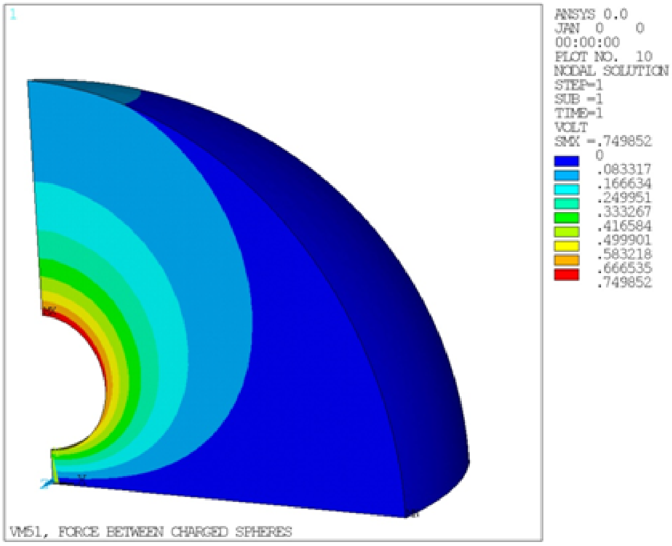


Figure 51.8: Voltage Plot with SOLID123 and INFIN111 Elements



VM52: Automobile Suspension System Vibration

Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 181, ex. 6.7-1
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	3-D 2 Node Beam (BEAM188) Spring-Damper Elements (COMBIN14) Structural Mass Element (MASS21)
Input Listing:	vm52.dat

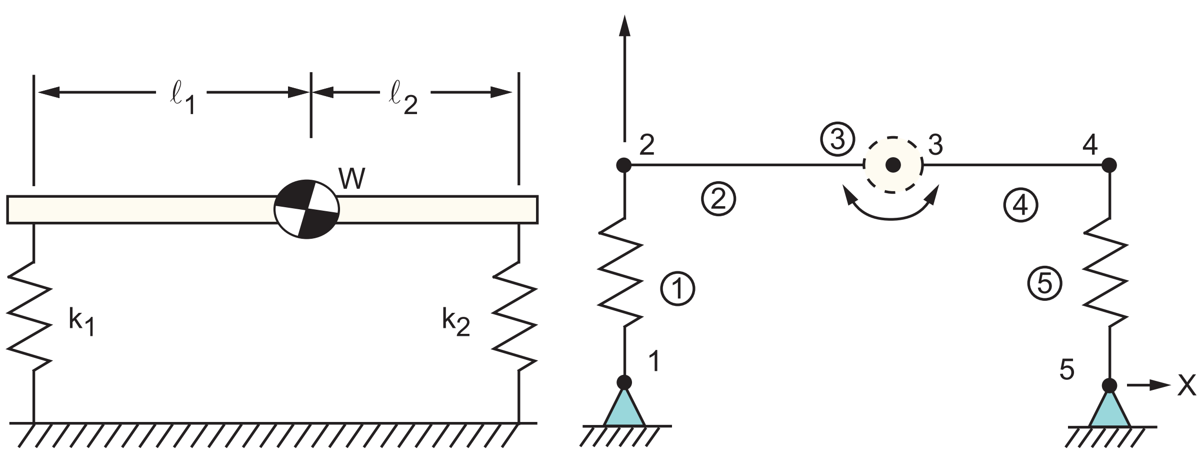
Test Case

An automobile suspension system is simplified to consider only two major motions of the system:

- up and down linear motion of the body
- pitching angular motion of the body

If the body is idealized as a lumped mass with weight W and radius of gyration r, determine the corresponding coupled frequencies f_1 and f_2.

Figure 52.1: Automobile Suspension Problem Sketch



Problem Sketch   Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 4 \times 10^9$ psf w = 3220 lb m = W/g = 100 lb-sec^2/ft k_1 = 2400 lb/ft k_2 = 2600 lb/ft	ℓ_1 = 4.5 ft ℓ_2 = 5.5ft r = 4 ft	g = 32.2 ft/sec^2

Analysis Assumptions and Modeling Notes

The beam geometric properties are input (all as unity) but not used for this solution. The torsional moment of inertia I_T is calculated as $I_T = Wr^2/g$ = 1600 lb-sec^2-ft. The spring length is used only to define the spring direction.

Results Comparison

	Target	Mechanical APDL	Ratio
f_1 , Hz	1.0981	1.0979	1.000
f_2 , Hz	1.4406	1.4403	1.000

VM53: Vibration of a String Under Tension

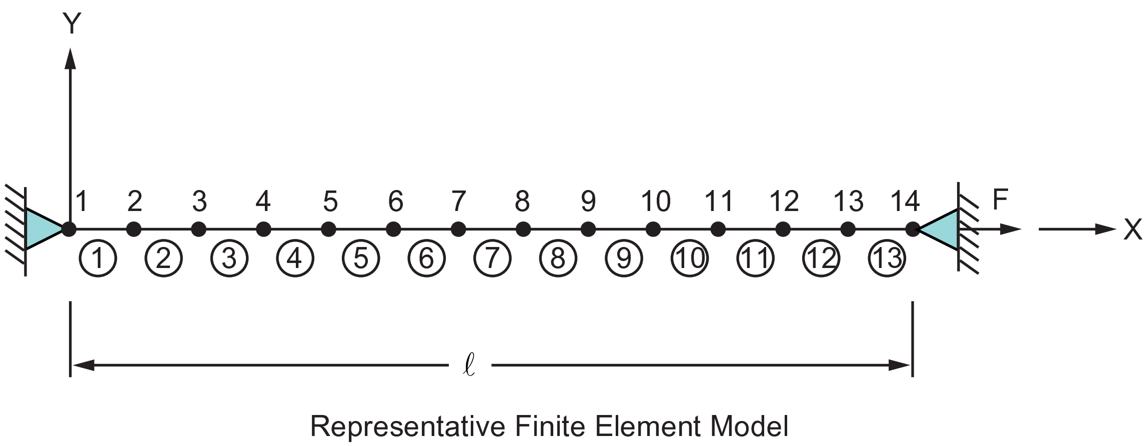
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 264, article 8.2.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0) Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	3-D Spar (or Truss) Elements (LINK180)
Input Listing:	vm53.dat

Test Case

A flexible string with mass per unit length ρA is fixed at the ends and stretched to an initial strain ε_o. Determine the stress σ and force F in the string under these conditions. Determine the first three natural frequencies f_i of lateral vibration of the stretched string.

Figure 53.1: String Under Tension Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi ρ = 0.00073 lb-sec^2/in^4	ℓ = 100 in A = 0.00306796 in^2	ε_o = 0.00543228

Analysis Assumptions and Modeling Notes

Enough elements are selected so that the same model can be used to adequately characterize the dynamic analysis. Linear perturbation modal analysis is performed to determine the frequencies of the pre-stressed structure

The Block Lanczos method for eigenvalue extraction is chosen solely for the sake of completeness in this manual. Other methods would also be suitable. Only the first three modes are requested.

Results Comparison

		Target	Mechanical APDL	Ratio
Static	F, lb	500.00	499.99	1.000
	Stress, psi	162,974.	162,974	1.000
Modal	f_1 , Hz	74.708	74.890	1.002
	f_2 , Hz	149.42	150.875	1.010
	f_3 , Hz	224.12	229.060	1.022

VM54: Vibration of a Rotating Cantilever Blade

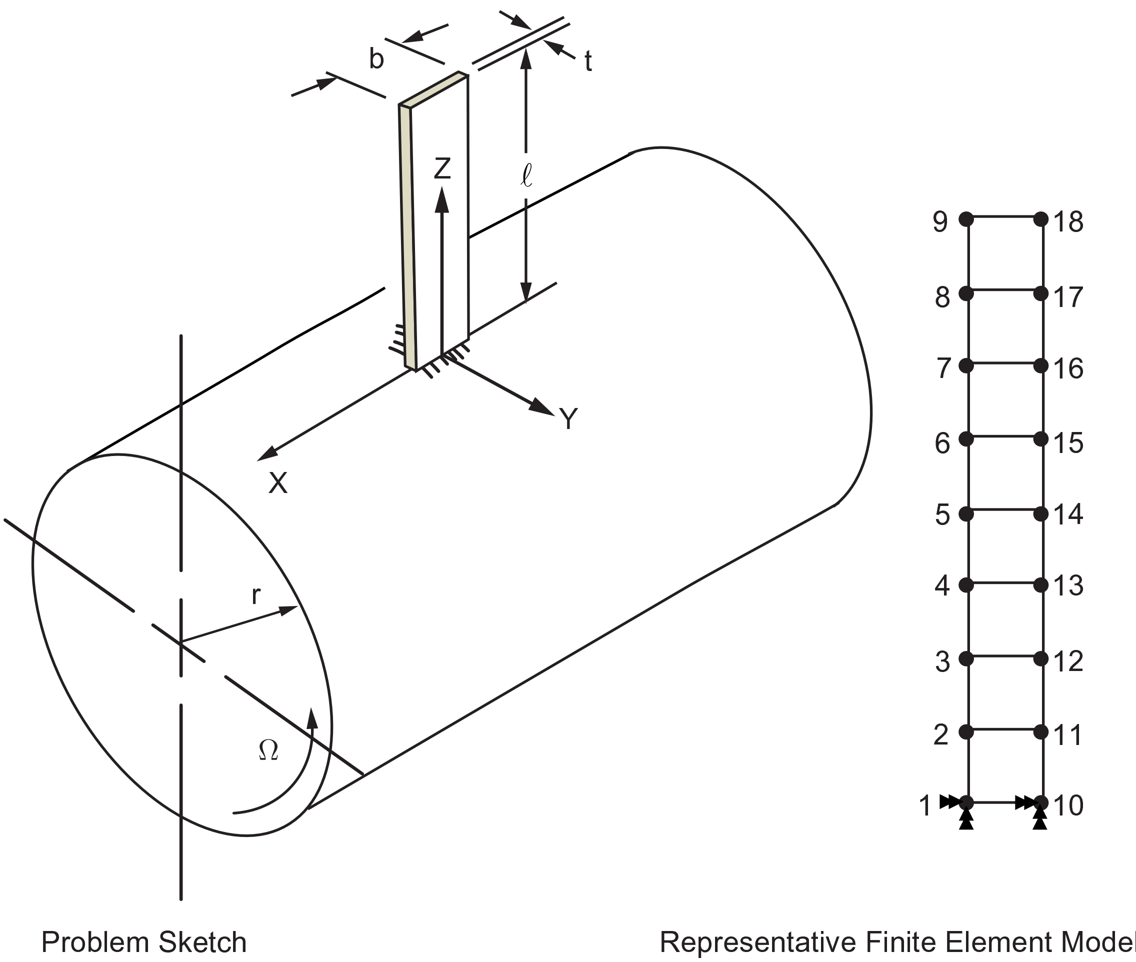
Overview

Reference:	W. Carnegie, "Vibrations of Rotating Cantilever Blading", *Journal Mechanical Engineering Science*, Vol. 1 No. 3, 1959, pg. 239
Analysis Type(s):	Static Analysis (**ANTYPE** = 0) Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	Elastic Shell Elements (SHELL63) 3-D Structural Solid Shell Elements (SOLSH190) 4-Node Finite Strain Shell Elements (SHELL181) 8-Node Finite Strain Shell Elements (SHELL281)
Input Listing:	vm54.dat

Test Case

A blade is cantilevered from a rigid rotating cylinder. Determine the fundamental frequency of vibration of the blade, f, when the cylinder is spinning at a rate of Ω .

Figure 54.1: Rotating Cantilever Blade



Material Properties	Geometric Properties	Loading
$E = 217 \times 10^9$ Pa $\rho = 7850$ kg/m^3 $\upsilon = 0.3$	r = 150 mm ℓ = 328 mm b = 28 mm t = 3mm	$\Omega = 100\pi$ rad/sec

Analysis Assumptions and Modeling Notes

The problem is solved in four different ways:

- Using Elastic Shell Elements (SHELL63).
- 3-D Solid Shell Elements (SOLSH190) using linear perturbation analysis.
- Low order Finite Strain Shell Elements (SHELL181) using linear perturbation analysis.
- High order Finite Strain Shell Elements (SHELL281) using linear perturbation analysis.

Since the cylinder is rigid, the base of the blade has its displacements constrained. A static prestress analysis is performed to include the inertial effects resulting from the rotation of the cylinder.

Results Comparison

	Target	Mechanical APDL	Ratio
SHELL63			
f, Hz	52.75	52.01	0.986
SOLSH190			
f, Hz	52.75	51.87	0.983
SHELL181			
f, Hz	52.75	51.87	0.983
SHELL281			
f, Hz	52.75	51.92	0.984

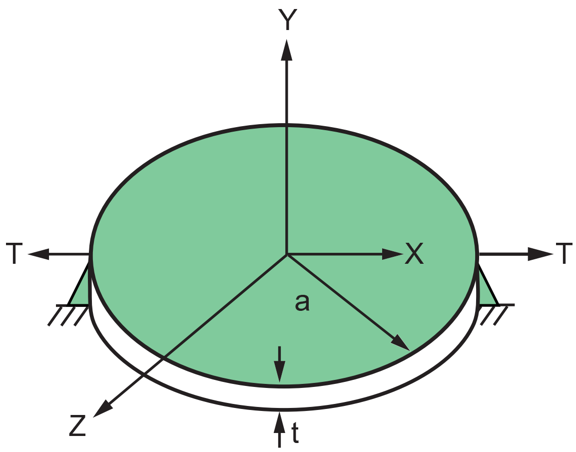
VM55: Vibration of a Stretched Circular Membrane

Overview

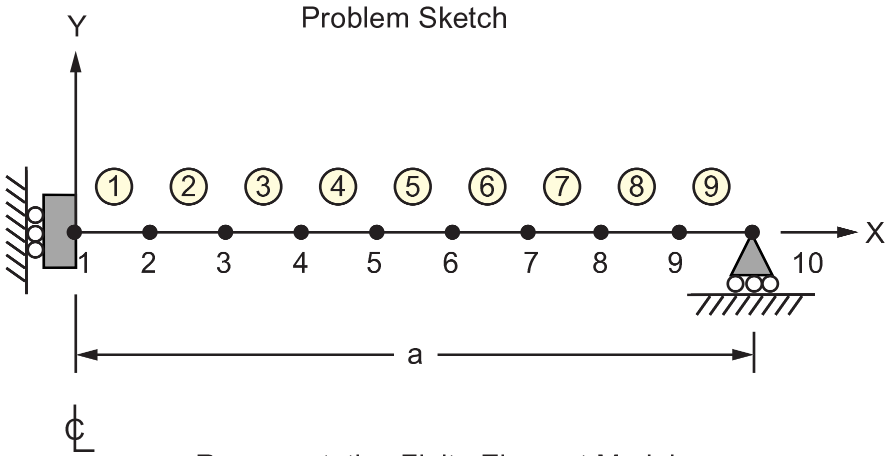
Reference:	S. Timoshenko, D. H. Young, *Vibration Problems in Engineering*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 439, eq. 182.
Analysis Type(s):	Linear Perturbed Modal Analysis (**ANTYPE** = 2)
Element Type(s):	2-Node Finite Strain Axisymmetric Shell (SHELL208)
Input Listing:	vm55.dat

Test Case

A circular membrane of radius a, thickness t, and weight per unit area w is simply supported along its edge and subjected to an in-plane radial load of T lb/unit length of circumference. Determine the radial stress σ_r in the membrane and the first three natural frequencies f_i of lateral vibration of the membrane.



Problem Sketch



Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $w = 0.0028178$ lb/in^2	a = 15 in t = 0.01 in	T = 100 lb/in

Analysis Assumptions and Modeling Notes

The in-plane radial load F is calculated as: F = 2 πa T = 9424.778 lb. The mass density ρ is calculated as w/gt = 0.00073 lb-sec^2/in^4, where g = 386 in/sec^2. Enough elements are defined to adequately characterize the dynamic analysis. Linear perturbed modal analysis is performed on the prestressed structure using Block Lanczos eigensolver to determine the first three natural frequencies.

Results Comparison

		Target	Mechanical APDL	Ratio
Static	$Stress_r$, psi	10,000.	10,000.	1.000
Modal	f_1 , Hz	94.406	94.464	1.001
	f_2 , Hz	216.77	217.175	1.002
	f_3 , Hz	339.85	341.510	1.005

VM56: Hyperelastic Thick Cylinder Under Internal Pressure

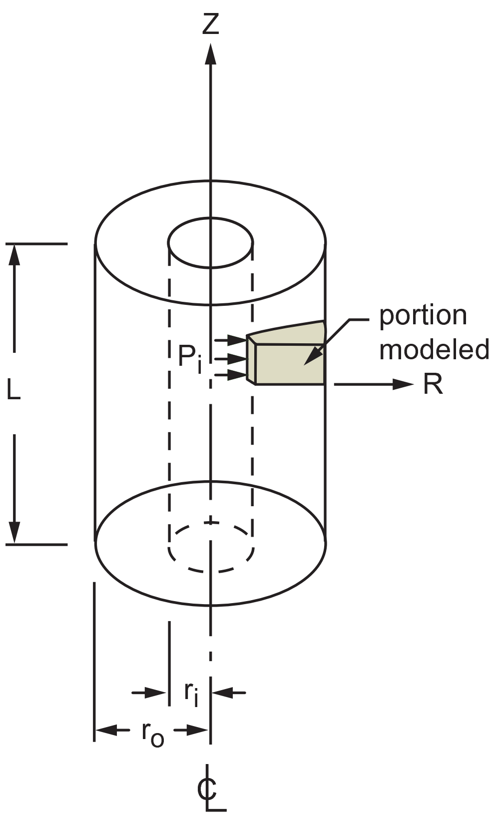
Overview

Reference:	J. T. Oden, *Finite Elements of Nonlinear Continua*, McGraw-Hill Book Co., Inc., New York, NY, 1972, pp. 325-331.
Analysis Type(s):	Static, Large Deflection Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 8-Node Stuctural Solid Elements (PLANE183) 3-D 8-Node Structural Solid Elements (SOLID185) 3-D 10-Node Tetrahedral Structural Solid Elements (SOLID186)
Input Listing:	vm56.dat

Test Case

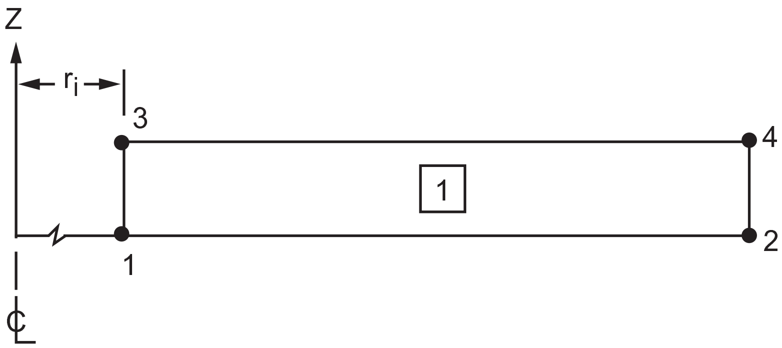
An infinitely long cylinder is made of Mooney-Rivlin type material. An internal pressure of P_i is applied. Find the radial displacement at the inner radius and the radial stress at radius R = 8.16 in (center of 1st element).

Figure 56.1: Hyperelastic Thick Cylinder Problem Sketch

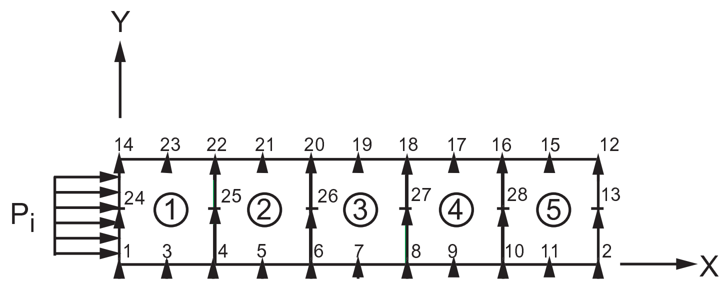


Problem Sketch

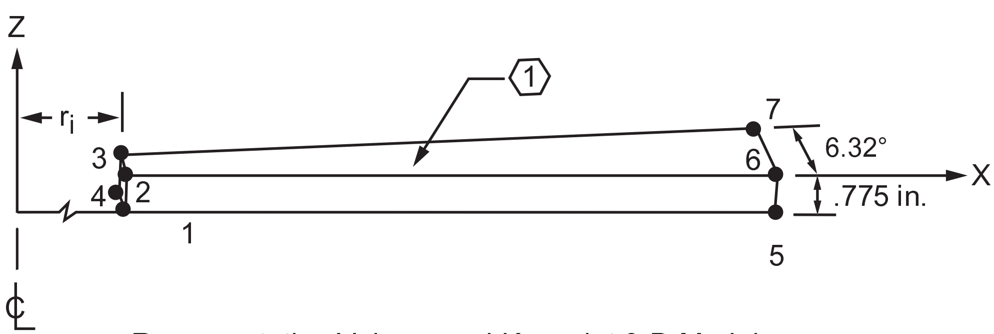
Figure 56.2: Hyperelastic Thick Cylinder Models



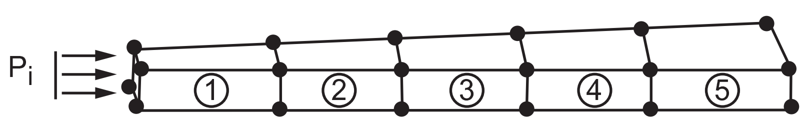
Representative Area and Keypoint 2-D Model



Representative Area and 2-D Finite Element Model



Representative Volume and Keypoint 3-D Model



Representative Volume 3-D Finite Element Model

Material Properties	Geometric Properties	Loading
Mooney-Rivlin material coefficients A = 80 psi B = 20 psi	r_i = 7.0 in r_o = 18.625 in	P_i = 150 psi

Analysis Assumptions and Modeling Notes

The problem is solved first using PLANE183 and then using SOLID185 / SOLID186. Due to circumferential symmetry, only a small sector need be modeled. The height (and width for SOLID185) of the elements in the finite element model is chosen such that the elements have a reasonable aspect ratio. Only radial degrees of freedom are active. The total pressure is applied in two load increments. To approximate incompressible behavior, Poisson's ratio is set close to 1/2 (0.49) and reduced integration is requested. Temperature-dependent properties are used in the PLANE183 portion solely for verification purposes.

Results Comparison

		Target[1]	Mechanical APDL	Ratio
PLANE183	u_r (inner radius), in	7.180	7.491	1.043
	$Stress_r$ (element 1), psi	-122.0	-122.772	1.006
SOLID185	u_r (inner radius), in	7.180	7.450	1.038
	$Stress_r$ (element 1), psi	-122.0	-123.273	1.010
SOLID186	u_r (inner radius), in	7.180	7.401	1.031

1. Based on fully incompressible assumption, ν = 1/2

VM57: Torsional Frequencies of a Drill Pipe

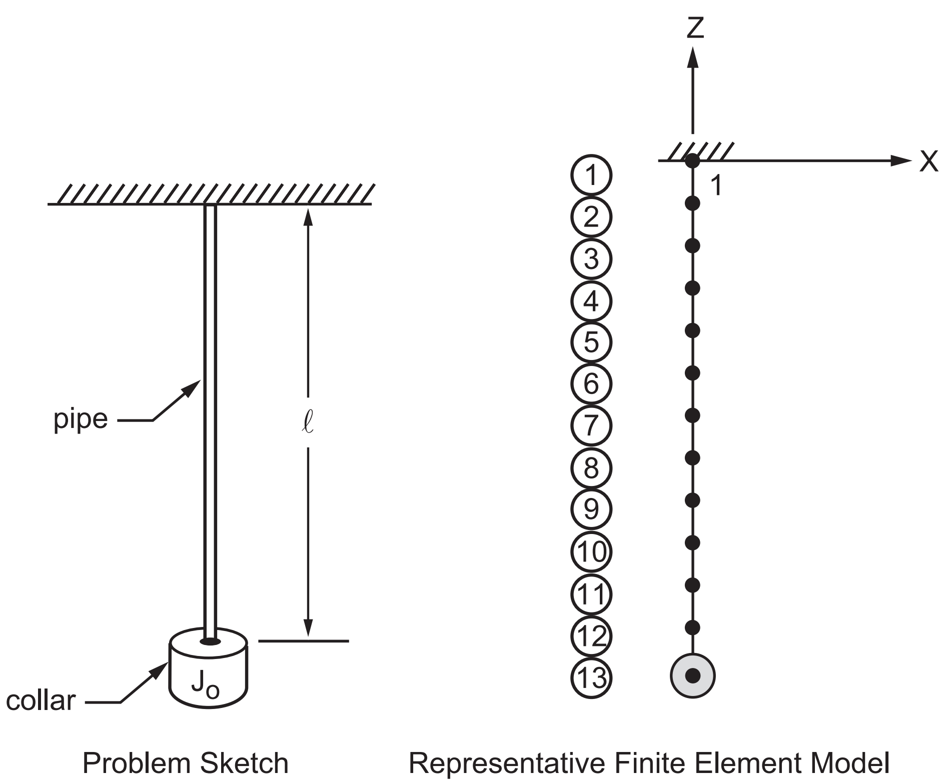
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 272, ex. 8.4-5.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	Elastic Straight Pipe Elements (PIPE16) Structural Mass Element (MASS21) 3-D 2 node pipe (PIPE288) 3-D 3 node pipe (PIPE289) 3-D 2 node beam(BEAM188) 3-D 3 node beam(BEAM189)
Input Listing:	vm57.dat

Test Case

Determine the first two natural frequencies f_1 and f_2 of an oil-well drill pipe of length ℓ and polar moment at inertia I_p fixed at the upper end and terminating at the lower end to a drill collar with torsional mass inertia J_o. The drill collar length is small compared to the pipe length.

Figure 57.1: Drill Pipe Problem Sketch



Material Properties	Geometric Properties
$G = 12 \times 10^6$ psi	ℓ = 5000 ft

Material Properties	Geometric Properties
$\upsilon = 0.3$ $\gamma = 490$ lb/ft^3 $\rho = \gamma / g = 15.2174$ lb-sec^2/ft^4	OD = 4.5 in = (4.5/12) ft ID = 3.83 in = (3.83/12) ft $J_o = 29.3$ lb-ft-sec^2 $I_p = 0.0009226$ ft^4

Analysis Assumptions and Modeling Notes

The drill pipe is modeled using pipe and beam elements. Modal analysis is performed with Block Lanczos solver for (PIPE16), (PIPE288), (PIPE289), (BEAM188), and (BEAM189) elements. Young's modulus (E) is calculated as E = 2G (1 + υ)*144 = 4.4928 x 109lb/ft^2 and pipe thickness is calculated as (OD - ID)/2.

Results Comparison

		Target[1]	Mechanical APDL	Ratio
PIPE16 Elements	f_1, Hz	0.3833	0.3834	1.000
	f_2, Hz	1.2600	1.2639	1.003
PIPE288 Elements	f_1, Hz	0.3833	0.3834	1.000
	f_2, Hz	1.2600	1.2606	1.000
PIPE289 Elements	f_1, Hz	0.3833	0.3834	1.000
	f_2, Hz	1.2600	1.2606	1.000
BEAM188 Elements	f_1, Hz	0.3833	0.3831	1.000
	f_2, Hz	1.2600	1.2597	1.000
BEAM189 Elements	f_1, Hz	0.3833	0.3831	1.000
	f_2, Hz	1.2600	1.2597	1.000

1. Solution recalculated

VM58: Centerline Temperature of a Heat Generating Wire

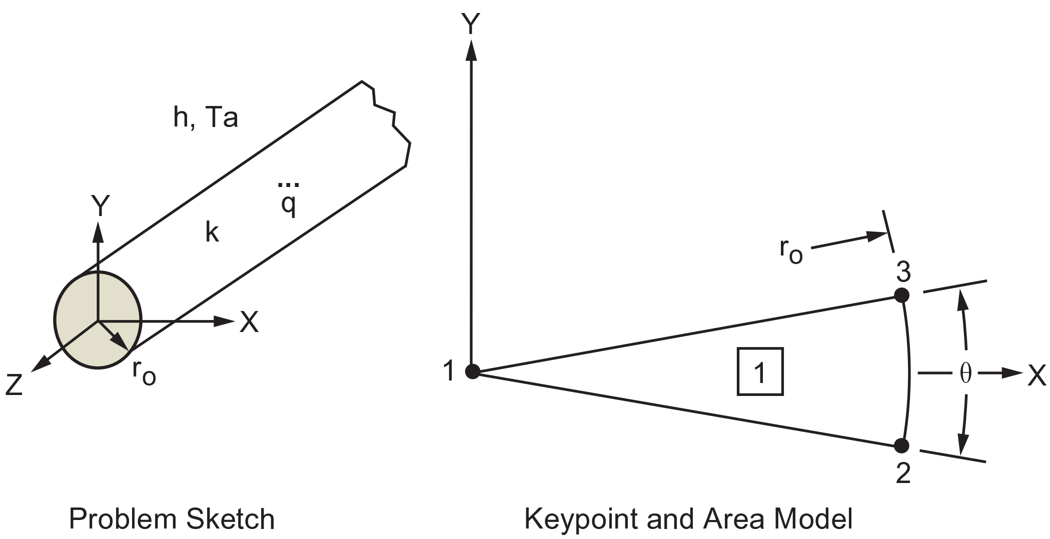
Overview

Reference:	W. M. Rohsenow, H. Y. Choi, *Heat, Mass and Momentum Transfer*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1963, pg. 106, ex. 6.5.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 6-Node Triangular Thermal Solid Element (PLANE35) 2-D Thermal Surface Effect Element (SURF151)
Input Listing:	vm58.dat

Test Case

Determine the centerline temperature $T_{℄}$ and the surface temperature T_s of a bare steel wire generating heat at the rate $\dddot{q}$. The surface convection coefficient between the wire and the air (at temperature T_a) is h. Also, determine the heat dissipation rate q.

Figure 58.1: Heat Generating Wire Problem Sketch



Material Properties	Geometric Properties	Loading
k = 13 Btu/hr-ft-°F h = 5 Btu/hr-ft^2-°F	r_o = 0.375 in = 0.03125 ft	T_a = 70°F $\dddot{q}$ = 111311.7 Btu/hr-ft^3

Analysis Assumptions and Modeling Notes

Since the problem is axisymmetric, only a small sector is needed. An angle Θ= 30° is used for modeling the circular sector. Four mesh divisions are chosen radially for accuracy considerations. Temperatures of the outer nodes are coupled to ensure symmetry. The solution is based on a wire 1 foot long (Z direction). Postprocessing is used to determine $T_{℄}$, T_s, and q.

Results Comparison

	Target	Mechanical APDL	Ratio
Centerline Temperature, °F	419.9	419.9	1.000
Surface Temperature, °F	417.9	417.8	1.000
q, BTU/hr	341.5	341.5[1]	1.000

1. Calculated from heat flow rate per 30° sector x 12 sectors

VM59: Lateral Vibration of an Axially-loaded Bar

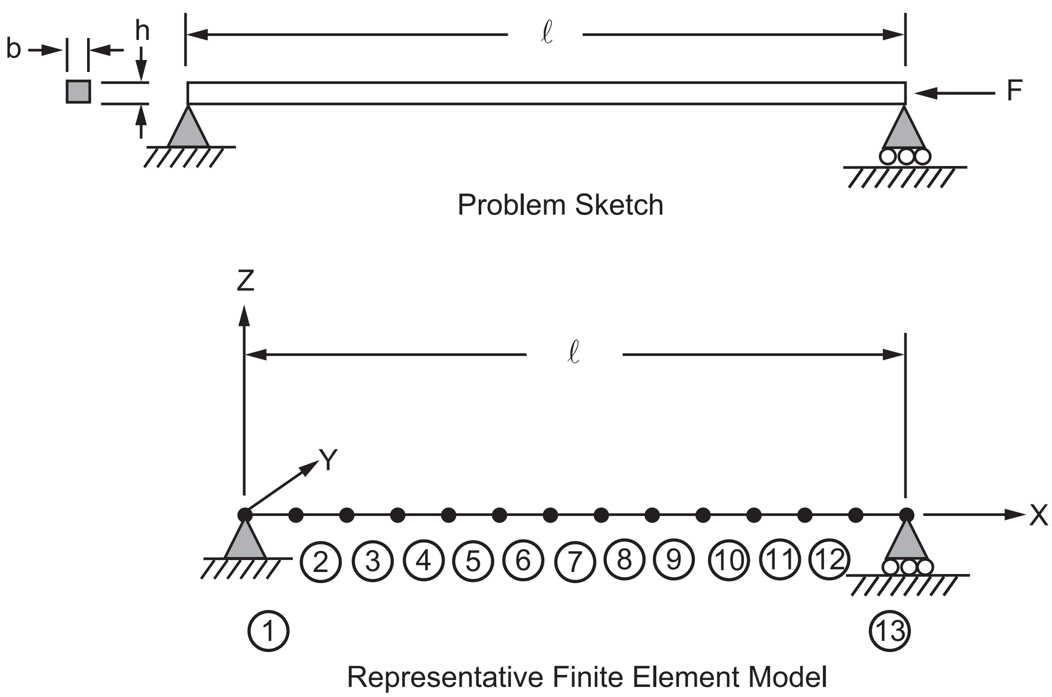
Overview

Reference:	S. Timoshenko, D. H. Young, *Vibration Problems in Engineering*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 374, article 59.
Analysis Type(s):	Linear Perturbed Modal Analysis (**ANTYPE** = 2)
Element Type(s):	3-D 2 node beam (BEAM188)
Input Listing:	vm59.dat

Test Case

A square cross-sectioned bar of length ℓ and weight per unit length γA is pinned at its ends and subjected to an axial compressive force F. Determine the stress σ and the axial displacement δ of the bar under these conditions. Determine the first three natural frequencies f_i of lateral vibration of the bar.

Figure 59.1: Axially-Loaded Bar Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\gamma = 0.281$ lb/in^3 $\rho = \gamma / g = 0.000727973$ lb-sec^2/in^4	b = h = 2 in ℓ = 80 in	F = 40,000 lb

Analysis Assumptions and Modeling Notes

Enough elements are selected so that the same model can be used to adequately characterize the dynamic analysis. Linear perturbed modal analysis is performed to include the prestress effects generated in the base static solve..

Results Comparison

		Target	Mechanical APDL	Ratio
Static	Deflection, in	-0.026667	-0.026667	1.000
	Stress , psi	-10,000	-10,000	1.000
Modal	**F = 40,000 lb**			
	f_1 , Hz	17.055	17.013	0.998
	f_2 , Hz	105.32	104.82	0.995
	f_3 , Hz	249.39	246.94	0.990
	F = 0 lb			
	f_1 , Hz [see VM50]	28.766	28.761	1.000

VM60: Natural Frequency of a Cross-ply Laminated Shell

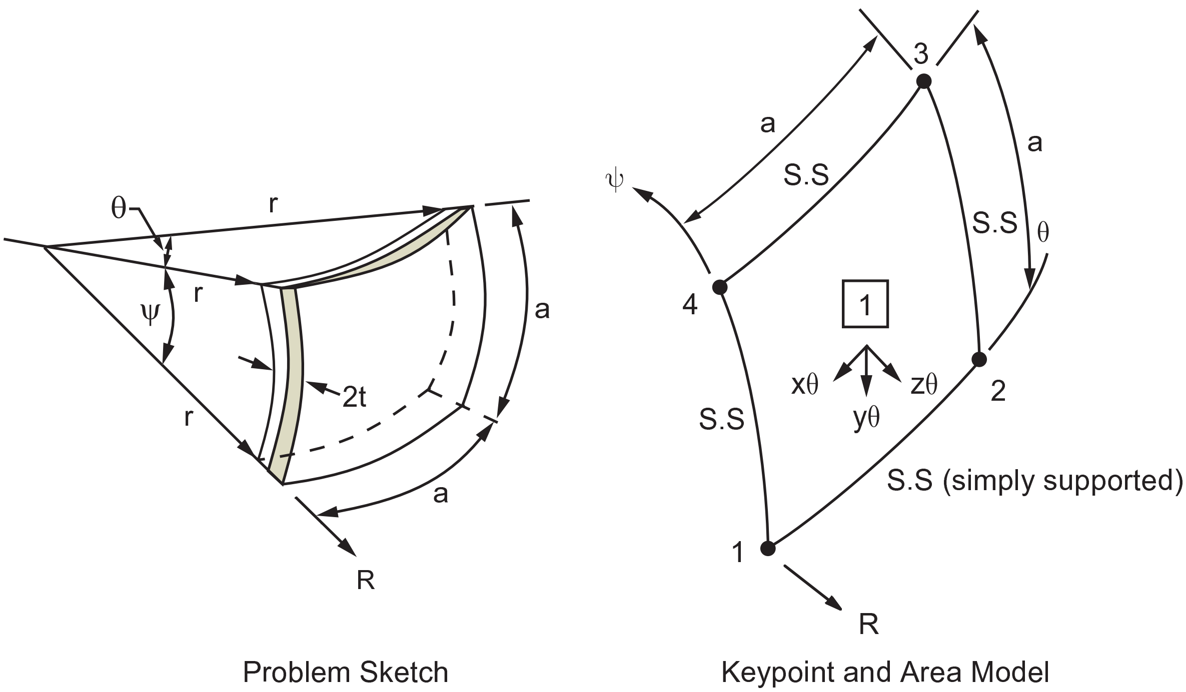
Overview

Reference:	J. N. Reddy, "Exact Solutions of Moderately Thick Laminated Shells", *ASCE Journal Engineering Mechanics*, Vol. 110 No. 5, 1972, pg. 806, tab. 6.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	8-Node Finite Strain Shell Elements (SHELL281)
Input Listing:	vm60.dat

Test Case

Determine the first mode natural frequency f of a simply-supported equal-sided sector of a spherical shell of radius r. The shell sector consists of a 0°/90° cross-ply laminate (2 layers of equal thickness, t).

Figure 60.1: Laminated Spherical Shell Problem Sketch



Material Properties	Geometric Properties
ρ = 1 gm/mm^3 E_x = 25 x 10^6 Pa E_y = 1 x 10^6 Pa G_{xy} = G_{xz} = 5 x 10^5 Pa G_{yz} = 2 x 10^5 Pa υ_{yx} = .25 (major Poisson's ratio)	r = 300 mm a = 100 mm t = 0.5 mm

Analysis Assumptions and Modeling Notes

Four elements are chosen along each edge of area 1. The reduced method of eigenvalue solution is chosen and the first five modes are extracted. Note that the input value for υ_{xy} is calculated from:

$$v_{xy} = v_{yx} \frac{E_y}{E_x} = .25 \frac{1x10^6}{25x10^6} = .01 \quad \text{(minor Poisson's ratio)}$$

The geometric input in spherical coordinates is calculated as:

$$\theta = \psi = \frac{180}{\pi} \frac{100}{300} = 19.0986^\circ$$

The alternate method of Poisson's ratio input (PRXY) could also have been used.

The model is solved using layered finite strain shell elements (SHELL281).

Results Comparison

	Target	Mechanical APDL	Ratio
SHELL281			
f, Hz	0.73215	0.73528	1.004

VM61: Longitudinal Vibration of a Free-free Rod

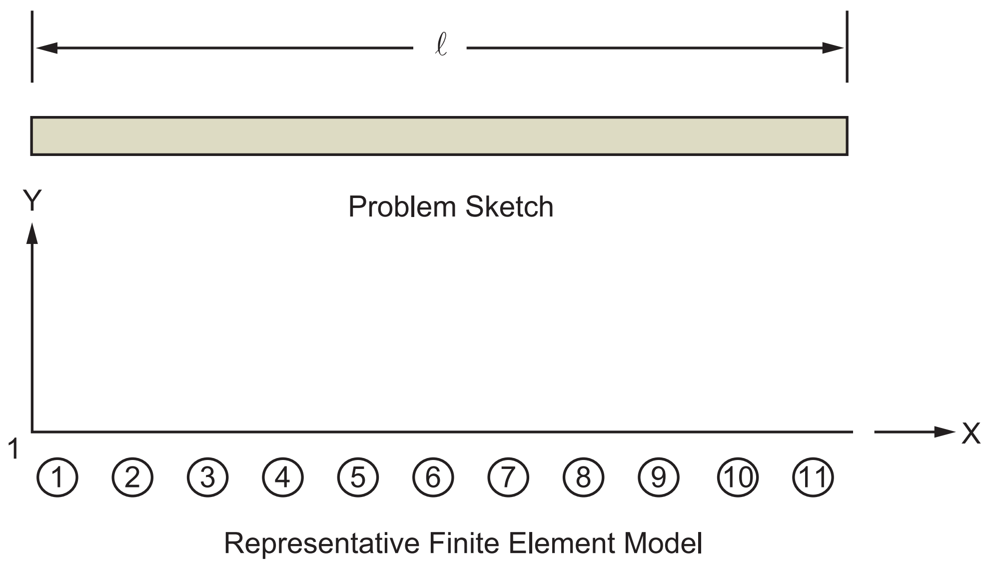
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 269, ex. 8.3-1.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	3-D 2 Node Beam (BEAM188)
Input Listing:	vm61.dat

Test Case

Determine the first three natural frequencies f_i of a free-free rod (a rod with both ends free) having a length ℓ.

Figure 61.1: Rod Problem Sketch



Material Properties	Geometric Properties
$E = 30 \times 10^6$ psi $\rho = 0.00073$ lb-sec^2/in^4	ℓ = 800 in

Analysis Assumptions and Modeling Notes

An arbitrary value of 1 is assigned to beam moment of inertia, area, and thickness. Modal analysis is performed using Block-Lanczos eigensolver.

Results Comparison

	Target	Mechanical APDL	Ratio
f_1, Hz[1]	0.	0.	-

	Target	Mechanical APDL	Ratio
f_2, Hz	126.70	127.13	1.003
f_3, Hz	253.40	256.86	1.014

1. Rigid body mode

VM62: Vibration of a Wedge

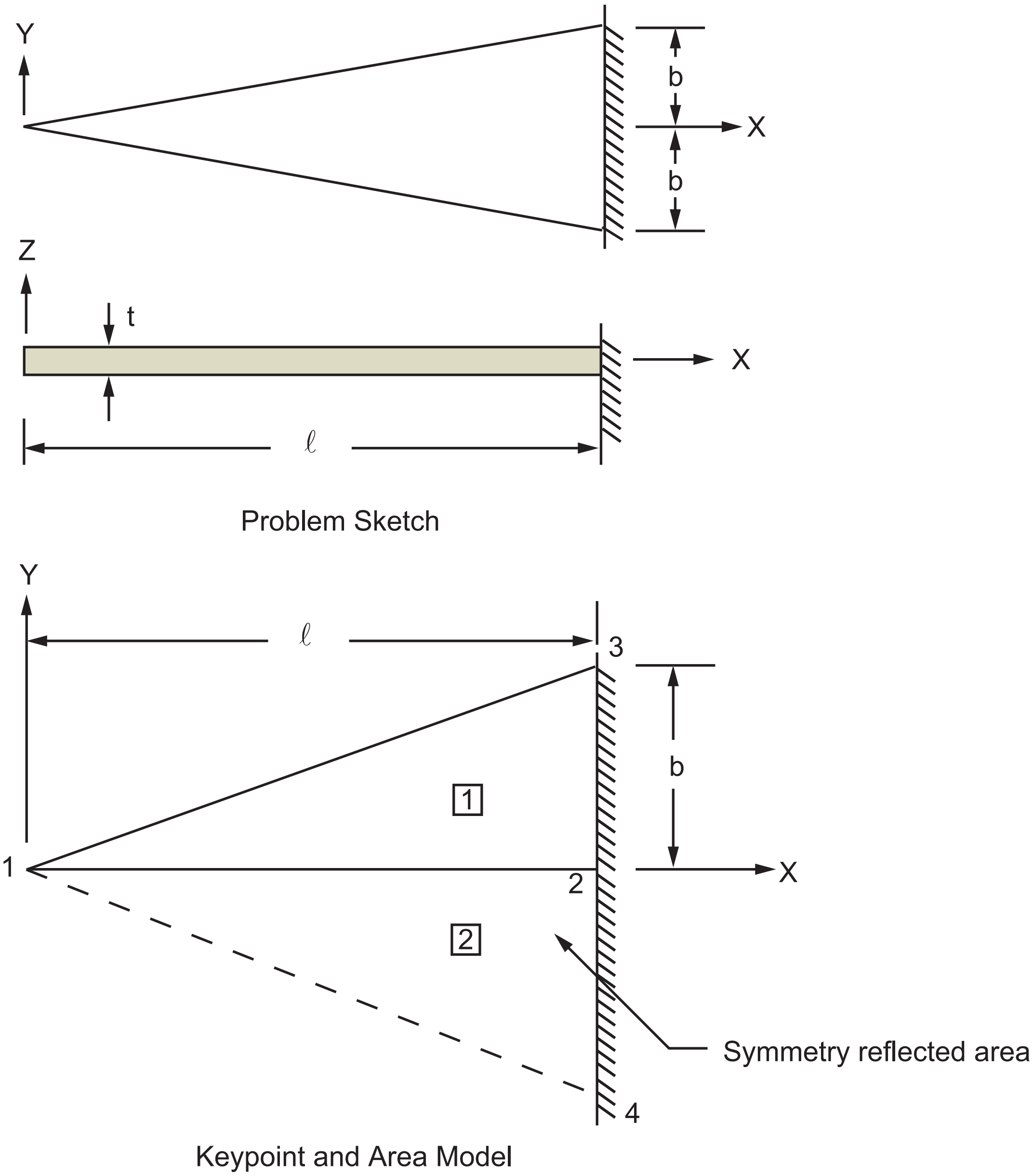
Overview

Reference:	S. Timoshenko, D. H. Young, *Vibration Problems in Engineering*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 392, article 62.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	Elastic Shell Elements (SHELL63) 4-Node Finite Strain Shell Elements (SHELL181) 8-Node Finite Strain Shell Elements (SHELL281)
Input Listing:	vm62.dat

Test Case

Determine the fundamental frequency of out-of-plane vibration f of a wedge-shaped plate of uniform thickness t, base 2b, and length ℓ.

Figure 62.1: Wedge Vibration Problem Sketch



Material Properties	Geometric Properties
$E = 30 \times 10^6$ psi ρ = 0.000728 lb-sec^2/in^4 $\upsilon = 0$	t = 1 in b = 2 in ℓ = 16 in

Analysis Assumptions and Modeling Notes

The problem is solved first using "plate" elements (SHELL63 with bending stiffness only) and then using "shell" elements (SHELL63 with bending and membrane stiffness). Two symmetric areas are created to ensure model symmetry about the plate centerline. Each area is meshed with 4 elements along the X axis and 1 element along the Y axis. Poisson's ratio is assumed to be zero.

The model is then solved using SHELL181 and SHELL281 elements using bending and membrane stiffness option.

Results Comparison

		Target	Mechanical APDL	Ratio
Plate Elements SHELL63	f, Hz	259.16	261.08	1.007
Shell Elements SHELL63	f, Hz	259.16	261.08	1.007
Shell Elements SHELL181	f, Hz	259.16	256.99	0.992
Shell Elements SHELL281	f, Hz	259.16	258.97	0.999

VM63: Static Hertz Contact Problem

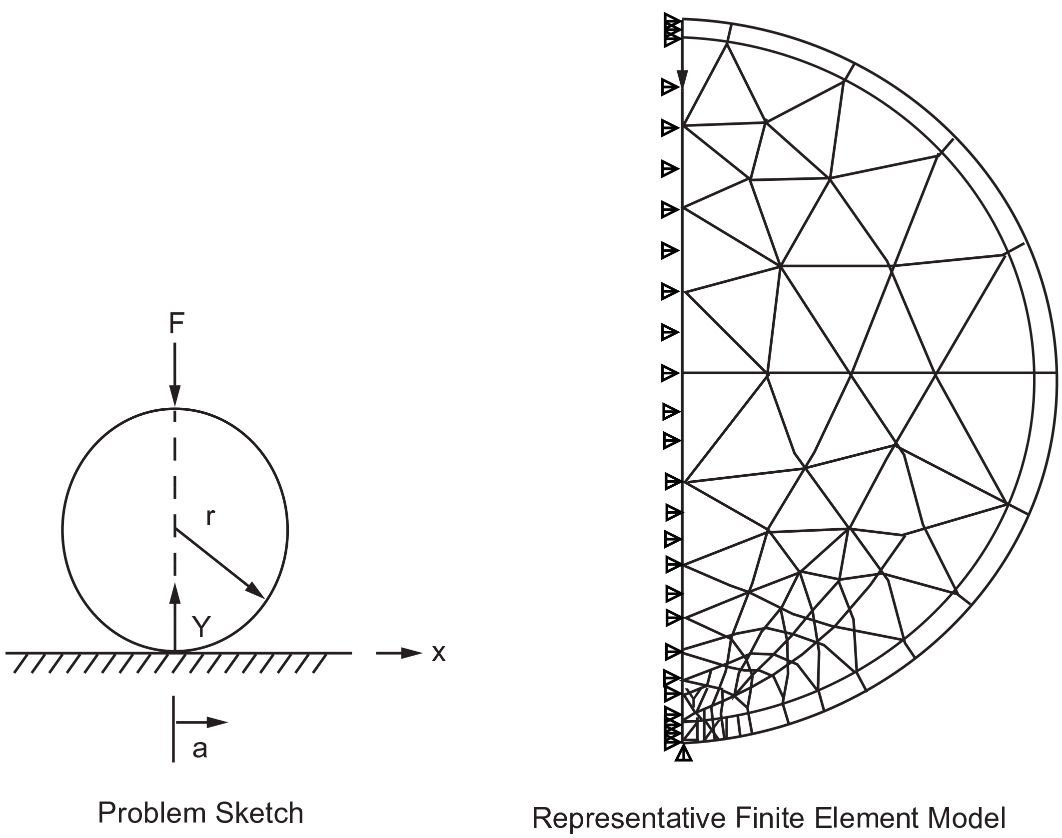
Overview

Reference:	S. Timoshenko, J. N. Goodier, *Theory of Elasticity*, 3rd Edition, McGraw-Hill Book Co., Inc., New York, NY, 1970, pg. 409-413, article 140.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 8-Node Structural Solid Elements (PLANE82) 2-D 8-Node Structural Solid Elements (PLANE183) 3-D Node-to-Node Contact Elements (CONTA178)
Input Listing:	vm63.dat

Test Case

A sphere of radius r is pressed against a rigid flat plane. Determine the contact radius, a, for a given load F.

Figure 63.1: Static Hertz Problem



Material Properties	Geometric Properties	Loading
E = 1000 N/mm^2 υ = 0.3	r = 8 mm	F = (30 x 2 π) N

Analysis Assumptions and Modeling Notes

An axisymmetric model is used. A node is placed near the expected radius of contact. Midside nodes are removed along the surface where contact is likely to occur. The model is comprised of both PLANE82 and PLANE183 for verification purposes, but could be solved using either element type alone. The model is solved using 3-D node-to-node contact elements (CONTA178).

Results

a, mm	Target	Mechanical APDL	Ratio
CONTA178	1.010	1.011	1.001

VM64: Thermal Expansion to Close a Gap at a Rigid Surface

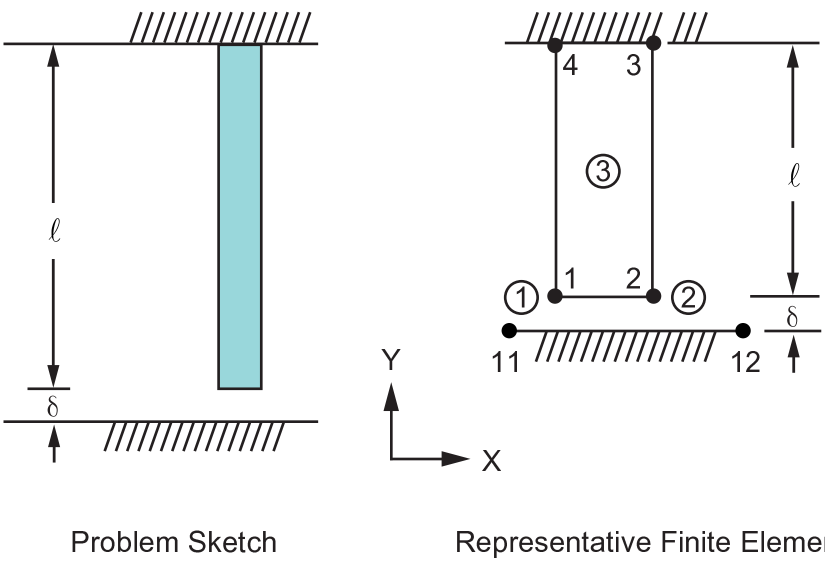
Overview

Reference:	C. O. Harris, *Introduction to Stress Analysis*, The Macmillan Co., New York, NY, 1959, pg. 58, problem 8.
Analysis Type(s):	Static thermal Stress Analysis (**ANTYPE** = 0)
Element Type(s):	2-D/3-D Node-to-Surface Contact Element (CONTA175) 2-D Target Segment Element (TARGE169) 2-D 4-Node Structural Solid Elements (PLANE182)
Input Listing:	vm64.dat

Test Case

An aluminum-alloy bar is initially at a temperature of 70°F. Calculate the stresses in the bar after it has been heated to 170°F. The supports are assumed to be rigid.

Figure 64.1: Rigid Surface



Material Properties	Geometric Properties	Loading
$E = 10.5 \times 10^6$ psi $\alpha = 12.5\ 10^{-6}$ in/in-°F $\upsilon = 0$	$\ell = 3$ in $\delta = 0.002$ in	$\Delta t = 170° - 70°F$

Results Comparison

	Target	Mechanical APDL	Ratio
$Stress_x$, psi	-13125	-13125	1.000
$Stress_y$, lb	-6125	-6122	0.999

VM65: Transient Response of a Ball Impacting a Flexible Surface

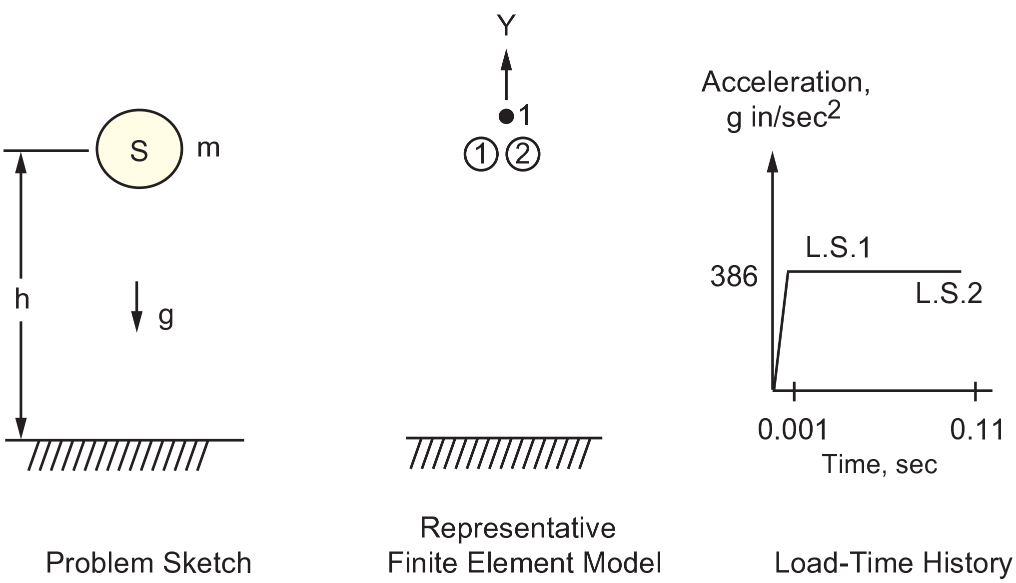
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 110, ex. 4.6-1.
Analysis Type(s):	Nonlinear Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	Structural Mass Elements (MASS21) 2-D/3-D Node-to-Surface Contact Elements (CONTA175)
Input Listing:	vm65.dat

Test Case

A rigid ball of mass m is dropped through a height h onto a flexible surface of stiffness k. Determine the velocity, kinetic energy, and displacement y of the ball at impact and the maximum displacement of the ball.

Figure 65.1: Ball Problem Sketch



Material Properties	Geometric Properties	Loading
m = 0.5 lb-sec^2/in k = 1973.92 lb/in	h = 1 in	g = 386 in/sec^2

Analysis Assumptions and Modeling Notes

The node locations are arbitrarily selected. The final time of 0.11 seconds allows the mass to reach its largest deflection. The integration time step (0.11/110 ≈ 0.001 sec) is based on ≈ 1/100 of the period (during impact), to allow the initial step acceleration change to be followed reasonably well and to produce sufficient printout for the theoretical comparison. At release h, the mass acceleration is 386 in/sec^2. Therefore, a load step with a small time period is used to ramp to the appropriate acceleration while maintaining essentially zero velocity. Displacements and velocities are listed against time in POST26 and stored kinetic energy is obtained in POST1.

The model is solved using the node-to-surface CONTA175 element.

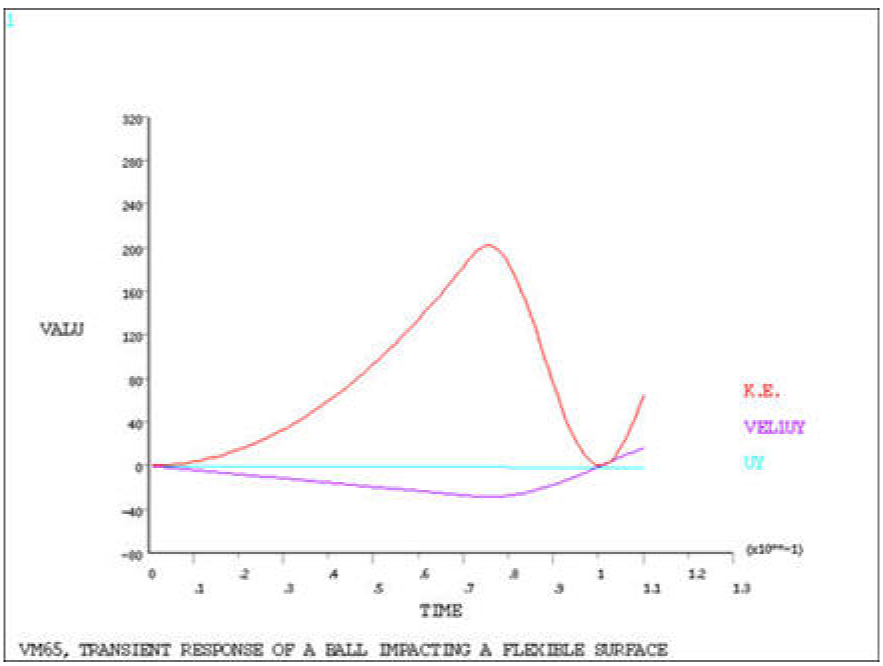
Results

		Target	Mechanical APDL	Ratio
CONTA175 At Impact[1]	time,sec	0.07198	0.072	1.000
	y displacement, in	-1.0000	-0.9991	0.999
	y velocity, in/sec	-27.79	-27.76	0.999
	K enrg, lb-in	193.00000	192.64604	0.998
At "Zero" Velocity[2]	time,sec	0.10037	0.10100	1.006
	max. y displacement, in	-1.5506	-1.5503	1.000

1. Target results are for t = 0.07198 sec. Mechanical APDL results are reported for closest time point, t = 0.072 sec.

2. ANSYS results are from the time point closest (reported in POST26) to the change in velocity from negative to positive.

Figure 65.2: Kinetic Energy, Velocity and Displacement vs. Time Display



VM66: Vibration of a Flat Plate

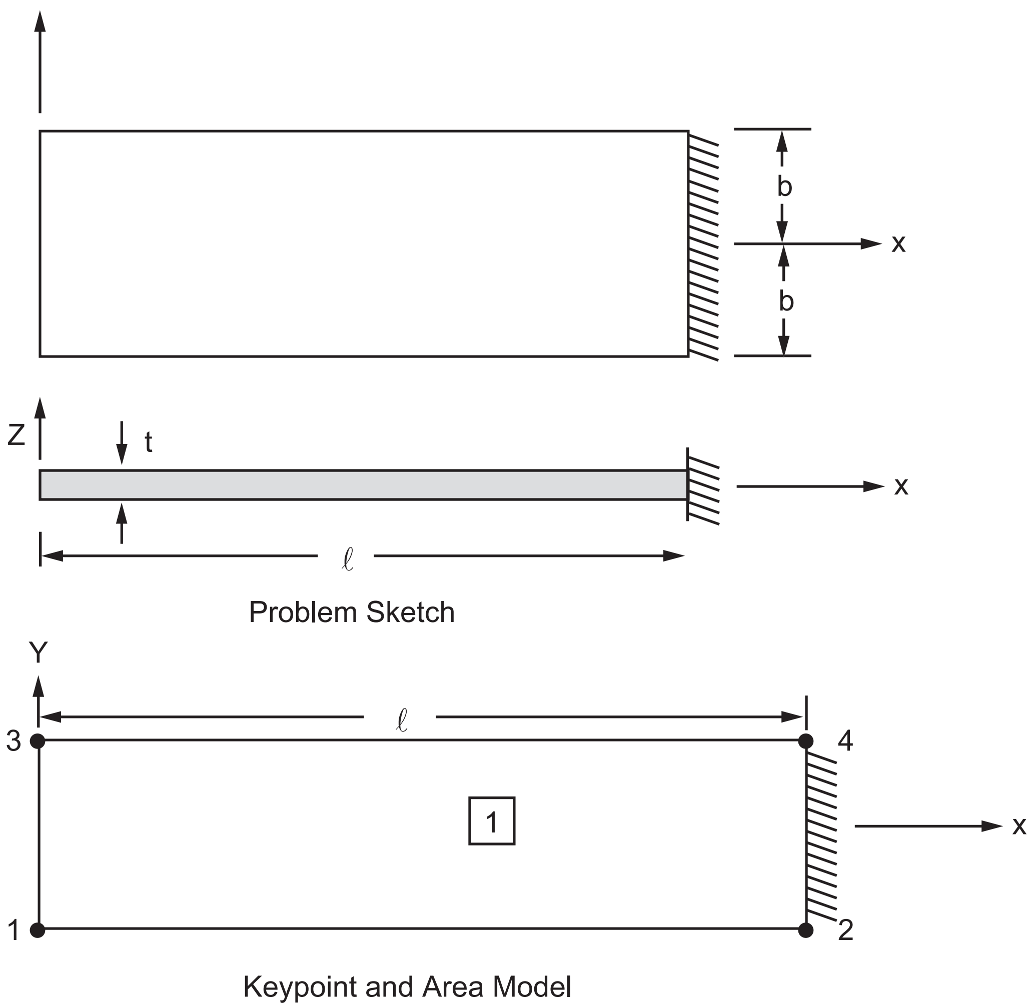
Overview

Reference:	S. Timoshenko, D. H. Young, *Vibration Problems in Engineering*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 338, article 53.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	Elastic Shell Elements (SHELL63) 3-D Structural Solid Shell Elements (SOLSH190) 4-Node Finite Strain Shell Elements (SHELL181) 8-Node Finite Strain Shell Elements (SHELL281)
Input Listing:	vm66.dat

Test Case

Determine the fundamental natural frequency of lateral vibration f of a flat rectangular plate. The plate is of uniform thickness t, width 2b, and length ℓ.

Figure 66.1: Flat Plate Problem Sketch



Material Properties	Geometric Properties
$E = 30 \times 10^6$ psi $\rho = 0.000728$ lb-sec^2/in^4 $\upsilon = 0$	t = 1 in b = 2 in ℓ = 16 in

Analysis Assumptions and Modeling Notes

The problem is solved in four different ways:

- Using Elastic Shell Elements (SHELL63)
- Using 3-D Solid Shell Elements (SOLSH190)
- Using 4-Node Finite Strain Shell Elements (SHELL181)
- Using 8-Node Finite Strain Shell Elements (SHELL281)

The area is meshed with 4 elements along the X axis and 2 elements along the Y axis. Poisson's ratio is assumed to be zero.

Results Comparison

	Target	Mechanical APDL	Ratio
SHELL63			
f, Hz	128.09	128.41	1.002
SOLSH190			
f, Hz	128.09	128.71	1.005
SHELL181			
f, Hz	128.09	128.67	1.005
SHELL281			
f, Hz	128.09	127.78	0.998

VM67: Radial Vibrations of a Circular Ring

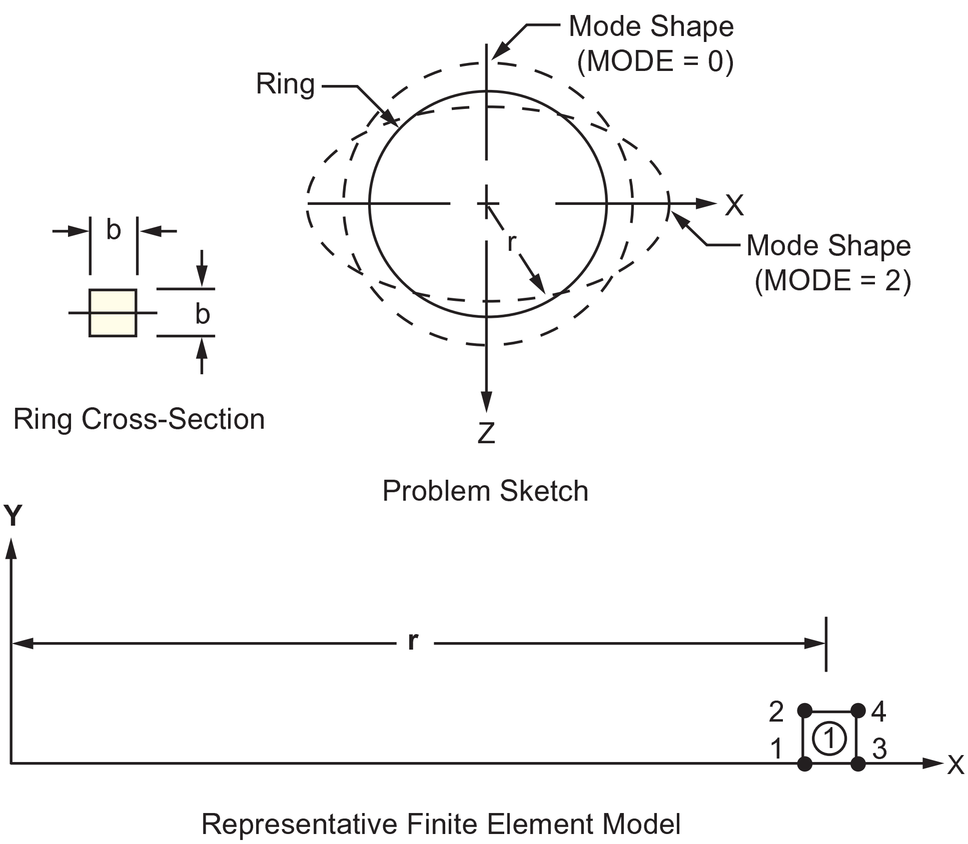
Overview

Reference:	S. Timoshenko, D. H. Young, *Vibration Problems in Engineering*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 425, article 68.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	Axisymmetric-Harmonic 4-Node Structural Solid Elements (PLANE25)
Input Listing:	vm67.dat

Test Case

Determine the fundamental frequency f_o of axisymmetric in-plane radial vibration and the second (extensional) harmonic frequency f_2 of in-plane radial vibration of a circular ring. The cross-section of the ring is square with side length b, at a radius r to the centerline.

Figure 67.1: Ring Axisymmetric Problem Sketch



Material Properties	Geometric Properties
$E = 30 \times 10^6$ psi $\rho = 0.00073$ lb-sec^2/in^4 $\upsilon = 0.0$	r = 10 in b = 0.05 in

Analysis Assumptions and Modeling Notes

MODE = 0 for the axisymmetric mode of vibration and MODE = 2 for the second harmonic frequency of vibration. Coupling is used to ensure mode symmetry. A local coordinate system is defined at (x, y) = (9.975,0) for convenience.

Results Comparison

	Target	Mechanical APDL	Ratio
f_o, Hz	3226.4	3226.398	1.000
f_2, Hz	12.496	12.496	1.000

VM68: PSD Response of a Two DOF Spring-mass System

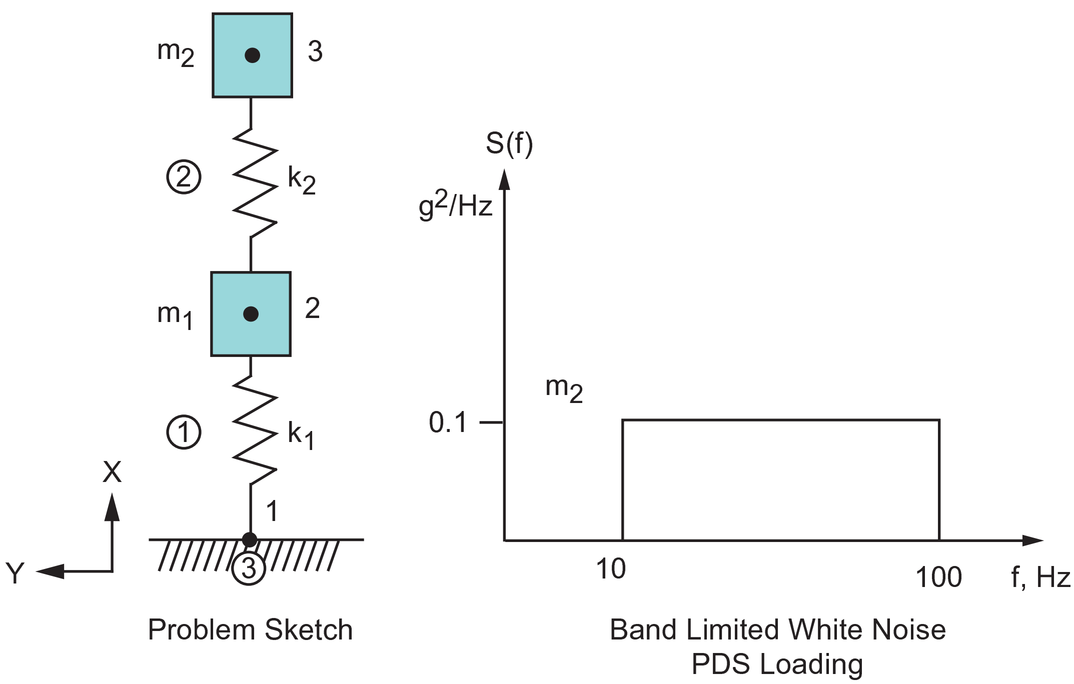
Overview

Reference:	R. K. Vierck, *Vibration Analysis*, 2nd Edition, Harper & Row Publishers, New York, NY, 1979, sec. 7-2, 7-14.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2) Spectrum Analysis (**ANTYPE** = 8)
Element Type(s):	Combination Elements (COMBIN40)
Input Listing:	vm68.dat

Test Case

Determine the first two natural frequencies, f_1 and f_2, and the response of a damped two degree of freedom system subject to a random acceleration with a spectral density function as shown in the figure below.

Figure 68.1: DOF Spring-mass System Problem Sketch



Material Properties
k_1 = 42832 lb/in
k_2 = 32416 lb/in
m_1 = 0.5 lb-sec^2/in
m_2 = 1.0 lb-sec^2/in

Analysis Assumptions and Modeling Notes

The load is applied at node 1 to simulate base excitation. A 2% constant modal damping is assumed. The acceleration results are converted from in/sec^2 to g in POST1.

Results Comparison

	Target	Mechanical APDL	Ratio
f_1 , Hz	20.57	20.572	1.000
f_2 , Hz	64.88	64.885	1.000
Mass 1 - 1 stress Std. dev.	9.059[1]	9.059	1.000
Mass 2 - 1 stress Std. dev.	10.63[1]	10.63	1.000

1. Numerical solution with a uniform frequency spacing equal to 0.001 Hz in the frequency range of 10 to 100 Hz

VM69: Seismic Response

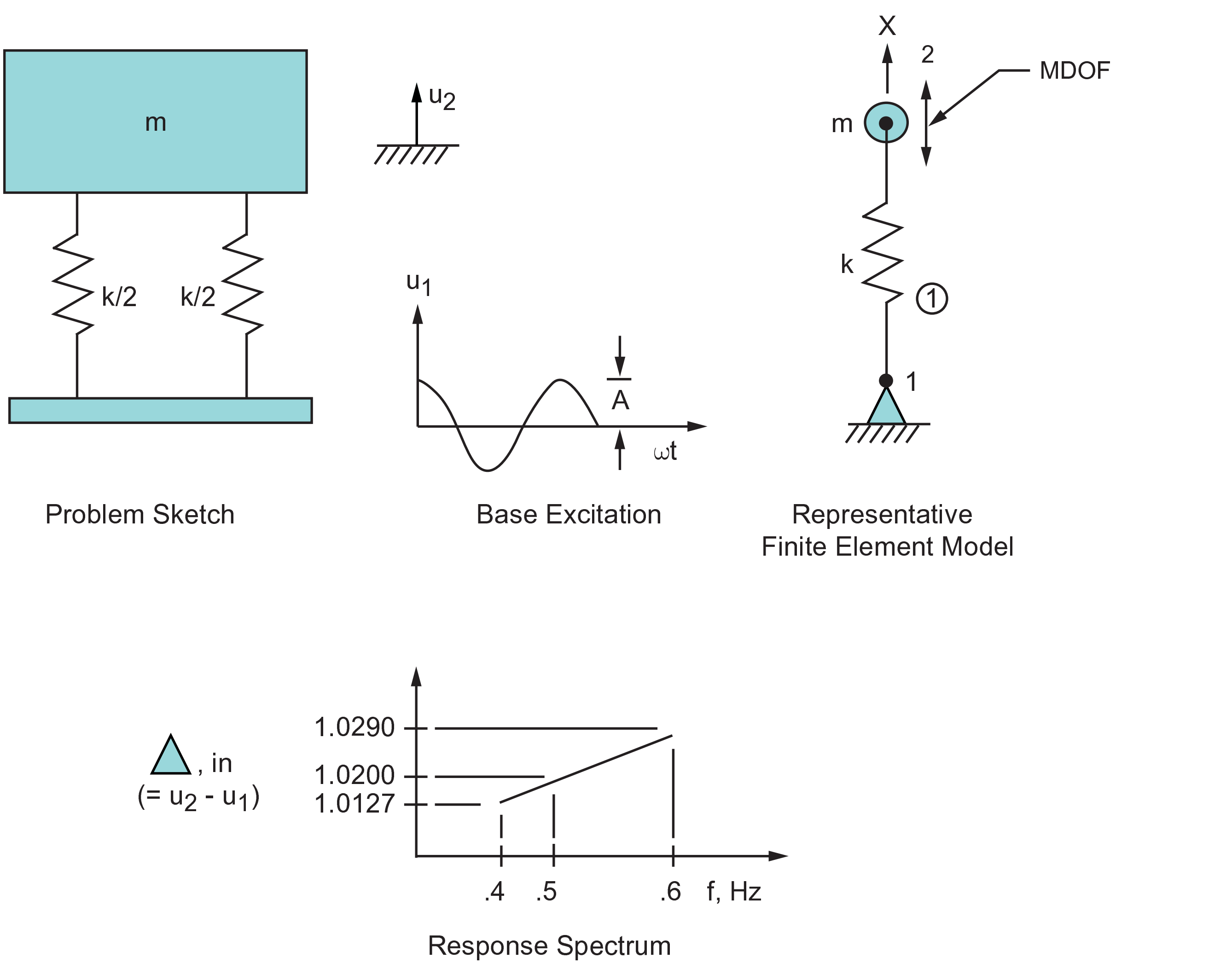
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 78, ex. 3.11-1
Analysis Type(s):	Mode-frequency, Seismic Analysis (**ANTYPE** = 2)
Element Type(s):	Combination Elements (COMBIN40)
Input Listing:	vm69.dat

Test Case

The spring-mass system shown below represents a vibrometer. Determine its natural frequency f. The displacement response spectrum for the vibrometer is shown for 3 points, based on an input of $u_i = A \cos \omega t$, where u_i is the excitation at the support (node 1). Show that the vibrometer response Δ is 2% in error when operated at frequency ω.

Figure 69.1: Seismic Response Problem Sketch



Material Properties	Loading
$m = 1$ lb-sec^2/in $k = 9.8696$ lb/in	$\omega = 22.43537$ rad/sec $A = 1$ in

Analysis Assumptions and Modeling Notes

The node locations are arbitrarily selected. The spring is arbitrarily assumed to vibrate in the X direction.

Results Comparison

	Target	Mechanical APDL	Ratio
f, Hz	0.5000	0.5000	1.000
A_e, in[1]	1.0200	1.0200	1.000

1. A_e = expanded mode shape amplitude. Vibrometer accuracy is equal to 100 x (A_e - A)/A = 2%

VM70: Seismic Response of a Beam Structure

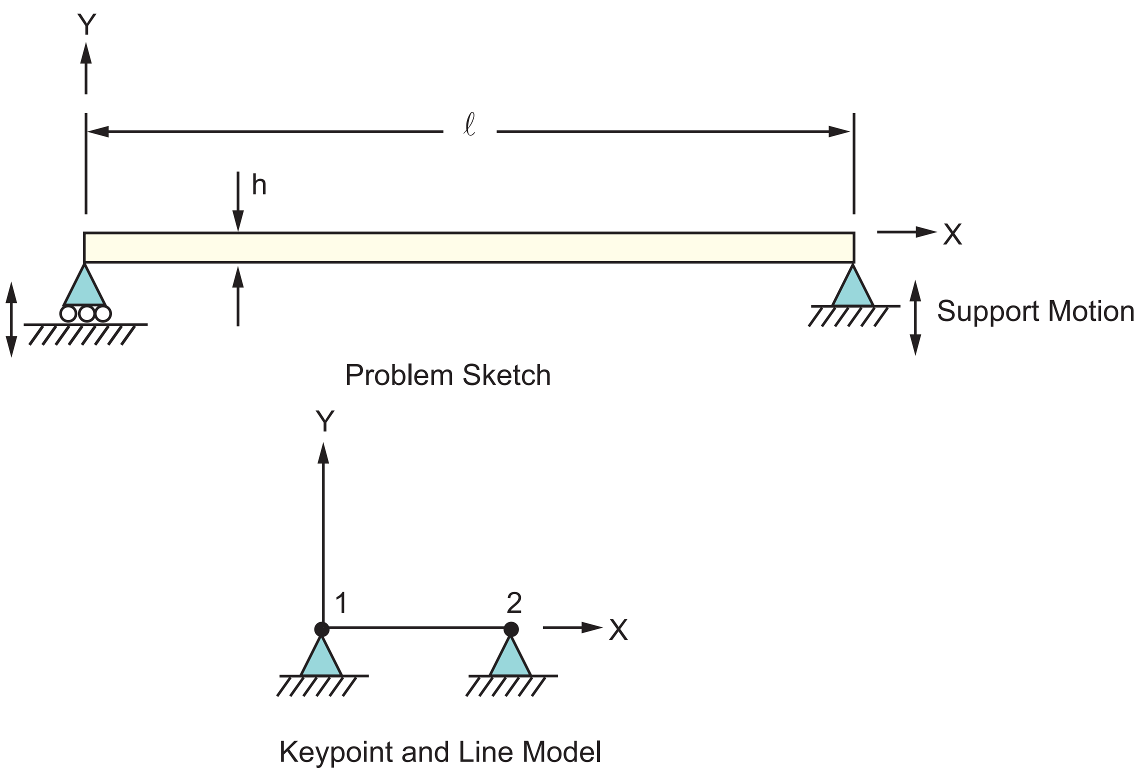
Overview

Reference:	J. M. Biggs, *Introduction to Structural Dynamics*, McGraw-Hill Book Co., Inc., New York, NY, 1964, pg. 262, article 6.4.
Analysis Type(s):	Mode-frequency, Seismic Analysis (**ANTYPE** = 2)
Element Type(s):	3-D 3 Node Beam (BEAM189)
Input Listing:	vm70.dat

Test Case

A simply supported beam of length ℓ, mass per unit length m, and section properties shown below is subjected to a vertical motion of both supports. The motion is defined in terms of a seismic displacement response spectrum. Determine the fundamental displacement δ, and the corresponding maximum bending stress σ_{max}.

Figure 70.1: Beam Structure Problem Sketch



Material Properties	Geometric Properties
$E = 30 \times 10^6$ psi $m = 0.2$ lb-sec^2/in^2 Response Spectrum Frequency, Hz Displacement, in 0.1 0.44 10.0 0.44	$I = (1000/3)$ in^4 $A = 273.9726$ in^2 $\ell = 240$ in $h = 14$ in

Analysis Assumptions and Modeling Notes

The beam geometry data is modeled using ASEC subtype (SECTYPE,1,BEAM,ASEC).

The bending stem is calculated using:

SByB = -Mz * y_{min} / Izz

Where:

Mz is the bending moment.

y_{min} is the height of the beam (minimum y coordinate in the cross section measured from the centroid).

Izz is the moment of inertia.

Results Comparison

	Target	Mechanical APDL	Ratio
f, H_z	6.0979	6.09594	1.000
Deflection, in	0.56000	0.56016	1.000
$Stress_{max}$, psi	20158.	20399.01587	1.012

VM71: Transient Response of a Spring-Mass-Damper System

Overview

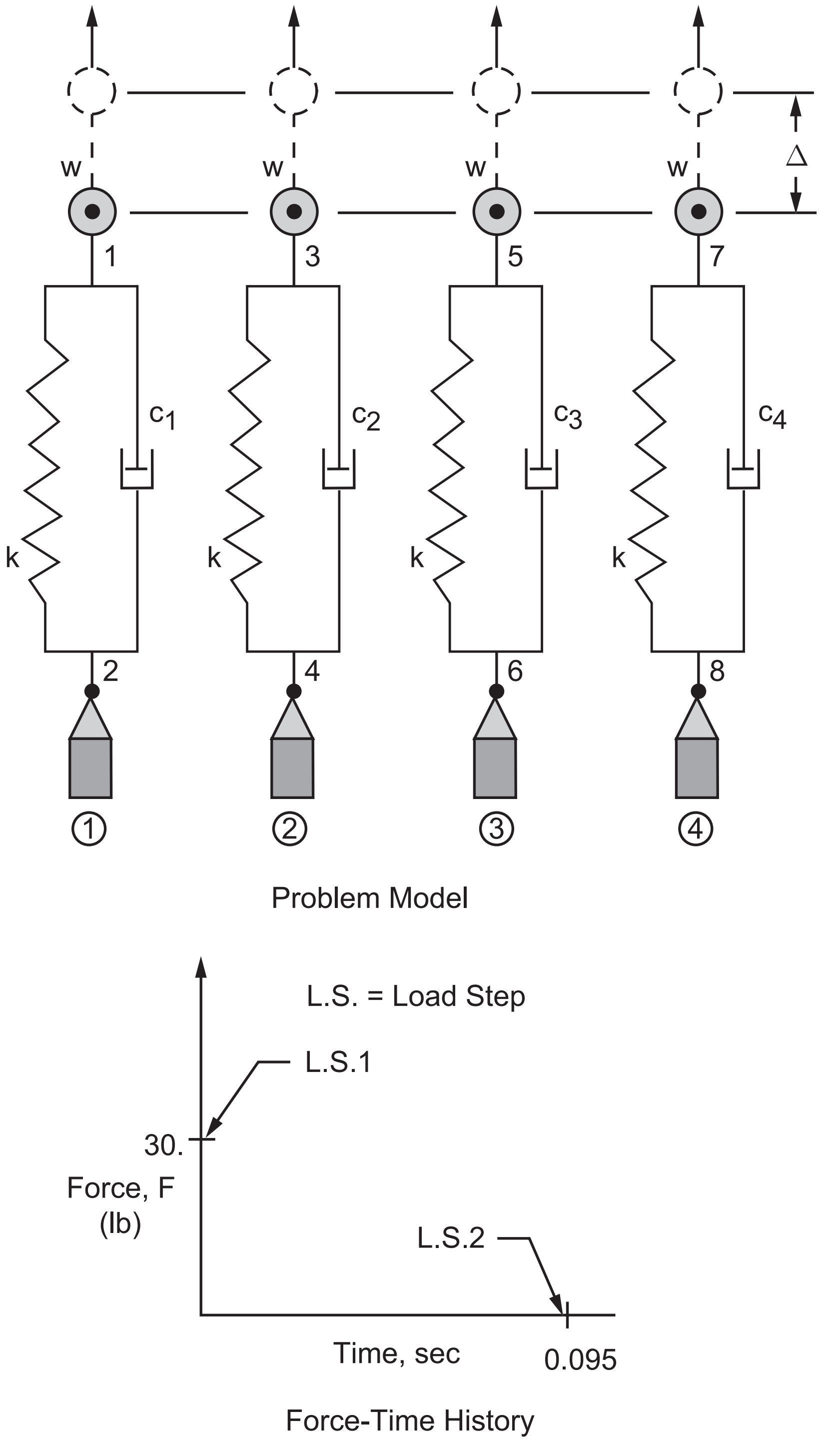
Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 41, ex. 2.2-1.
Analysis Type(s):	Mode-Superposition Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	Combination Elements (COMBIN40)
Input Listing:	vm71.dat

Test Case

A spring-mass system with viscous damping is displaced by a distance Δ and released. Determine the displacement u at time t for four damping ratios:

- ξ = 2.0
- ξ = 1.0 (critical)
- ξ = 0.2
- ξ = 0.0 (undamped)

Figure 71.1: Spring-Mass-Damper System Problem Sketch



Material Properties	Loading
$w = 10$ lb $k = 30$ lb/in $m = w/g = 0.02590673$ lb-sec^2/in	$\Delta = 1$ in $g = 386$ in/sec^2

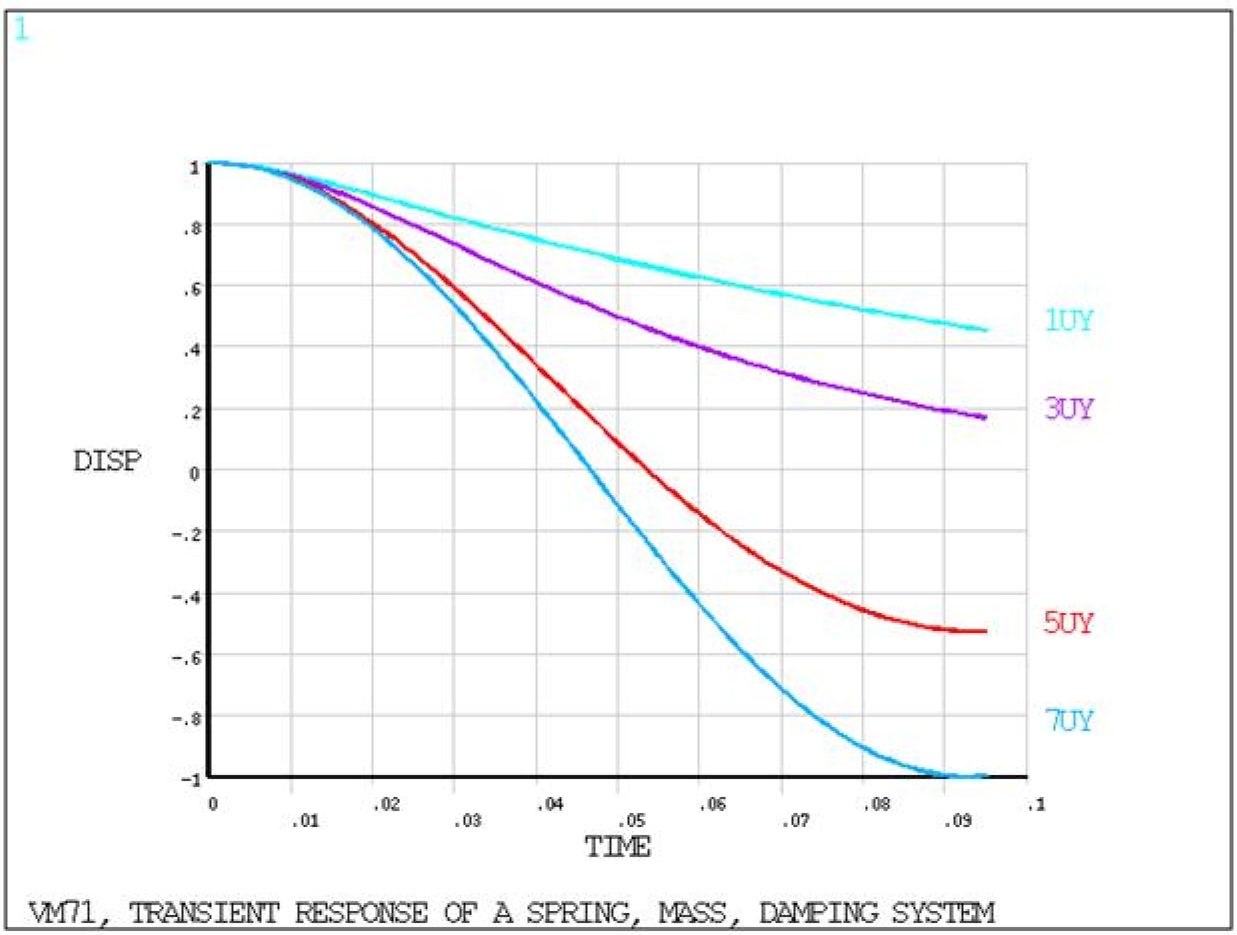
Analysis Assumptions and Modeling Notes

The initial static force is calculated as k∆ = 30 lb and the damping coefficients are calculated as c = 2ξsqrt(km) = 3.52636, 1.76318, 0.352636, and 0.0 lb-sec/in for the four damping ratios (ξ) given in the test case, respectively. The node locations are arbitrarily selected. The integration time step (0.001 sec) is based on ≈ 1/180 of the period to allow the step changes in acceleration to be followed reasonably well and to produce sufficient printout for the theoretical comparison. The maximum time of 0.095 sec covers about 1/2 the period. A static solution is done at the first load step. POST26 is used to extract results from the solution phase.

Results Comparison

t = 0.09 sec	Target	Mechanical APDL	Ratio
u, in (for damping ratio = 2.0)	0.47420	0.47637	1.005
u, in (for damping ratio = 1.0)	0.18998	0.19245	1.013
u, in (for damping ratio = 0.2)	-0.52108	-0.51951	0.997
u, in (for damping ratio = 0.0)	-0.99688	-0.99498	0.998

Figure 71.2: Displacement vs. Time Display



VM72: Logarithmic Decrement

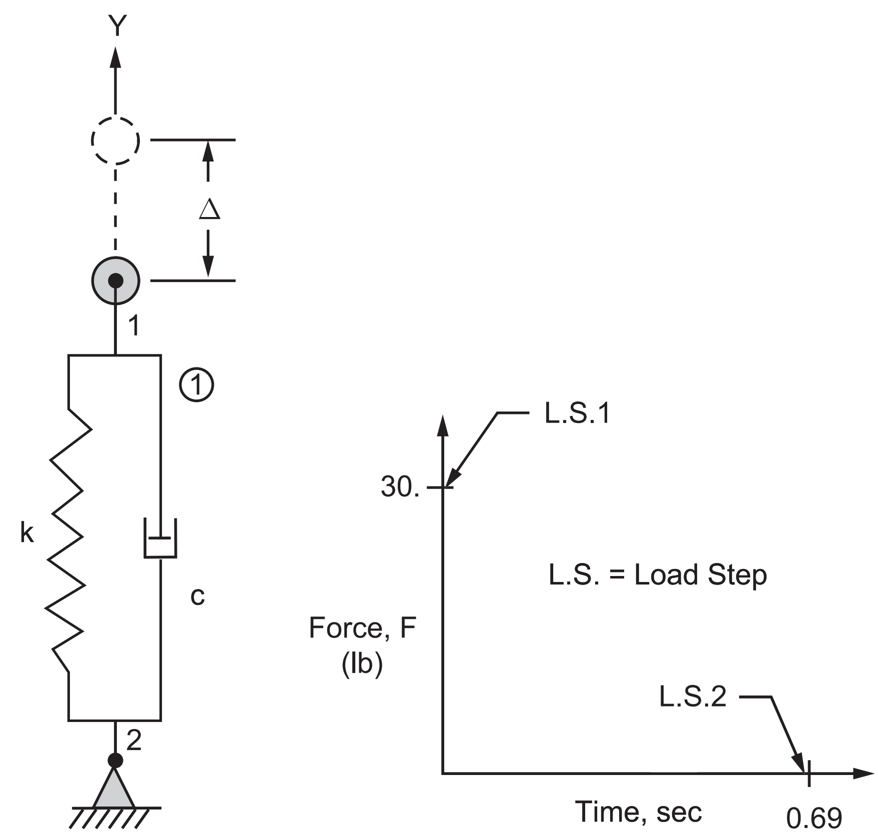
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 45, ex. 2.3-1.
Analysis Type(s):	Mode-Superposition Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	Combination Elements (COMBIN40)
Input Listing:	vm72.dat

Test Case

Determine the damped natural period τ_d and the ratio R between any two successive amplitudes of the freely vibrating spring-mass-viscous damping system. The system is initially held at rest at the stretched position Δ and then released.

Figure 72.1: Logarithmic Decrement Problem Sketch



Representative Finite Element Model Force-Time History

Material Properties	Loading
W = 10 lb k = 30 lb/in c = 0.12 lb-sec/in	Δ = 1 in g = 386 in/sec^2

Analysis Assumptions and Modeling Notes

The node locations are arbitrarily selected. The initial static force is k Δ = 30 lb and the mass is m = W/g = 0.02590673 sec^2/in^2 . The integration time step (0.003 sec) is based on $\approx$ 1/60 of the period to allow the step changes in acceleration to be followed reasonably well and to produce sufficient printout for the theoretical comparison. Almost 4 cycles are included in the 0.0 to 0.69 sec time range. A static solution is done at the first load step. POST26 is used to get a displacement versus time display.

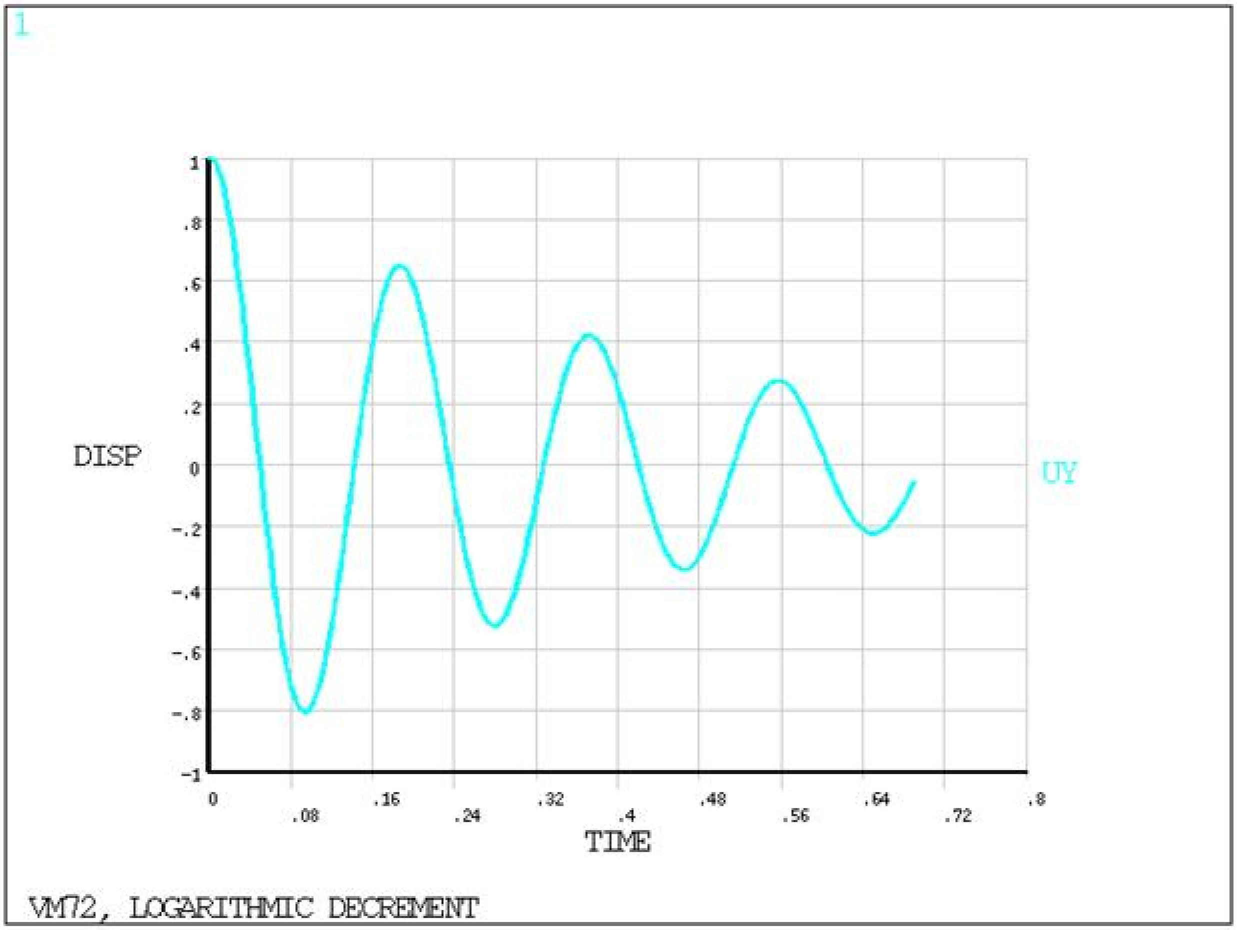
Results Comparison

Peak Number[1]	**1**	**2**	**3**	**4**
Max. Amplitude, in	1.0000	0.64981	0.42306	0.27525
Time, sec	0.0000	0.18600	0.37200	0.55800

1. Sequence number of the positive displacement vibration amplitude peaks

	Target	**Mechanical APDL**	**Ratio**
R_{1-2}	1.5350	1.5389	1.003
R_{2-3}	1.5350	1.5360	1.001
R_{3-4}	1.5350	1.5370	1.001
Damped natural period$_{1-2}$	0.18507	0.18600	1.005
Damped natural period$_{2-3}$	0.18507	0.18600	1.005
Damped natural period$_{3-4}$	0.18507	0.18600	1.005

Figure 72.2: Displacement vs. Time Display



VM73: Free Vibration with Coulomb Damping

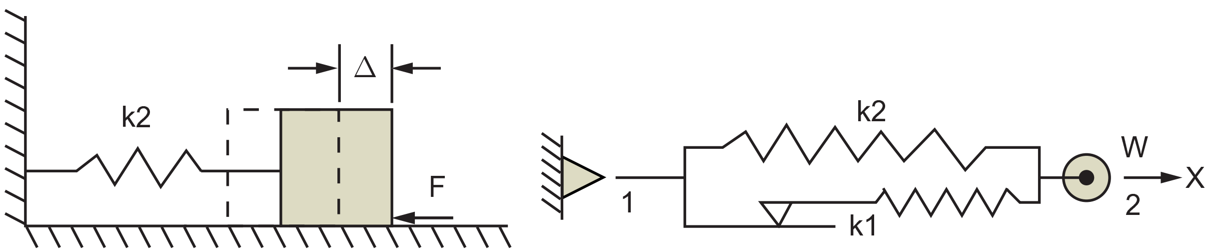
Overview

Reference:	F. S. Tse, I. E. Morse, R. T. Hinkle, *Mechanical Vibrations*, Allyn and Bacon, Inc., Boston, MA, 1963, pg. 175, case 1.
Analysis Type(s):	Full Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	Combination Elements (COMBIN40)
Input Listing:	vm73.dat

Test Case

A spring-mass system with coulomb damping is displaced a distance Δ and released. Dry friction is assumed to act as a limiting sliding force F between the sliding mass and the surface. Determine the displacement u at various times t.

Figure 73.1: Free Vibration Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Loading
W = 10 lb k_2 = 30 lb/in m = W/g	Δ = -1 in F = 1.875 lb

Initial Conditions		
	Z	$\dot{X}$
t = 0	-1.	0.

Analysis Assumptions and Modeling Notes

One combination element is used with the slider in parallel with the spring. The slider spring constant (k_1 = 10,000 lb/in) is arbitrarily selected high enough to minimize the elastic contact effect but low enough to also allow a practical integration time step size. The integration time step (0.2025/405 = 0.0005 sec) is based on $\approx$ 1/Nf where N = 20 and f is the system natural frequency. At release, the mass acceleration is not necessarily zero. Therefore, a load step with a small time period is used to ramp up to the appropriate acceleration while maintaining an essentially zero velocity. The final time of 0.2025 sec allows one full cycle of motion. POST26 is used to postprocess results from the solution phase.

Results Comparison

	Target	Mechanical APDL	Ratio
u, in (t = 0.09 sec)	0.87208	0.87147	0.999
u, in (t = 0.102 sec)	0.83132	0.83185	1.001
u, in (t = 0.183 sec)	-0.74874	-0.74841	0.999

Figure 73.2: Displacement vs. Time Display

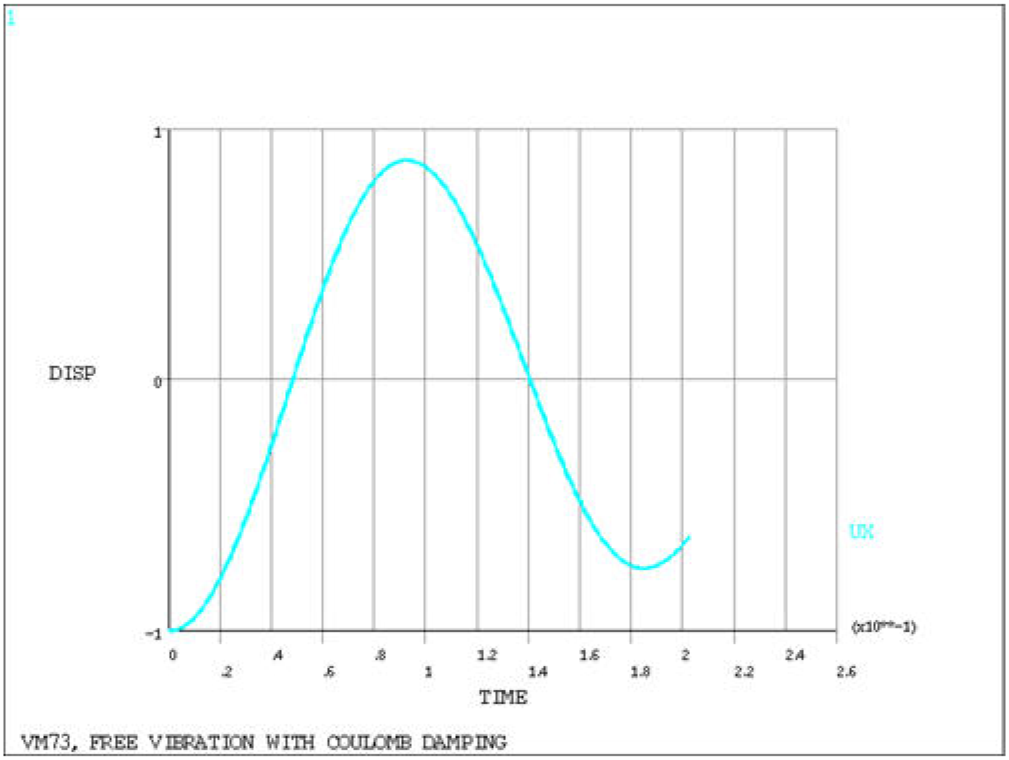
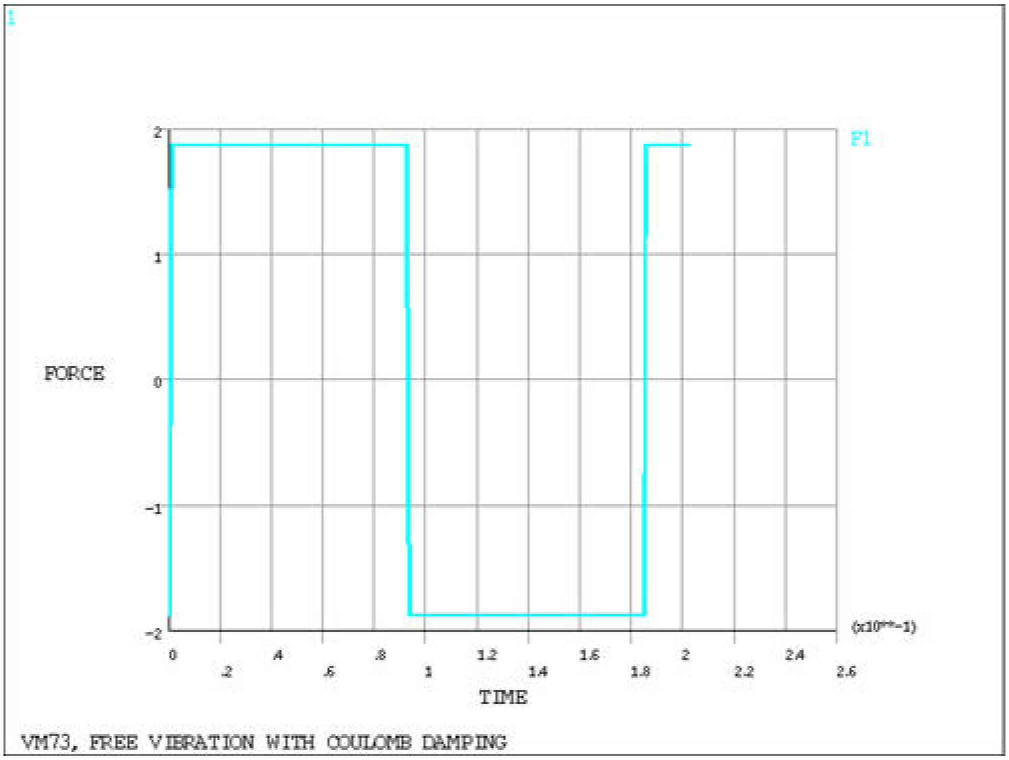


Figure 73.3: Sliding Force vs. Time Display



VM74: Transient Response to an Impulsive Excitation

Overview

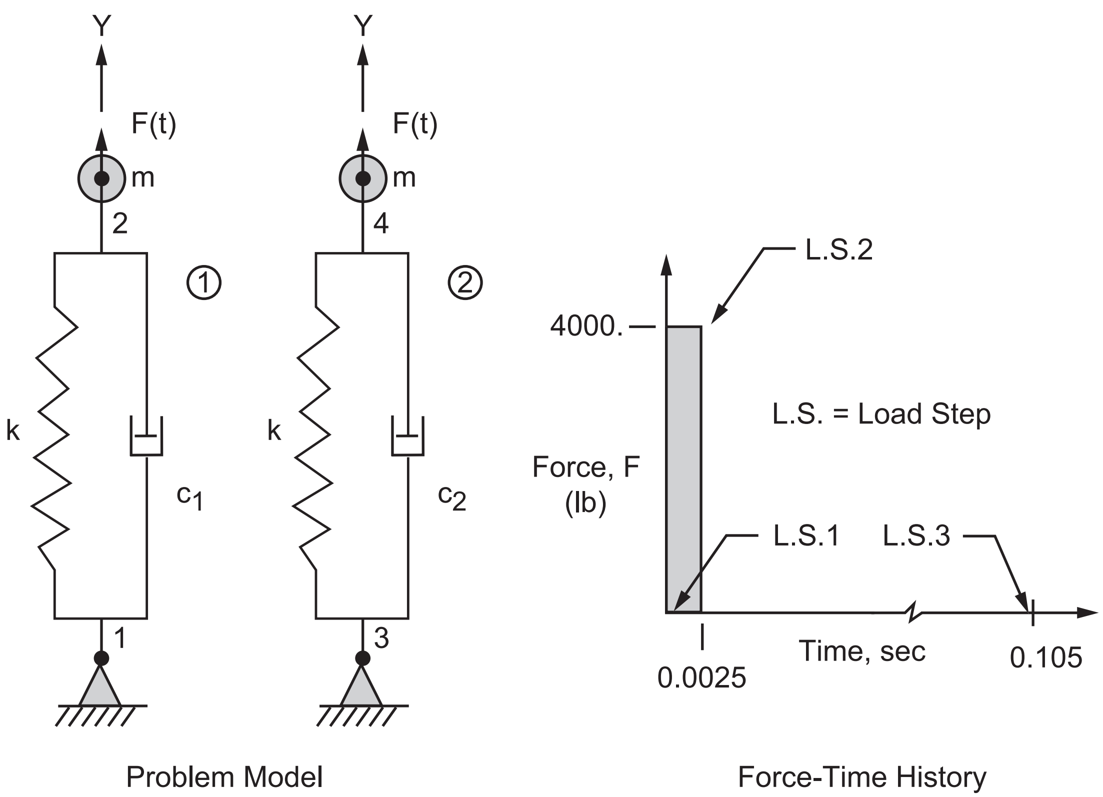
Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 99, article 4.1.
Analysis Type(s):	Mode-Superposition Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	Combination Elements (COMBIN40)
Input Listing:	vm74.dat

Test Case

A mass supported on a spring is subjected to an impulse force F(t) and thereafter undergoes free vibration. Determine the maximum deflection y_{max} of the mass for the undamped case and the deflection y at time t for two damping ratios:

- ξ = 0.0 (undamped)
- ξ = 0.7.

Figure 74.1: Impulsive Excitation Problem Sketch



Material Properties	Loading
m = 0.5 lb-sec^2/in k = 200 lb/in	(see time history in Figure 74.1: Impulsive Excitation Problem Sketch (p. 203))

Analysis Assumptions and Modeling Notes

The node locations are arbitrarily selected. The damping coefficient c is calculated as $2\xi\text{sqrt}(km)$ = 0.0 and 14.0 lb-sec/in for ξ = 0.0 and ξ = 0.7 respectively. A static solution is done at the first load step. The final time of 0.105 sec allows the masses to reach their largest deflections. The integration time step (0.0025 sec) is based on $\approx$ 1/120 of the period to allow the step changes in acceleration to be followed reasonably well and to produce sufficient printout for the theoretical comparison. The impulse is applied over one integration time step.

Results Comparison

		Target	Mechanical APDL	Ratio
Time = 0.08 sec Damping ratio = 0.0	$y_{,max}$ in	0.99957	0.99523	0.996
Time = 0.1 sec	y, in (for damping ratio = 0.0)	0.90930	0.92469[1]	1.017
	y, in (for damping ratio = 0.7)	0.34180	0.35167[1]	1.029

1. Based on time = 0.1 + 0.0025 sec to account for finite impulse duration of 0.0025 sec.

VM75: Transient Response to a Step Excitation

Overview

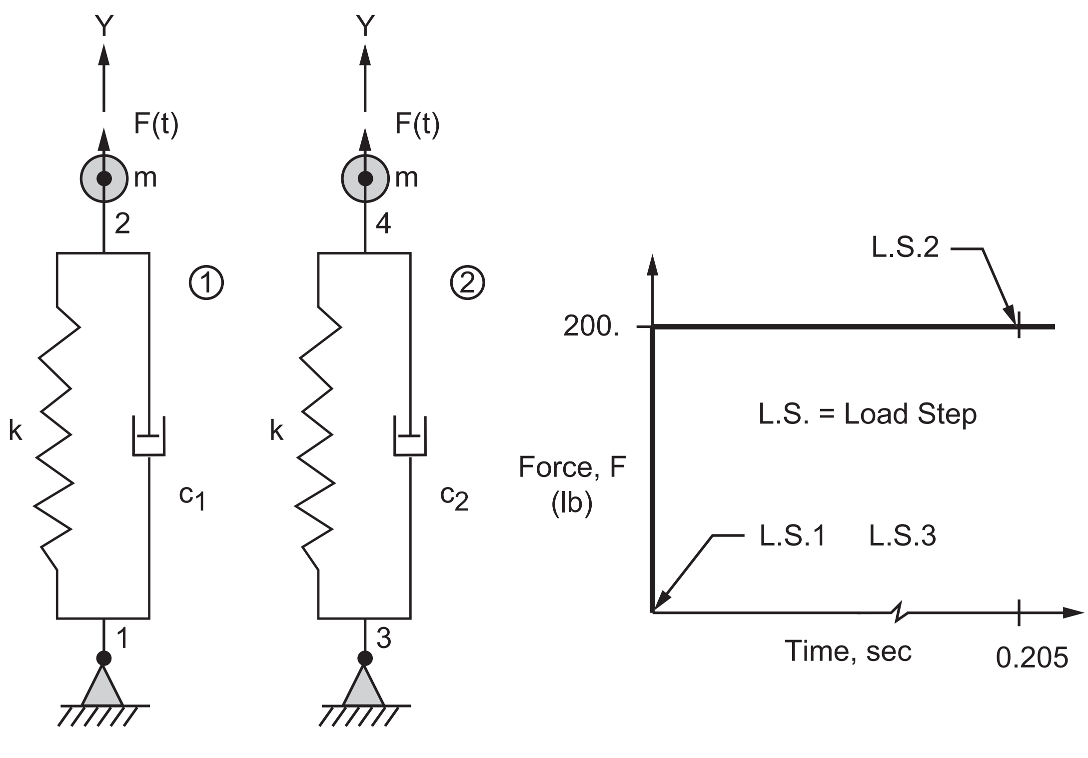
Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 102, article 4.3.
Analysis Type(s):	Mode-Superposition Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	Combination Elements (COMBIN40)
Input Listing:	vm75.dat

Test Case

A spring-mass-damping system, initially at rest, is subjected to a step force change F acting on the mass. Determine the maximum deflection u_{max} for the undamped case. Determine the displacement u at time t for two damping ratios:

- $\xi = 0.0$ (undamped)
- $\xi = 0.5$

Figure 75.1: Step Excitation Problem Sketch



Representative Finite Element Model

Force-Time History

Material Properties	Loading
$m = 0.5$ lb-sec^2/in $k = 200$ lb/in	F = 200 lb (see Figure 75.2: Displacement vs. Time Display (p. 206))

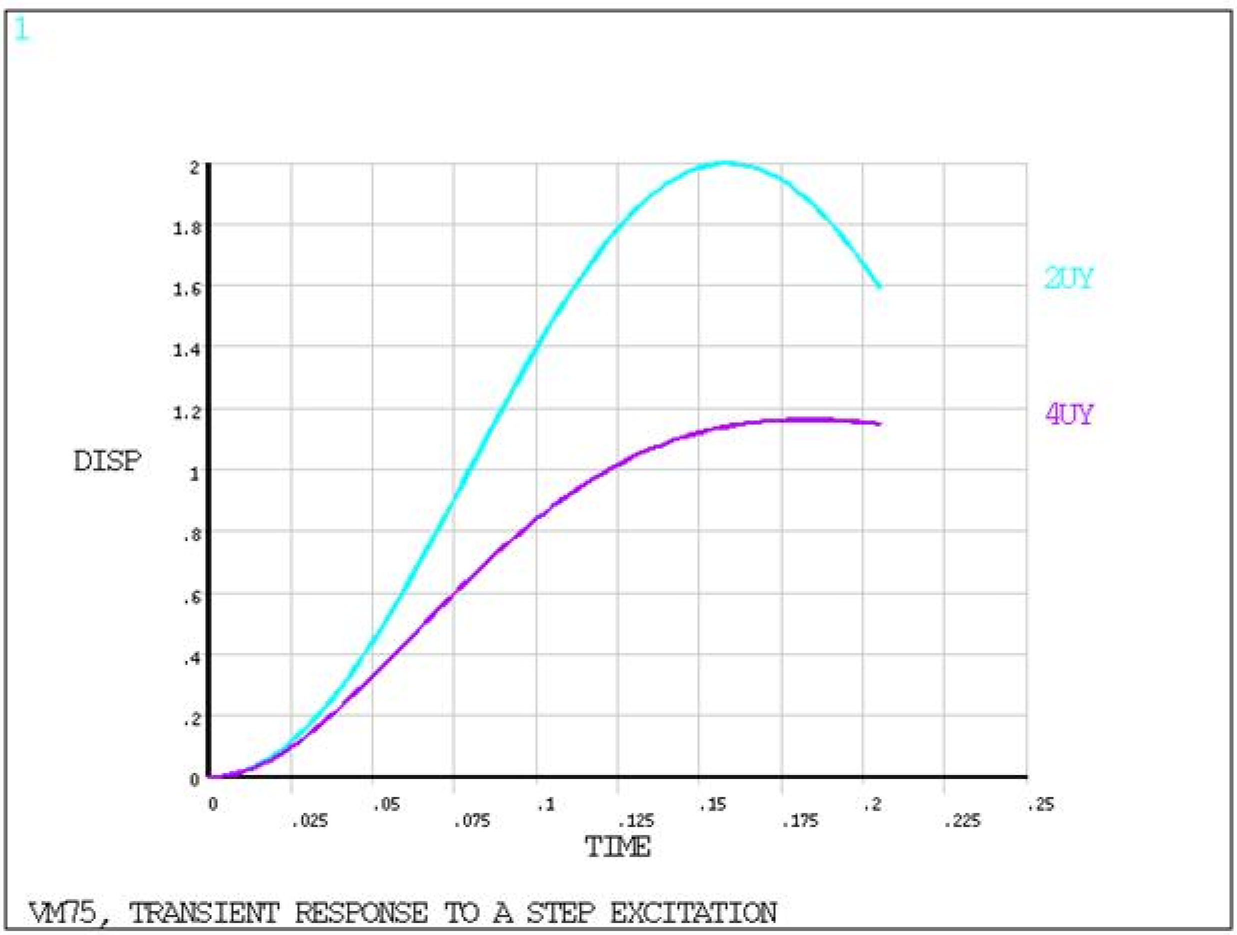
Analysis Assumptions and Modeling Notes

The node locations are arbitrarily selected. The damping coefficient c is calculated as 2ξ sqrt(km) = 0.0 and 10 lb-sec/in for ξ = 0.0 and ξ = 0.5 respectively. A static solution is done at the first load step. The maximum time of 0.205 sec allows the masses to reach their largest deflections. The integration time step (0.0025 sec) is based on ≈ 1/120 of the period to allow the initial step acceleration change to be followed reasonably well and to produce sufficient printout for the theoretical comparison. POST26 is used to get displacement versus time display.

Results Comparison

		Target	Mechanical APDL	Ratio
Time = 0.1575 sec	$u_{max, in}$	2.0000	1.9992	1.000
Time = 0.20 sec	$u_{, in}$ (for Damping ratio = 0.0)	1.6536	1.6723	1.011
	$u_{, in}$ (for Damping ratio = 0.5)	1.1531	1.1544	1.001

Figure 75.2: Displacement vs. Time Display



VM76: Harmonic Response of a Guitar String

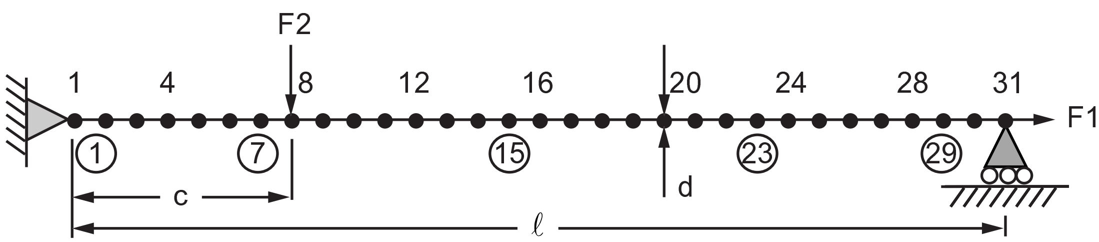
Overview

Reference:	R. D. Blevins, *Formulas for Natural Frequency and Mode Shape*, Van Nostrand Reinhold Co., New York, NY, 1979, pg. 90, tab. 7-1.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0) Linear Perturbed Modal Analysis (**ANTYPE** = 2) Linear Perturbed Harmonic Analysis (**ANTYPE** = 3)
Element Type(s):	3-D Spar (or Truss) Elements (LINK180)
Input Listing:	vm76.dat

Test Case

A uniform stainless steel guitar string of length ℓ and diameter d is stretched between two rigid supports by a tensioning force F_1, which is required to tune the string to the E note of a C scale. The string is then struck near the quarter point with a force F_2. Determine the fundamental frequency, f_1. Also, show that only the odd-numbered frequencies produce a response at the midpoint of the string for this excitation.

Figure 76.1: Guitar String Problem Sketch



Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 190 \times 10^9$ Pa $\rho = 7920$ kg/m^3	ℓ = 710 mm c = 165 mm d = 0.254 mm	F_1 = 84 N F_2 = 1 N

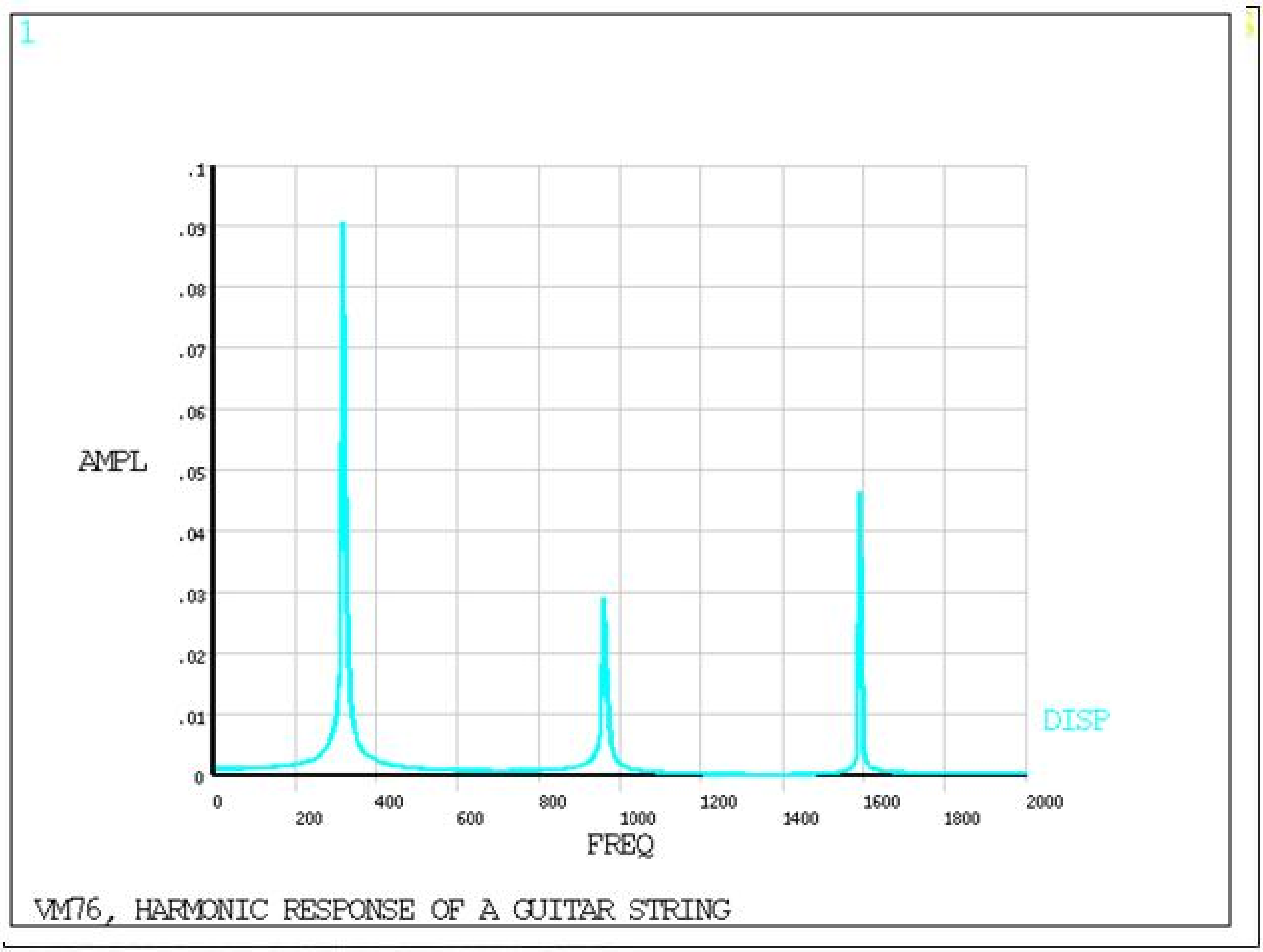
Analysis Assumptions and Modeling Notes

Enough elements are selected so that the model can be used to adequately characterize the string dynamics. The stress stiffening capability of the element is used. Linear perturbed harmonic analysis determines the displacement response to the lateral force F_2. The harmonic response is displayed with the time-history postprocessor, POST26, to show the excitation of the odd-numbered frequencies at peak displacement amplitudes. Refer to Figure 76.2: String Midpoint Displacement Amplitude (p. 208).

Results Comparison

		Target	Mechanical APDL	Ratio
Modal	f, Hz	322.2	322.3	1.000
POST26	f_1, (322.2 Hz)	Response	Response, 320 < f < 328	-
	f_2, (644.4 Hz)	No Response	No Response	-
	f_3, (966.6 Hz)	Response	Response, 968 < f < 976	-
	f_4, (1288.8 Hz)	No Response	No Response	-
	f_5, (1611.0 Hz)	Response	Response,1624 < f < 1632	-
	f_6, (1933.2 Hz)	No Response	No Response	-

Figure 76.2: String Midpoint Displacement Amplitude



VM77: Transient Response to a Constant Force

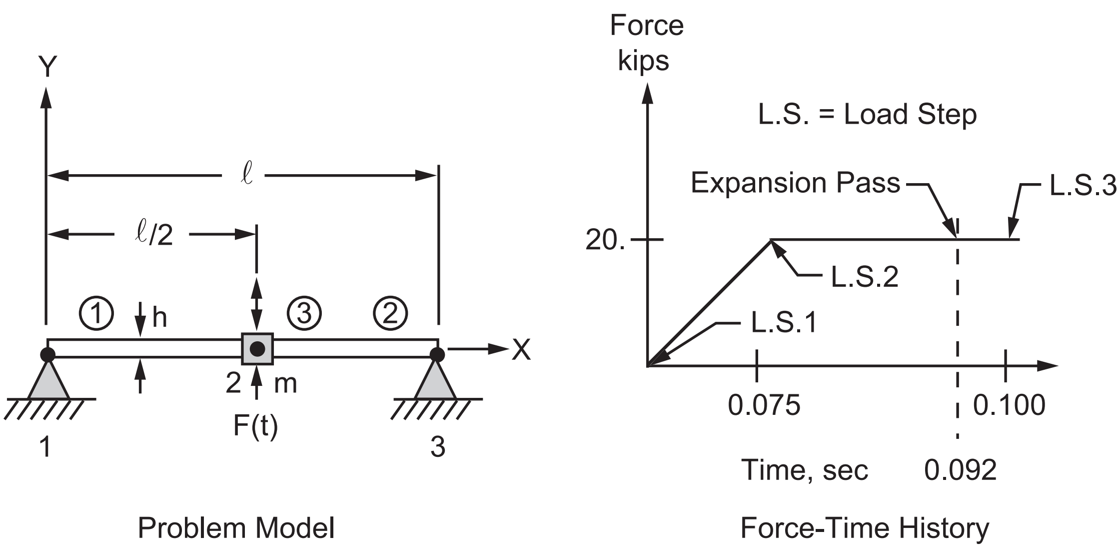
Overview

Reference:	J. M. Biggs, *Introduction to Structural Dynamics*, McGraw-Hill Book Co., Inc., New York, NY, 1964, pg. 50, ex. E.
Analysis Type(s):	Mode-Superposition Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	3-D Elastic Beam Elements (BEAM188) Structural Mass Elements (MASS21)
Input Listing:	vm77.dat

Test Case

A steel beam of length ℓ and geometric properties shown below, is supporting a concentrated mass, m. The beam is subjected to a dynamic load F(t) with a rise time t_r and a maximum value F_1. If the weight of the beam is considered negligible, determine the time of maximum displacement response t_{max} and the maximum displacement response y_{max}. Additionally, determine the maximum bending stress σ_{bend} in the beam.

Figure 77.1: Constant Force Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^3$ ksi $m = 0.0259067$ kips-sec^2/in	$I = 800.6$ in^4 $h = 18$ in ℓ = 20 ft = 240 in	F_1 = 20 kips t_r = 0.075 sec

Analysis Assumptions and Modeling Notes

The final time of 0.1 sec allows the mass to reach its largest deflection. A static solution is done at the first load step. The integration time step (0.004 sec) is based on $\approx$1/25 of the period to allow the abrupt change in acceleration to be followed reasonably well and to produce sufficient printout for the theoretical comparison. Symmetry could have been used in the model. The time of maximum response (0.092 sec) is selected for the expansion pass calculation.

Results Comparison

		Target[1]	Mechanical APDL	Ratio
Transient	t_{max} , sec	0.092	0.092	1.00
	y_{max} , in	0.331	0.335	1.01
Expansion Pass	$Stress_{bend}$, ksi	-18.6	-18.9	1.01

1. Based on graphical values

VM78: Transverse Shear Stresses in a Cantilever Beam

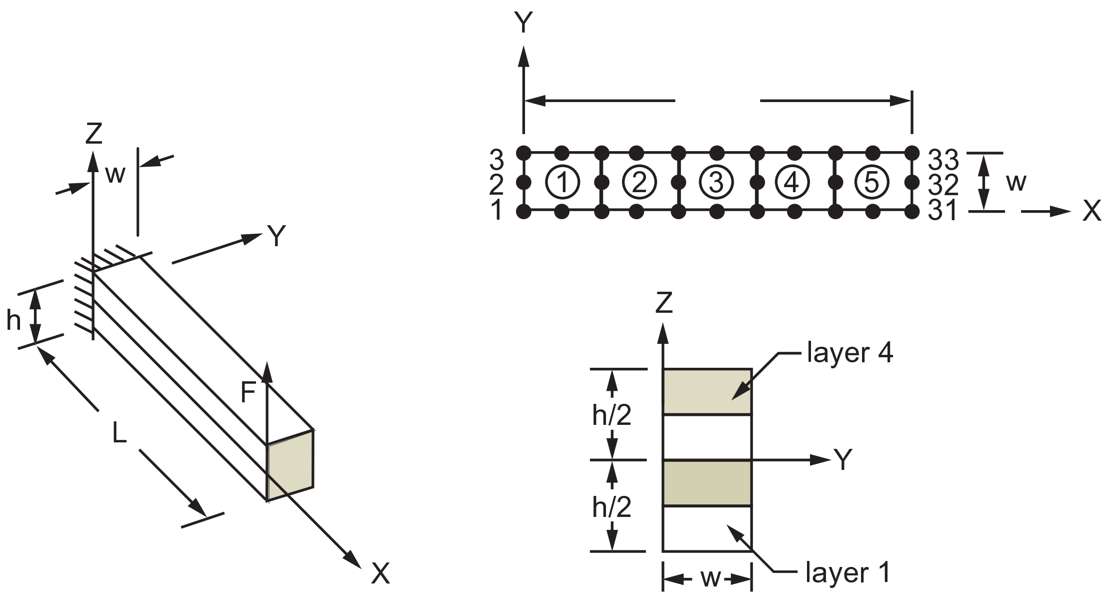
Overview

Reference:	S. Timoshenko, J. N. Goodier, *Theory of Elasticity*, 2nd Edition, McGraw-Hill Book Co., Inc., New York, NY, 1951, pg. 35, article 20.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Linear Layered Structural Shell Elements (SHELL281)
Input Listing:	vm78.dat

Test Case

A cantilever beam of length L, height h, and width w is bent by a force F applied at the free end. Modeling the beam using SHELL281 shell elements having four layers of identical material properties and thickness, determine the shear stress distribution through the beam thickness and the maximum Tsai-Wu failure criterion. The normal and shear failure stresses are $\sigma_x f$ and $\sigma_{xy} f$ respectively.

Figure 78.1: Cantilever Beam Problem Sketch



Problem Sketch   Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0$ $\sigma_x f = 25000$ psi $\sigma_{xy} f = 500$ psi	L = 10.0 in w = 1.0 in h = 2.0 in	$F_1 = 10000$ lb

Analysis Assumptions and Modeling Notes

Poisson's ratio is set to zero to model the narrow beam assumption. The failure stresses are input in the nonlinear material property table (**TB** commands). Compression values are allowed to default to negative tension values and arbitrary values are assigned to failure stresses in the Y and Z directions. The target solution for the maximum Tsai-Wu failure criterion (FC3) is obtained from equation 2–92 of the *Mechanical APDL Theory Reference*). Since $\sigma_y = \sigma_z = \sigma_{xy} = \sigma_{yx} = 0$, most terms vanish and the equation reduces to:

$$FC3 = \frac{\sigma_x^2}{\sigma_x^{f2}} + \frac{\sigma_{xz}^2}{\sigma_{xz}^{f2}}, \text{where } \sigma_{xz}^f = \sigma_{xy}^f \text{ (by default)}$$

By substituting relations for σ_{xz} (from S. Timoshenko, J. N. Goodier, *Theory of Elasticity*), it can be shown that σ_x and FC3 has a maximum value at the middle plane and:

$$FC3_{max} = \frac{9F^2}{4W^2h^2\sigma_{xy}^{f2}} = 225.0$$

POST1 is used to find the maximum value of the Tsai-Wu failure criterion (FCMX).

Results Comparison

	Target	Mechanical APDL	Ratio
$Stress_{xz}$, psi (z = h/2)	0.0	0.0[1]	1.000
$Stress_{xz}$, psi (z = h/4)	5625.0	5625.0[2]	1.000
$Stress_{xz}$, psi (z = 0)	7500.0	7500.0[3]	1.000
$FC3_{max}$ (FCMX)	225.0	225.0	1.000

1. SXZ for Layer, BOT or Layer 4, TOP (for any element)
2. ILSXZ for Layers 1-2 (or 3-4)
3. ILSXZ for Layers 2-3 (also ILMX)

Poisson's ratio is set to zero to model the narrow beam assumption. The failure stresses are input in the nonlinear material property table (**TB** commands). Compression values are allowed to default to negative tension values and arbitrary.

VM79: Transient Response of a Bilinear Spring Assembly

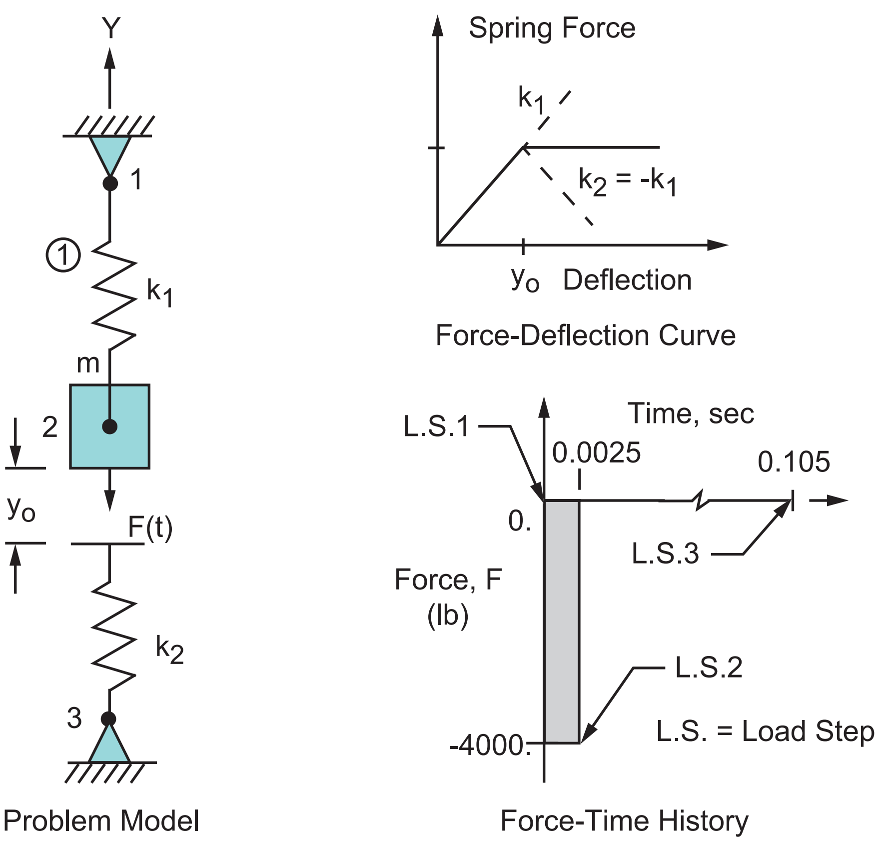
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 150, fig. 5.6-1.
Analysis Type(s):	Mode-Superposition Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	Combination Elements (COMBIN40) Gap Condition (GP)
Input Listing:	vm79.dat

Test Case

A mass supported on a nonlinear spring is subjected to an impulsive force F(t) and thereafter undergoes free vibration. The spring stiffness is characterized by the force-deflection curve shown below. Determine the maximum deflection y_{max} of the mass. Compare results with those of VM74.

Figure 79.1: Bilinear Spring Assembly Problem Sketch



Material Properties	Geometric Properties	Loading
$m = 0.5\ lb\text{-}sec^2/in$ $k_1 = 200\ lb/in$	$y_o = 0.75$ in	see time history in Figure 79.1: Bilinear Spring Assembly Problem Sketch (p. 213)

Analysis Assumptions and Modeling Notes

The node locations are arbitrarily selected. The final time of 0.105 sec allows the mass to reach its largest deflection. A static solution is done at the first load step. A gap condition with a spring constant of $-k_1$ is applied in parallel with k_1 to produce a combined spring stiffness of zero at gap closure. The integration time step (0.0025 sec) is based on $\approx$ 1/125 of the period to allow the step changes in acceleration to be followed reasonably well and to produce sufficient printout for the theoretical comparison. The impulse is applied over one integration time step.

Results Comparison

Time = 0.09 sec	**Target**	**Mechanical APDL**	**Ratio**
Y_{max}, in	-1.0417	-1.0405	0.999

Table 79.1: Comparison of Mechanical APDL Linear and Bilinear Spring Results

Time, sec	**0.040**	**0.070**	**0.085**	**0.105**
y, in (linear)[1]	-0.68122	-0.97494	-0.99604	-0.88666
y, in (bilinear)	-0.68122	-0.98672	-1.0383	-1.0020

1. From test case VM74 output. Positive displacement direction is reversed for comparison.

VM80: Plastic Response to a Suddenly Applied Constant Force

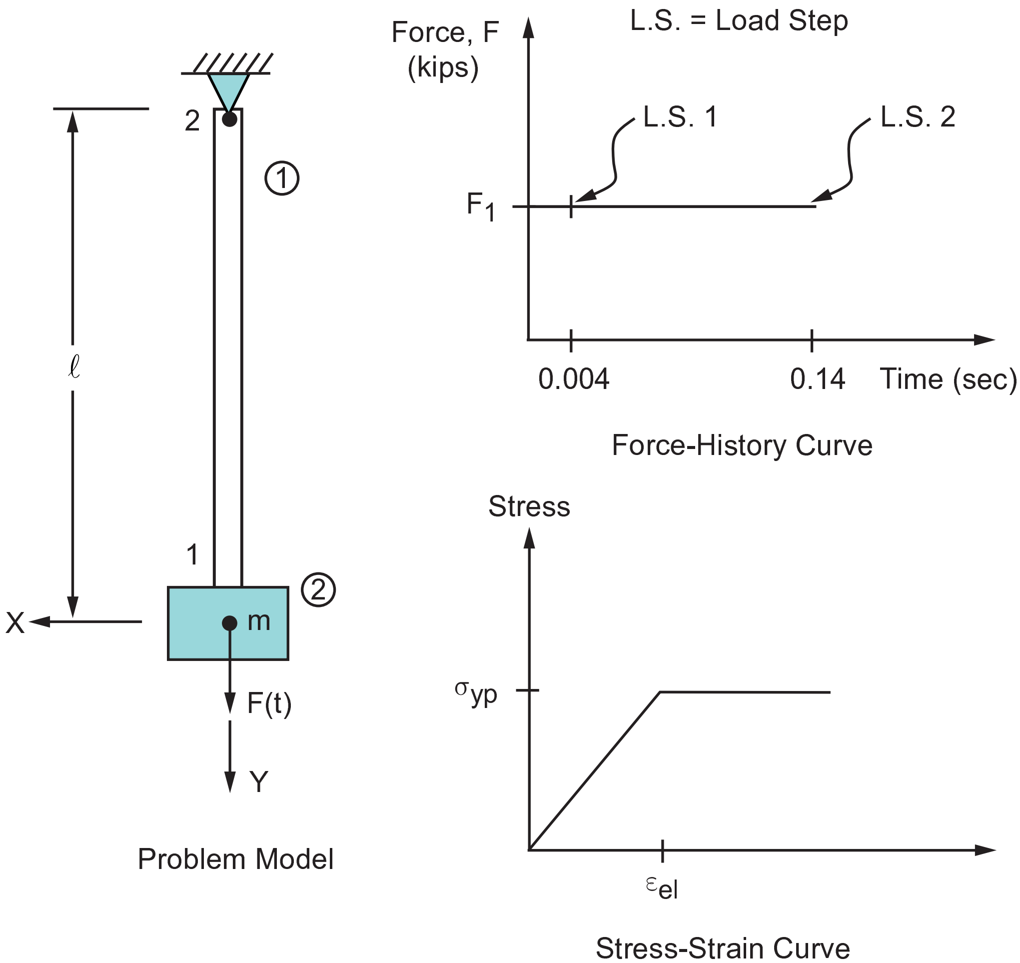
Overview

Reference:	J. M. Biggs, *Introduction to Structural Dynamics*, McGraw-Hill Book Co., Inc., New York, NY, 1964, pg. 69, article 2.7.
Analysis Type(s):	Full Transient Dynamic, Plastic Analysis (**ANTYPE** = 4)
Element Type(s):	3-D Spar (or Truss) Elements (LINK180) Structural Mass Elements (MASS21)
Input Listing:	vm80.dat

Test Case

A mass m supported on a thin rod of area A and length ℓ is subjected to the action of a suddenly applied constant force F_1. The stress-strain curve for the rod material is shown below. Determine the maximum deflection y_{max} and minimum deflection y_{min} of the mass, neglecting the mass of the rod.

Figure 80.1: Plastic Response Problem Sketch



Material Properties	Geometric Properties	Loading
m = 0.0259 kips-sec^2/in E = 30 x 10^3 ksi σ_{yp} = 162.9 ksi	ℓ = 100 in A = 0.278 in^2	F_1 = 30 kips (see time history in Figure 80.1: Plastic Response Problem Sketch (p. 215))

Analysis Assumptions and Modeling Notes

The initial integration time step (0.004/10 = 0.0004 sec) is chosen small enough to allow the initial step change in acceleration to be followed reasonably well. The final integration time step ((0.14-.004)/68 = 0.002 sec) is based on ≈ 1/60 of the period to produce sufficient printout for the theoretical comparison. The final time of 0.14 sec allows slightly more than 1 cycle of vibration to be followed. POST26 is used to extract results from the solution phase.

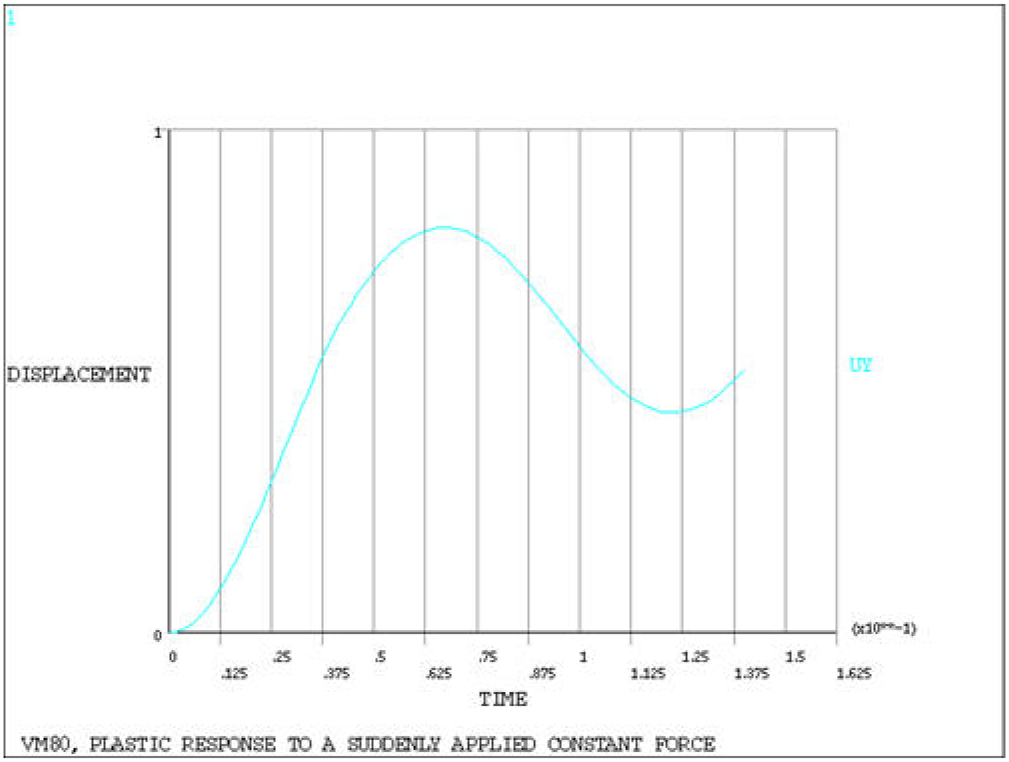
Results Comparison

	Target	Mechanical APDL [1]	Ratio
y_{max}, in	0.806	0.804	0.998
Time, sec	0.0669	0.0680	1.016
y_{min}, in	0.438 [2]	0.438	0.999
Time, sec	0.122 [2]	0.122	1.000

1. Mechanical APDL printout does not occur at theoretical time point given. Comparison (ratio) is therefore made with closest Mechanical APDL time and theoretical time point given.

2. Based on graphical values.

Figure 80.2: Displacement vs. Time Display



VM81: Transient Response of a Drop Container

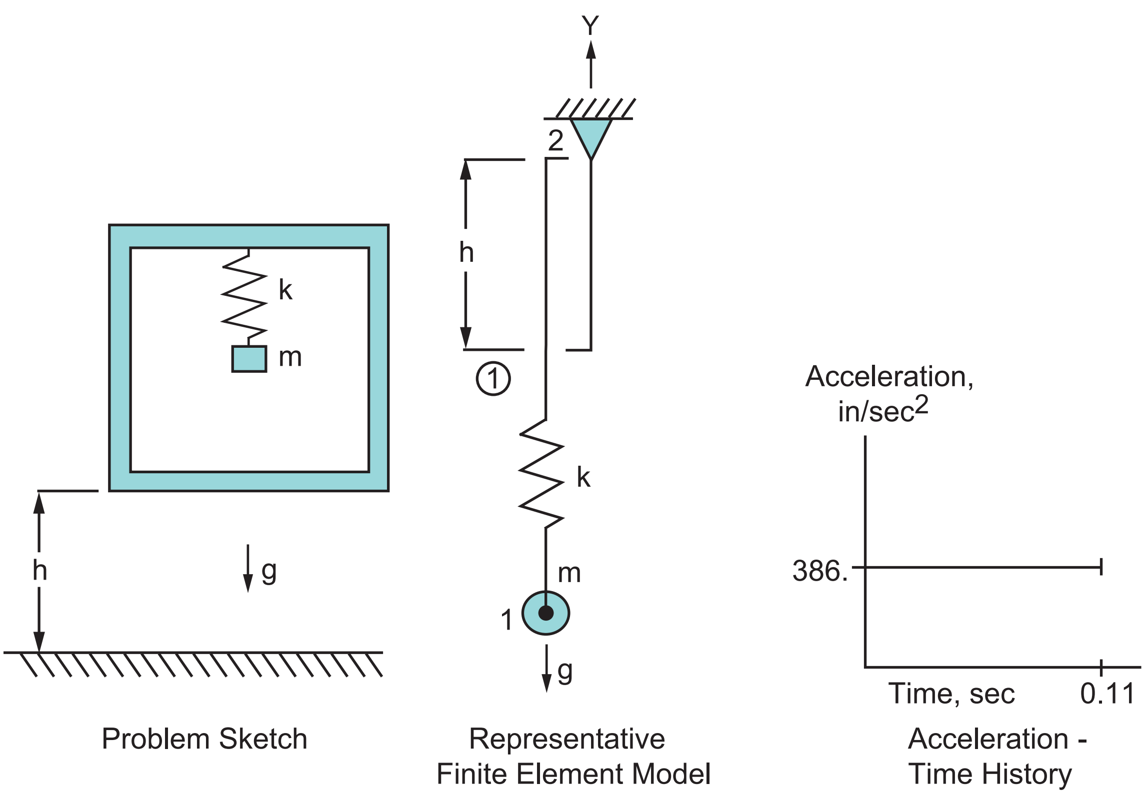
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 110, ex. 4.6-1.
Analysis Type(s):	Full Transient Dynamic Analysis (**ANTYPE** = 4) Mode-Superposition Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	Combination Elements (COMBIN40) Structural Mass Elements (MASS21) Gap Condition (GP)
Input Listing:	vm81.dat

Test Case

A mass m is packaged in a rigid box, as shown below, and dropped through a height h. Determine the velocity and displacement y of the mass at impact and the maximum displacement of the mass. Assume that the mass of the box is large compared to that of the enclosed mass m and that the box remains in contact with the floor after impact.

Figure 81.1: Drop Container Problem Sketch



Material Properties	Geometric Properties	Loading
$m = 0.5$ lb-sec^2/in $k = 1973.92$ lb/in	$h = 1$ in	$g = 386$ in/sec^2

Analysis Assumptions and Modeling Notes

The node locations are arbitrarily selected. The final time of 0.11 sec allows the mass to reach its largest deflection. The integration time step (0.11/110 = 0.001 sec) is based on ≈ 1/100 of the period (during impact), to allow the initial step acceleration change to be followed reasonably well, and to produce sufficient printout for the theoretical comparison.

The problem is solved first using the full method in a nonlinear transient dynamic analysis and then using the mode-superposition transient dynamic analysis. The COMBIN40 gap is replaced by a mass and a gap condition in the mode-superposition transient dynamic analysis. POST26, the time-history postprocessor, is used to extract results from the solution phase.

Results Comparison

At Impact			
Full Transient Dynamic	**Target**	**Mechanical APDL**	**Ratio[1]**
Time, sec	0.07198	0.072	1.000
y, in	-1.00	-1.0005	1.001
vel, in/sec	-27.79	-27.78	1.000
At zero velocity (theoretical y_{max} = -1.5506 in, at time = 0.100366 sec)			
Full Transient Dynamic	**Target[2]**	**Mechanical APDL**	**Ratio**
t = 0.100 sec y, in	-1.5505	-1.5503	1.000
t = 0.101 sec y, in	-1.5502	-1.5502	1.000
At Impact			
Mode-Superposition Transient Dynamic	**Target**	**Mechanical APDL**	**Ratio[1]**
Time, sec	0.07198	0.072	1.000
y, in	-1.00	-0.987	0.987
vel, in/sec	-27.79	-27.59	0.993
At zero velocity (theoretical y_{max} = -1.5506 in, at time = 0.100366 sec)			
Mode-Superposition Transient Dynamic	**Target[2]**	**Mechanical APDL**	**Ratio**
t = 0.100 sec y, in	-1.5505	-1.5495	0.999
t = 0.101 sec y, in	-1.5502	-1.5503	1.000

1. Mechanical APDL printout does not occur at theoretical time point given. Comparisons (ratios) of the nearest time results are made with the theoretical time point given.

2. Comparisons are made at the two time points bracketing the theoretical time of zero velocity.

VM82: Simply Supported Laminated Plate Under Pressure

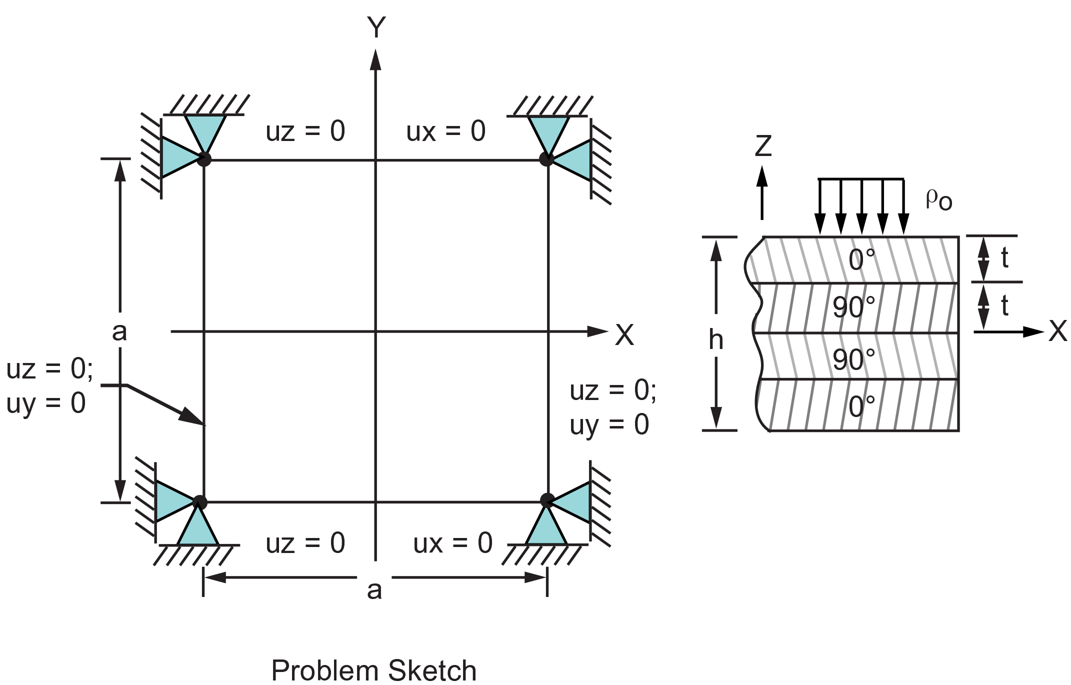
Overview

Reference:	J. N. Reddy, "Exact Solutions of Moderately Thick Laminated Shells", *ASCE Journal Engineering Mechanics*, Vol. 110 No. 5, 1972, pg. 805.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 8-Node Layered Solid Shell Elements (SOLSH190) 3-D 20-Node Layered Structural Solid Elements (SOLID186) 4-Node Finite Strain Shell Elements (SHELL181) 8-Node Finite Strain Shell Elements (SHELL281) 3-D 8-Node Structural Solid (SOLID185)
Input Listing:	vm82.dat

Test Case

A simply-supported square cross-ply laminated plate is subjected to a uniform pressure p_o. The stacking sequence of the plies is symmetric about the middle plane. Determine the center deflection δ (Z-direction) of the plate due to the pressure load.

Figure 82.1: Simply Supported Laminated Plate Problem Sketch



Problem Sketch

Material Properties	Geometric Properties	Loading
$E_x = 25 \times 10^6$ N/m^2 $E_y = 1 \times 10^6$ N/m^2 $\upsilon_{xy} = 0.25$ (Major Poisson's ratio) $G_{xy} = G = 0.5 \times 10^6$ N/m^2	a = 10 m h = 0.1 m t = 0.025 m	$p_o = 1.0$ N/m^2

Material Properties	Geometric Properties	Loading
$G_{yz} = 0.2 \times 10^6$ N/m^2		

Analysis Assumptions and Modeling Notes

A quarter of the plate is modeled due to symmetry in geometry, material orientation, loading, and boundary conditions. Five models using SHELL181, SOLID185, SOLID186, SOLSH190, and SHELL281 elements, respectively, are analyzed. Note that PRXY is used to directly input the major Poisson's ratio. EZ (explicitly input) is assumed to be equal to EY.

Results Comparison

	Target	Mechanical APDL	Ratio
Deflection, m (SOLID185)	0.0683	0.0677	0.991
Deflection, m (SOLSH190)	0.0683	0.0680	0.996
Deflection, m (SOLID186)	0.0683	0.0683	1.000
Deflection, m (SHELL181)	0.0683	0.0683	1.000
Deflection, m (SHELL281)	0.0683	0.0686	1.005

VM83: Impact of a Block on a Spring Scale

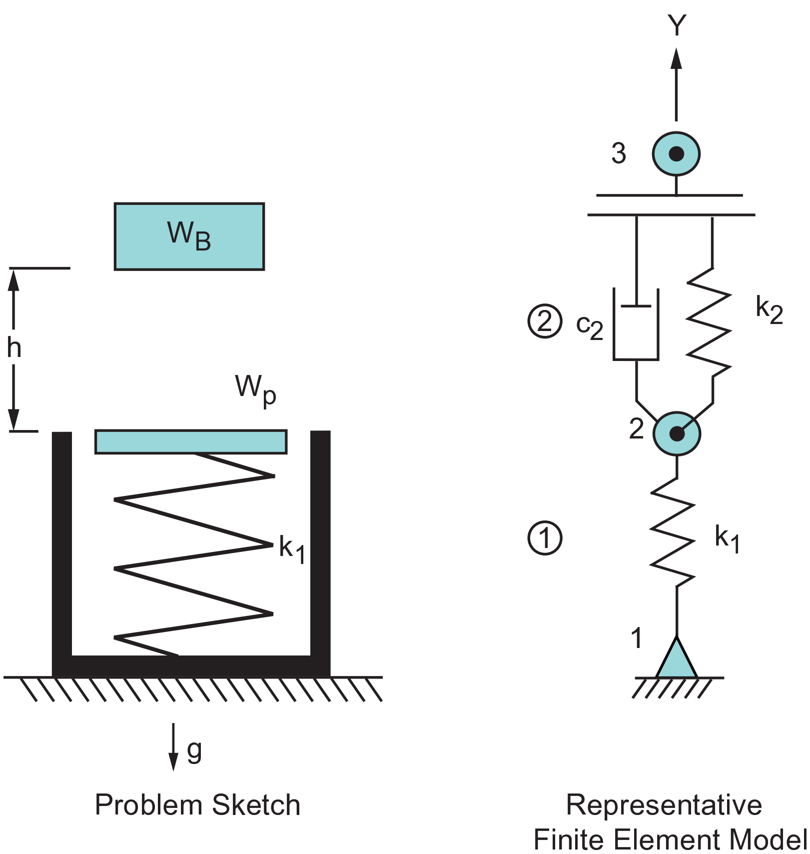
Overview

Reference:	F. P. Beer, E. R. Johnston, Jr., *Vector Mechanics for Engineers, Statics and Dynamics*, McGraw-Hill Book Co., Inc., New York, NY, 1962, pg. 531, problem 14.6.
Analysis Type(s):	Full Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	Combination Elements (COMBIN40)
Input Listing:	vm83.dat

Test Case

A block of weight W_B is dropped from a height h onto a spring scale pan of weight W_P. Determine the maximum deflection δ of the pan and the maximum fall of the block y. Assume the impact to be perfectly plastic as a theoretical approximation.

Figure 83.1: Spring Scale Problem Sketch



Material Properties	Geometric Properties	Loading
k_1 = 100 lb/in W_B = 50 lb W_P = 25 lb	h = 6 ft = 72 in	g = 386 in/sec^2

Analysis Assumptions and Modeling Notes

The mass of the block (m_B) and the mass of the pan (m_P) are calculated as $m_B = W_B/g = (50/386)$ lb-sec^2/in and $m_P = W_P/g = (25/386)$ lb-sec^2/in respectively. Deflection of the pan due to gravity is $W_P/k_1 = 0.25$ in, hence the initial gap becomes (72-0.25) = 71.75 inches.

The spring length is chosen arbitrarily. The closed-gap spring constant (k_2 = 10,000 lb/in) is arbitrarily selected high enough to minimize the elastic contact effect but low enough to also allow a practical integration time step size. The integration time step (0.0005 sec) is based on < 1/30 of the period of the contact spring to minimize the numerical damping effect, and to allow the acceleration change to be followed reasonably well.

Automatic time stepping is used to reduce the total number of iterations needed to solve the problem. A static solution is done at the first load step to produce the initial pan condition before the start of the transient analysis. The maximum time of 0.7 sec allows the pan to reach its largest deflection.

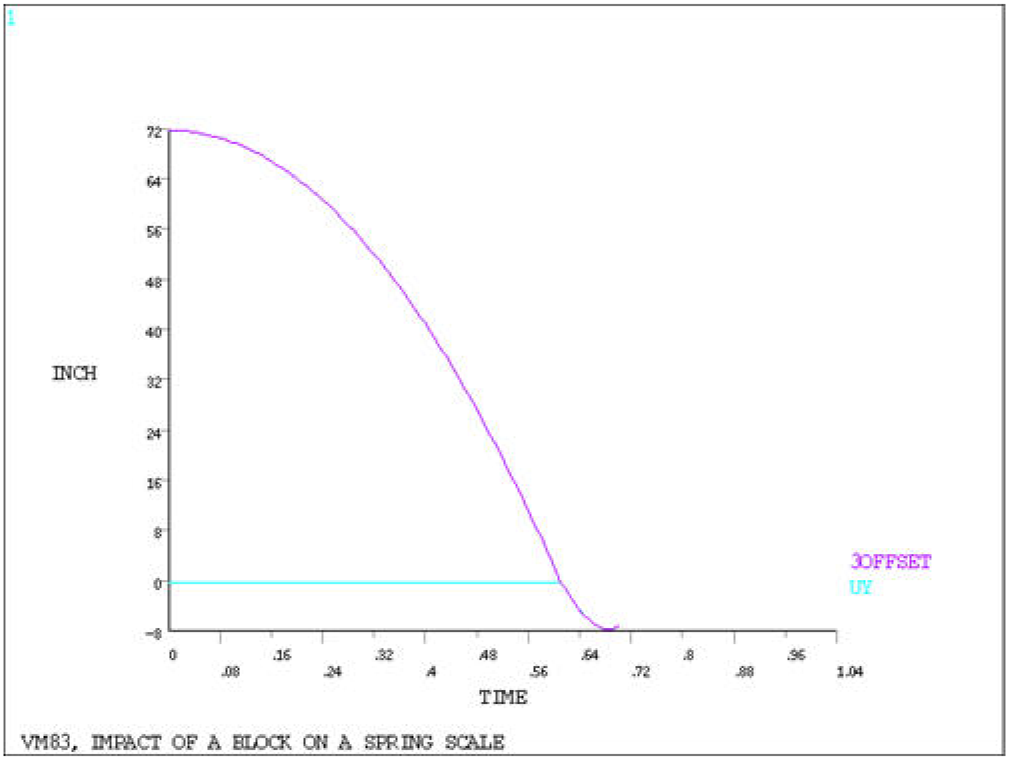
To model the "plastic impact" a damper (C_2) is used which has the value of critical damping to prevent oscillation of the contact spring. Also, the two masses are locked together after initial contact by use of KEYOPT(1) = 1 on combination element type 1 (COMBIN40). Natural frequency of the closed gap is $f_2 = \text{sqrt}(k_2 m_p)/(2\ \pi) = 62.54$ Hz. Critical damping is calculated as $C_2 = k_2/\pi f_2 = 10000 / (62.54\ \pi) = 50.90$ lb-sec/in. POST26 is used to extract results from the solution phase.

Results Comparison

Time = 0.689 sec	Target	Mechanical APDL	Ratio
Deflection, in	-7.7000	-7.6135	0.989
y, in	-79.450[1]	-79.414	1.000

1. Based on a perfectly plastic analytical solution.

Figure 83.2: Displacements of Block and Pan



VM84: Displacement Propagation along a Bar with Free Ends

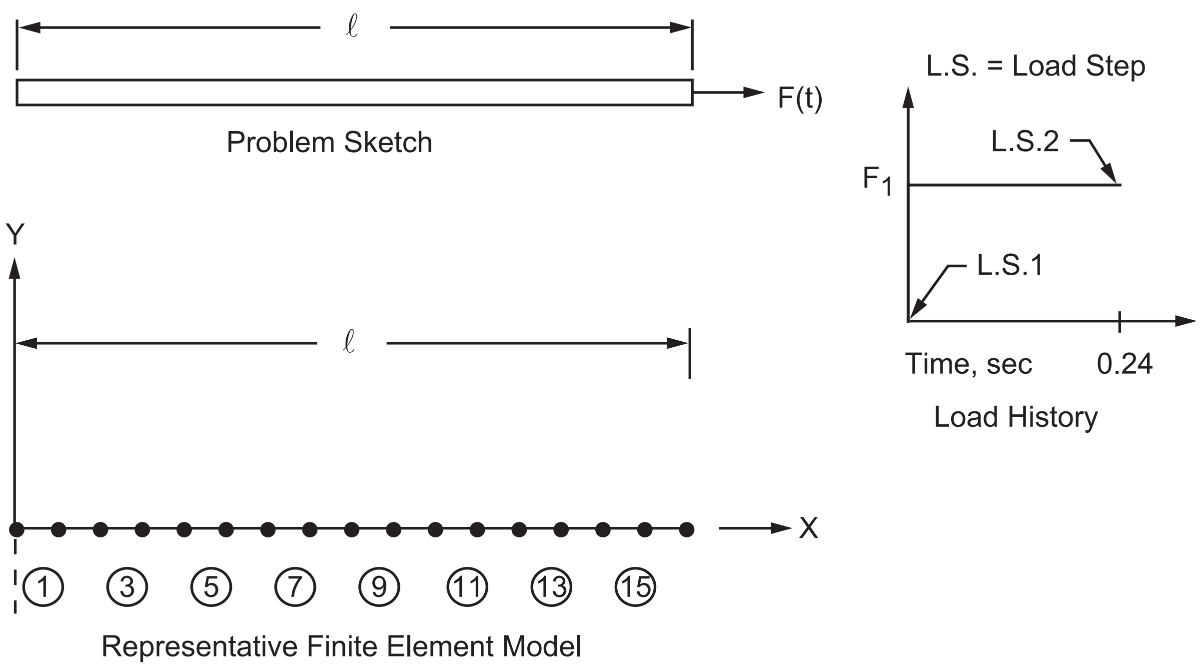
Overview

Reference:	S. Timoshenko, D. H. Young, *Vibration Problems in Engineering*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 311, problem 2.
Analysis Type(s):	Mode-Superposition Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	3-D Spar (or Truss) Elements (LINK180)
Input Listing:	vm84.dat

Test Case

A drill stem is a steel bar 4000 ft long. Considering it as a bar with free ends, find the displacement δ of the end ($x = \ell$) at $t = \tau/2$ produced by a force F_1 suddenly applied to this end.

Figure 84.1: Bar with Free Ends Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\gamma = 0.278$ lb/in^3 $\rho = \gamma / g =$ 0.0007202 lb-sec^2/in^4	$A = 2$ in^2 $g = 386$ in/sec^2 $\ell = 4000 \times 12 =$ 48,000 in	$F_1 = 6000$ lb (see load history in Figure 84.1: Bar with Free Ends Problem Sketch (p. 227))

Analysis Assumptions and Modeling Notes

A static solution is done at the first load step. The fundamental period of vibration (τ) is 0.47937 sec. The final time of 0.24 sec includes 1/2 of the fundamental period of vibration. The integration time step

(0.005 sec) is based on ≈ 1/10 of the shortest period, to allow the initial step change in acceleration to be followed reasonably well, and to produce sufficient printout for the theoretical comparison. POST26 is used to extract results from the solution phase.

Results Comparison

	Target	Mechanical APDL	Ratio
Displacement, in[1]	4.8000	4.8404	1.008

1. Target results are for t = 0.23969 sec (t/2). Mechanical APDL results are reported from the closest time point, t = 0.240 sec.

Figure 84.2: Displacement vs. Time Graph

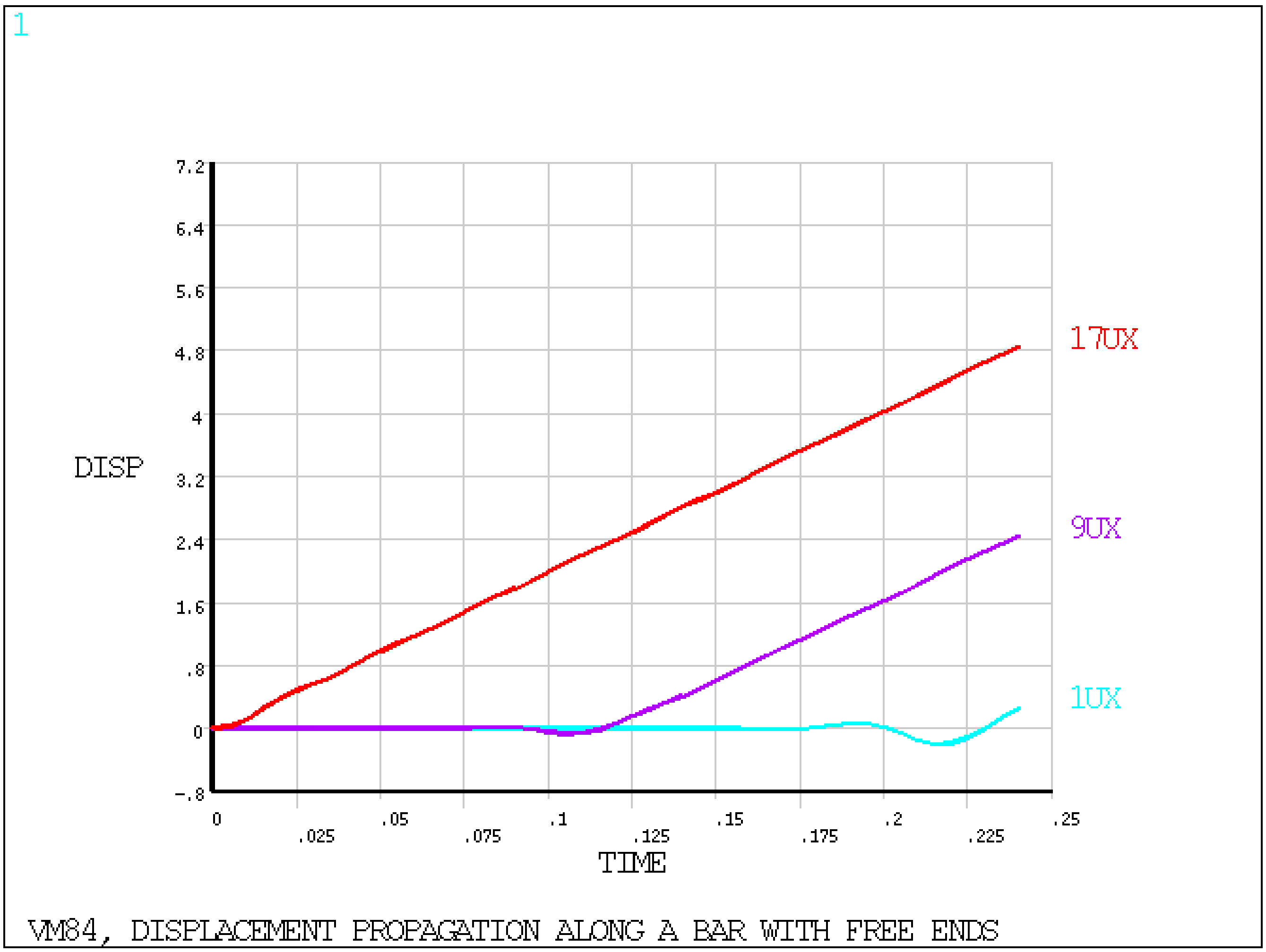
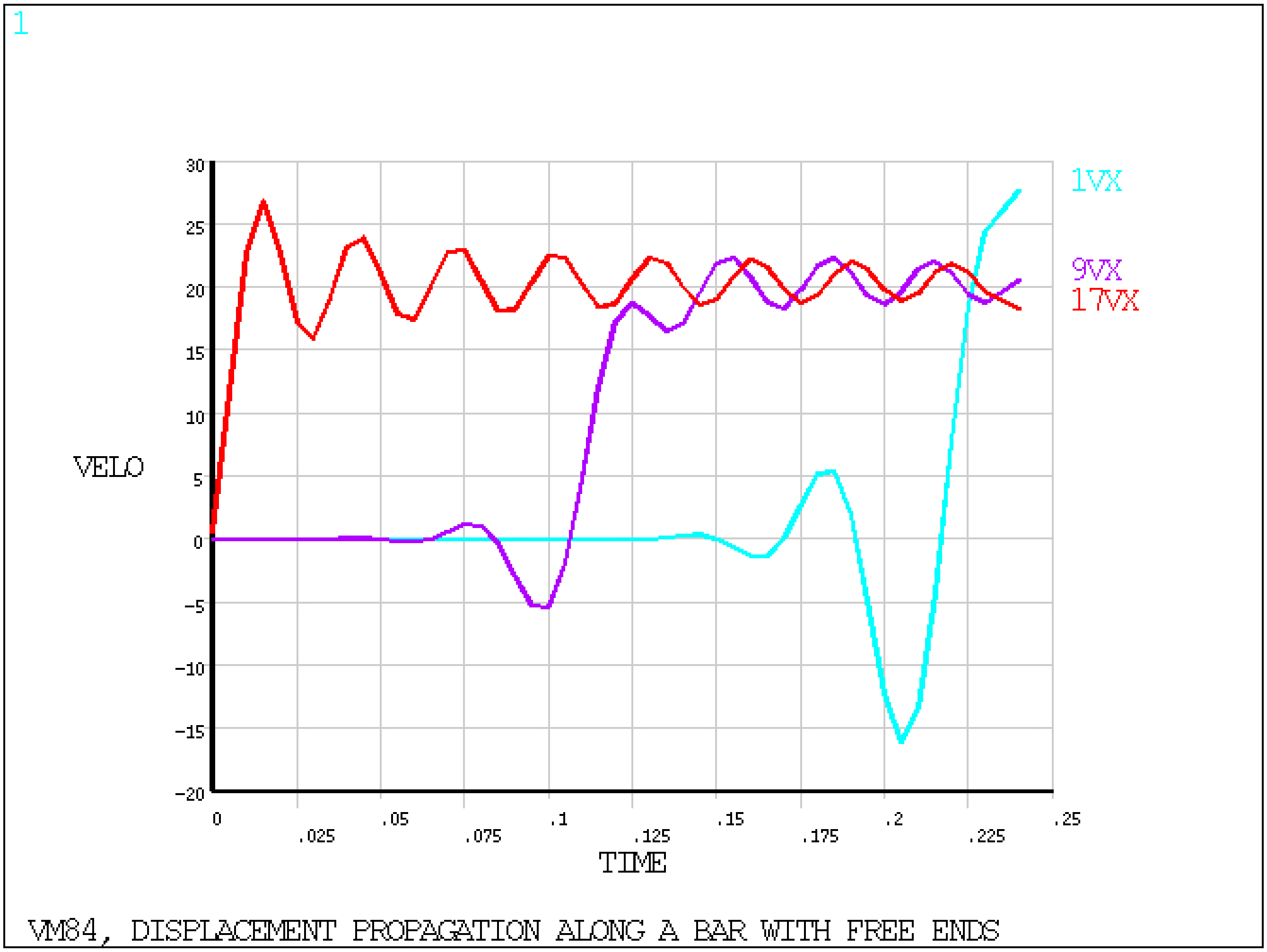


Figure 84.3: Velocity vs. Time Graph



VM85: Transient Displacements in a Suddenly Stopped Moving Bar

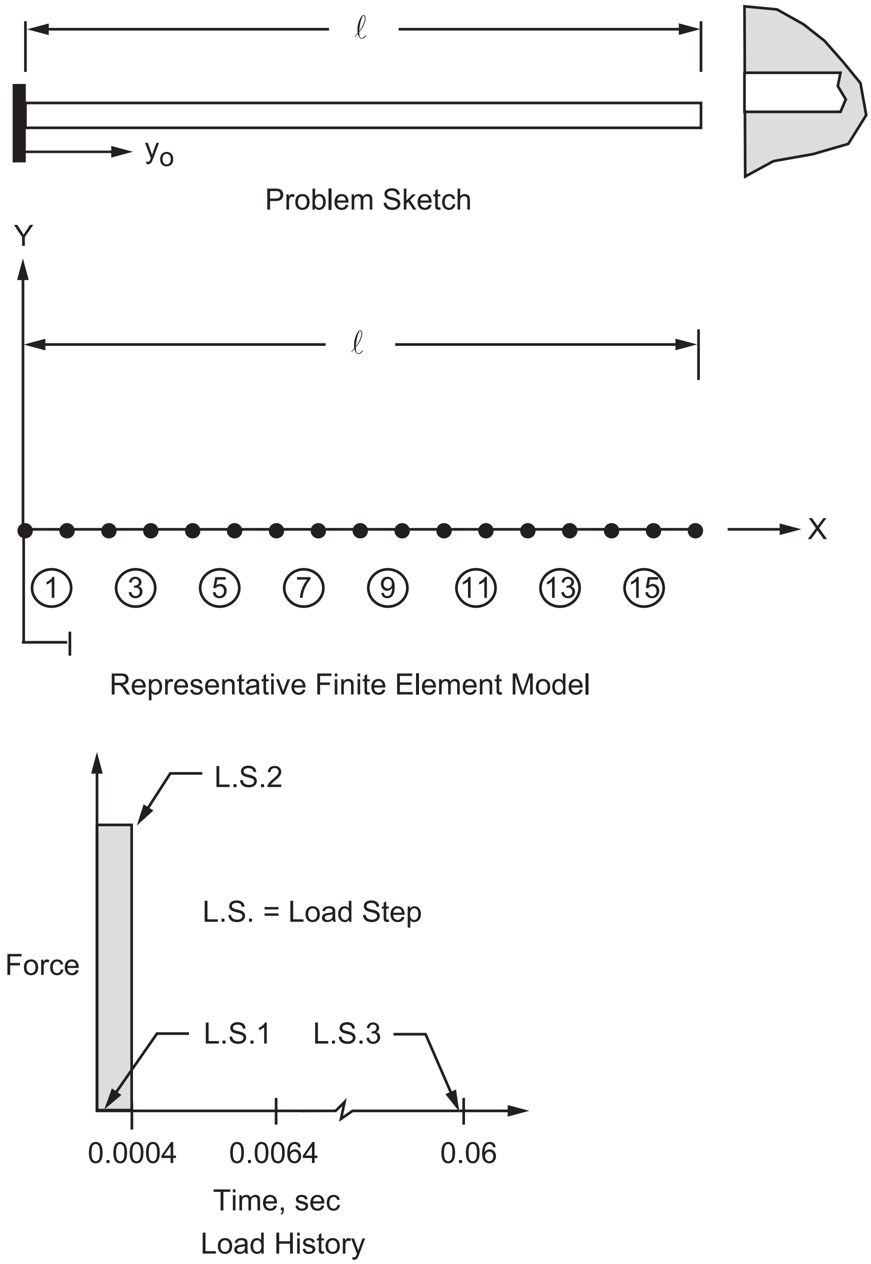
Overview

Reference:	S. Timoshenko, D. H. Young, *Vibration Problems in Engineering*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 305, problem 3.
Analysis Type(s):	Mode-Superposition Transient Dynamic Analysis (**ANTYPE** = 5)
Element Type(s):	3-D Spar (or Truss) Elements (LINK180) Gap Condition (GP)
Input Listing:	vm85.dat

Test Case

A steel bar moving along the X-axis with a constant velocity v_o is suddenly stopped at the end X = 0. Determine the displacement δ at the free end and the axial stress σ_x near the stopped end of the bar at time $t_1 = \ell/a$, where a is the speed of sound in the bar.

Figure 85.1: Moving Bar Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi r = 0.00073 lb-sec^2/in^4	ℓ = 10000 in A = 1 in^2 s_o = 0.64 in	v_o = 100 in/sec

Analysis Assumptions and Modeling Notes

The speed of sound in the bar is $a = \sqrt{E/g}$ = 202,721 in/sec, hence time $t_1 = \ell/a$ = 0.0493288 sec. A static solution is done at the first load step. The final time of 0.06 sec allows the bar to impact (at t_o = 0.0064 sec) and reach its maximum deflection (at $t = t_o + t_1$). The gap stiffness (k = 30,000,000 lb/in) is arbitrarily selected high enough to minimize the elastic contact deformation but low enough to also allow a practical integration time step size.

The integration time step size (ITS = 0.0001 sec) is based on the shortest period (during contact) to allow the abrupt changes in acceleration to be followed reasonably well, and to produce sufficient printout for the theoretical comparison.

The initial velocity is produced by a force = $v_o \rho A \ell$ / ITS = 1,825,000 lb acting over 4 ITS. A "coasting" period of 60 ITS is allowed before the gap (s_o = 0.64 in) closes at impact. An expansion pass is done at $t = t_o + t_1$ to obtain the stress solution. POST26 is used to get the displacement solution and displays versus time.

Results Comparison

		Target[1]	Mechanical APDL [2]	Ratio
Mode-Superposition Transient Dynamic	d, in (t = 0.05573 sec)	4.9329	-	-
	d, in (t = 0.0544 sec)	-	4.7733	0.968
	d, in (t = 0.0557 sec)	-	4.7471	0.962
Expansion Pass	$stress_x$, psi (t = 0.05573 sec)	14799.	-	-
	$stress_x$, psi (t = 0.0557 sec)	-	14803	1.000

- t is time before contact (0.0064 sec) included.
- d is relative displacement between the ends of the bar.

1. Assumes an infinitely rigid stop.
2. Uses a high, but finite stiffness for the stop.
3. Peak displacement.
4. Displacement at the time closest to the theoretical time point given.
5. From Element 1.

Figure 85.2: Displacements at Center and Ends of Bar

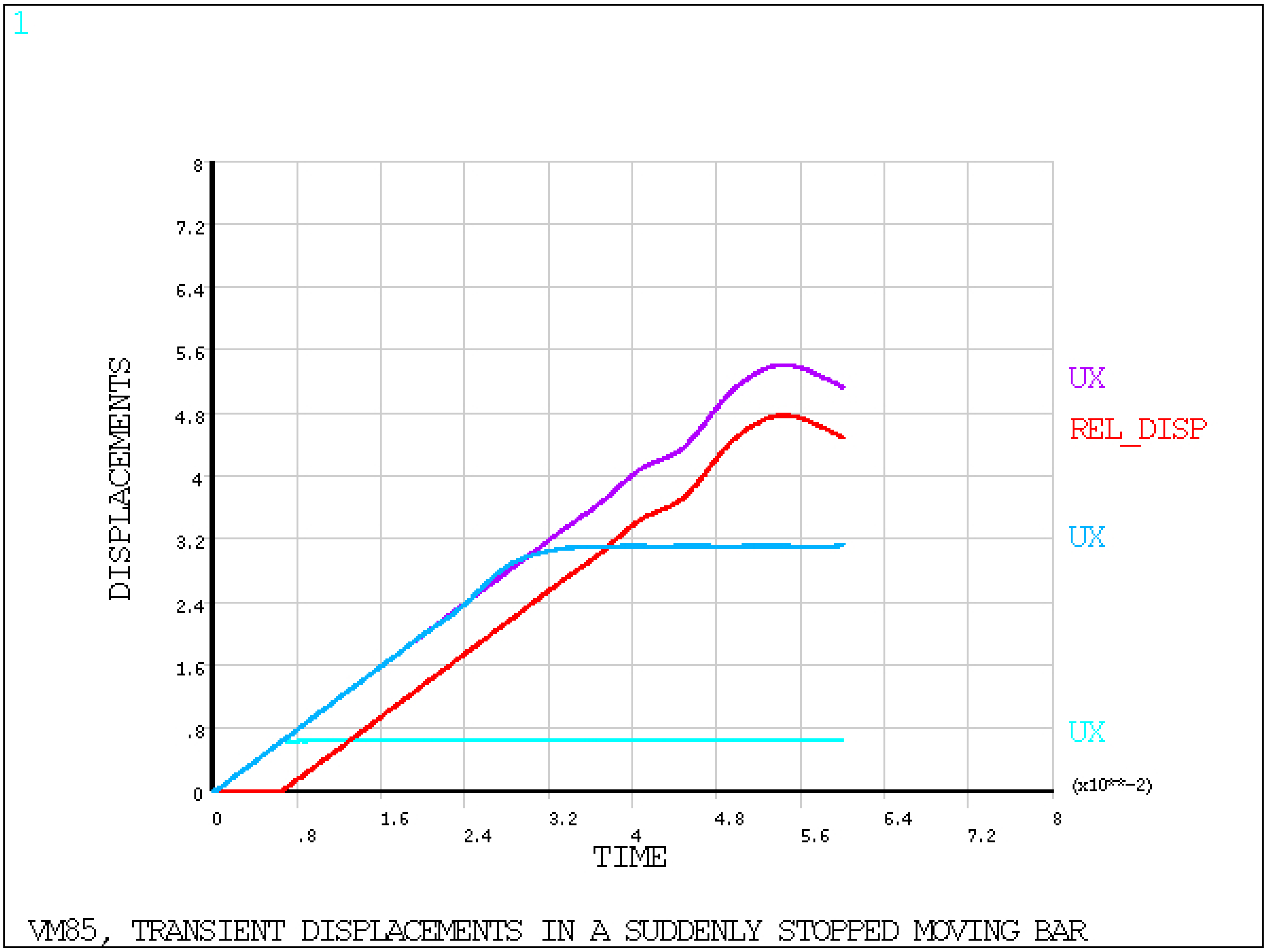
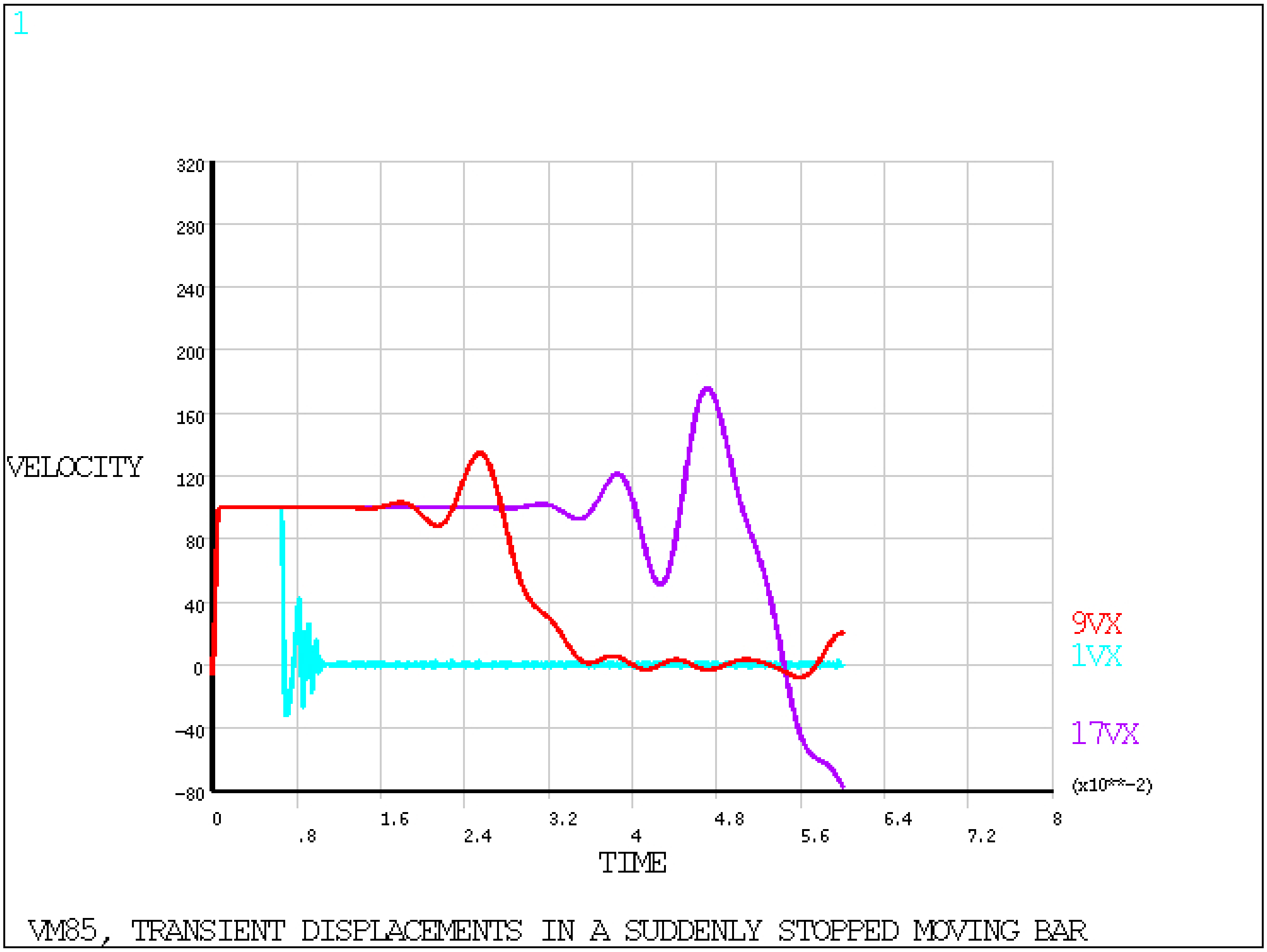


Figure 85.3: Velocities at Center and Ends of Bar



VM86: Harmonic Response of a Dynamic System

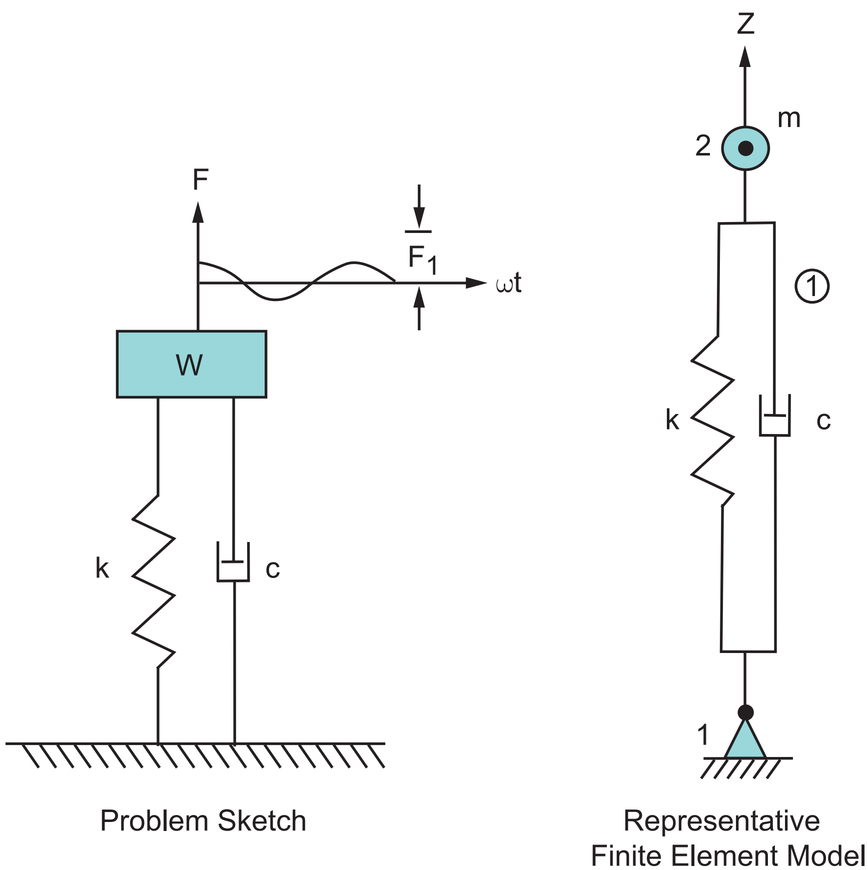
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 56, ex. 3.1-2.
Analysis Type(s):	Harmonic Analysis (**ANTYPE** = 3)
Element Type(s):	Combination Elements (COMBIN40)
Input Listing:	vm86.dat

Test Case

A machine of weight W is supported on springs of total stiffness k. If a harmonic disturbing force of magnitude F_1 and frequency f (equal to the natural frequency of the machine, f_n) acts on the machine, determine the displacement response in terms of the peak amplitude A_o and phase angle Φ. Assume a viscous damping coefficient c.

Figure 86.1: Dynamic System Problem Sketch



Material Properties	Loading
W = 193 lb k = 200 lb/in c = 6 lb-sec/in	g = 386 in/sec^2 F_1 = 10 lb

Analysis Assumptions and Modeling Notes

The mass of the machine is m = W/g = 0.5 lb-sec^2/in. Hence the frequency of the disturbing force (f) becomes f = f_n = sqrt(k/m)/2π = 3.1831 Hz. The node locations are arbitrarily selected.

Results Comparison

	Target	Mechanical APDL	Ratio
A_o, in	0.0833	0.0833	1.000
angle, deg	-90.0	-90.0	1.000

VM87: Equivalent Structural Damping

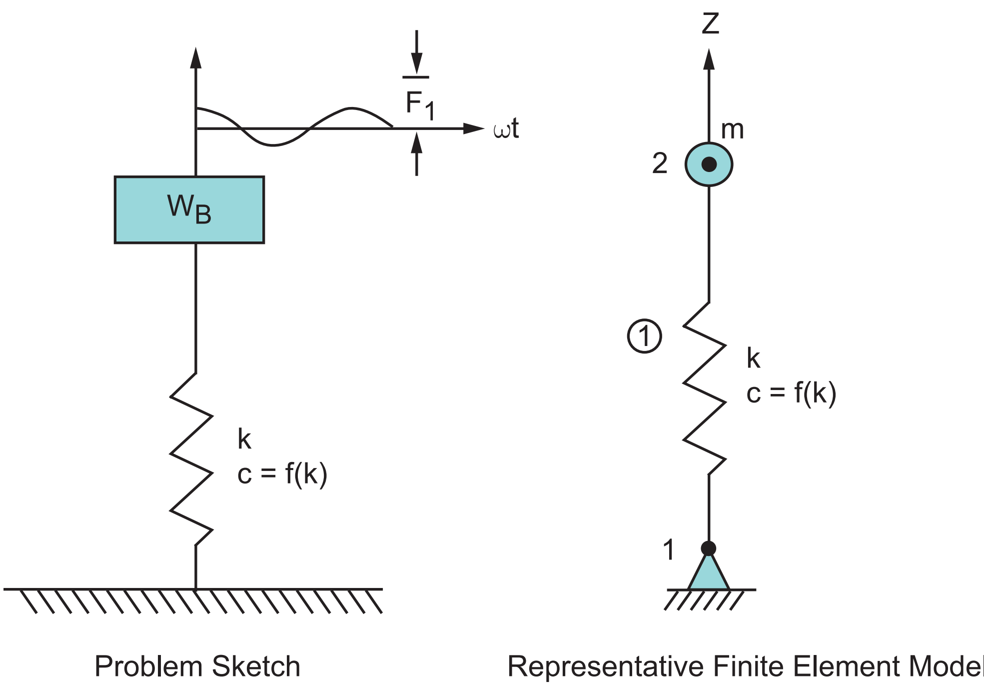
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 72, article 3.9 and pg. 56, ex. 3.1-2.
Analysis Type(s):	Harmonic Analysis (**ANTYPE** = 3)
Element Type(s):	Combination Elements (COMBIN40)
Input Listing:	vm87.dat

Test Case

Test case description is the same as that for VM86 except for the assumption on damping. Assume that all damping is in the form of equivalent structural damping and there is no element damping.

Figure 87.1: Structural Damping Problem Sketch



Analysis Assumptions and Modeling Notes

The structural damping factor is $\gamma = 2\ \xi\ \omega/\omega_n$ where ξ is the damping ratio and is equal to $c/2m\ \omega_n$. Therefore, $\gamma = c/(m\ \omega_n) = 6/(0.5 \times 20) = 0.6$ since $\omega = \omega_n$. The frequency-dependent multiplier β is calculated as $\beta = 2\ \xi/\omega_n = \gamma/\omega = 0.6/20 = 0.03$ seconds. The node locations are arbitrarily selected.

Results Comparison

	Target	Mechanical APDL	Ratio
Amp, in	0.083333	0.083333	1.000

	Target	Mechanical APDL	Ratio
angle, deg	-90.000	-90.000	1.000

VM88: Response of an Eccentric Weight Exciter

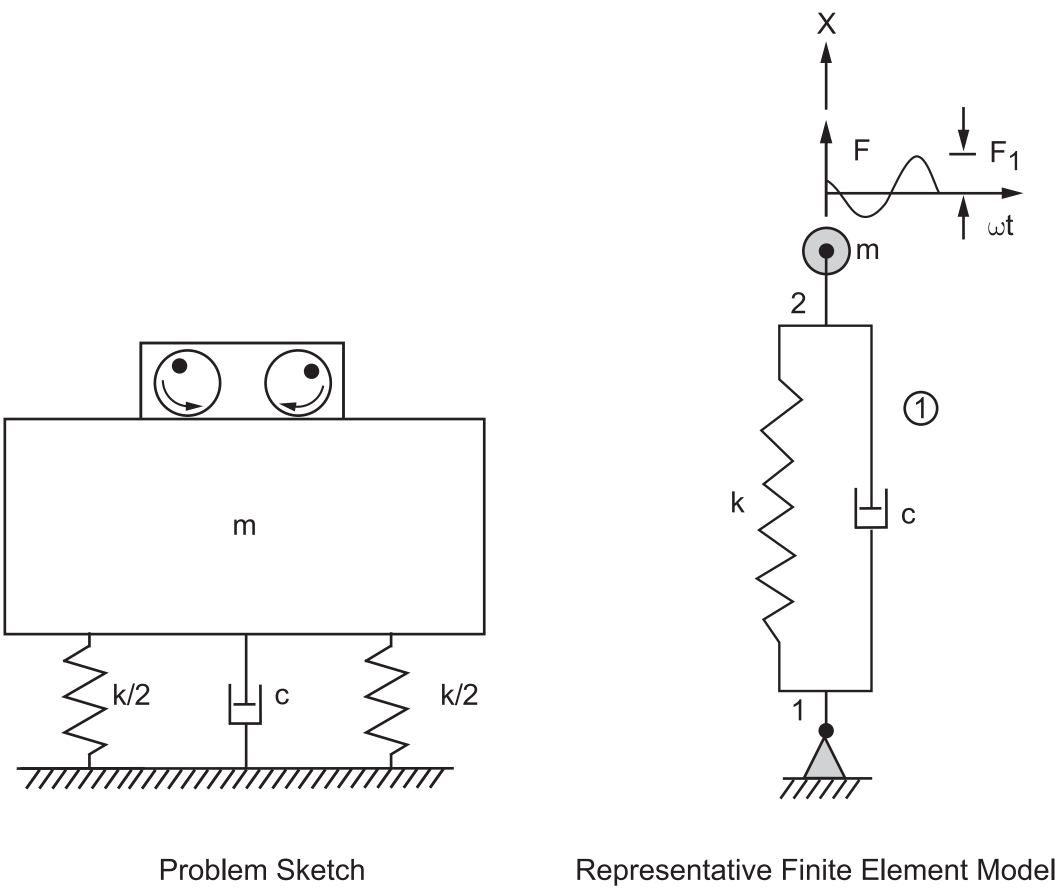
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 60, ex. 3.3-1.
Analysis Type(s):	Harmonic Analysis (**ANTYPE** = 3)
Element Type(s):	Combination Elements (COMBIN40)
Input Listing:	vm88.dat

Test Case

A counter-rotating eccentric weight exciter of mass m having a mass unbalance m_u on an eccentricity e is used to produce forced oscillation of a spring-supported mass. For a viscous damping factor c, determine the amplitude and phase angle Φ of the displacement response when the rotating frequency f is (1) the resonant frequency f_n, and (2) f >> f_n.

Figure 88.1: Eccentric Weight Exciter Problem Sketch



Material Properties
m = 0.02590673 lb-sec^2/in

Material Properties
$c = 0.11754533$ lb-sec/in $m_u = 0.08 \times m$ $k = 30$ lb/in

Analysis Assumptions and Modeling Notes

The node locations are arbitrarily selected. When the rotating frequency f is equal to the resonant frequency f_n, the force $F_1 = m_u\omega^2 = 2.4$ lb where $\omega = \omega_n = \text{sqrt}(k/m) = 34.0294$ rad/sec is the resonant circular frequency. When f >> f_n, it is assumed that f = 100 f_n = 541.5947 Hz and the corresponding force F_1 = 24000 lb.

Results Comparison

		Target	Mechanical APDL	Ratio
$f = f_n$	Amp, in	0.60000	0.60000	1.000
	angle, deg	-90.000	-90.000	1.000
$f = 100\ f_n$	Amp, in	0.080000[1]	0.080008	1.000
	angle, deg	-180.00	-179.92	1.000

1. Based on f = ∞

VM89: Natural Frequencies of a Two-mass-spring System

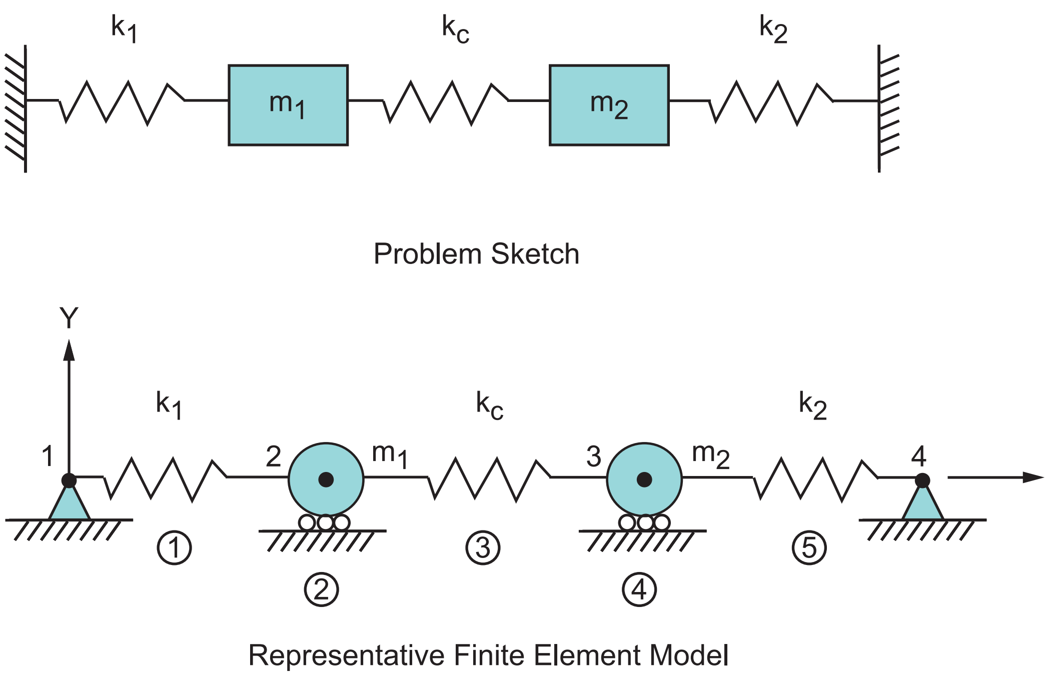
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 163, ex. 6.2-2.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	Spring-Damper Elements (COMBIN14) Structural Mass Elements (MASS21)
Input Listing:	vm89.dat

Test Case

Determine the normal modes and natural frequencies of the system shown below for the values of the masses and spring stiffnesses given.

Figure 89.1: Two-mass-spring System Problem Sketch



Material Properties
$m_2 = 2m_1 = 1.0$ lb-sec^2/in $k_2 = k_1 = 200$ lb/in $k_c = 4k_1 = 800$ lb/in

Analysis Assumptions and Modeling Notes

The spring lengths are arbitrarily selected and are used only to define the spring direction. Modal analysis is performed using Block-Lanczos eigensolver.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
f_1, Hz	2.5814	2.5814	1.000
f_2, Hz	8.3263	8.3263	1.000
$(A1/A2)_1$[2]	0.9212	0.9212	1.000
$(A1/A2)_2$[2]	-2.1711	-2.1712	1.000

1. Solution Recalculated

2. Normal Modes (UX of node 2 / UX of node 3)

VM90: Harmonic Response of a Two-Mass-Spring System

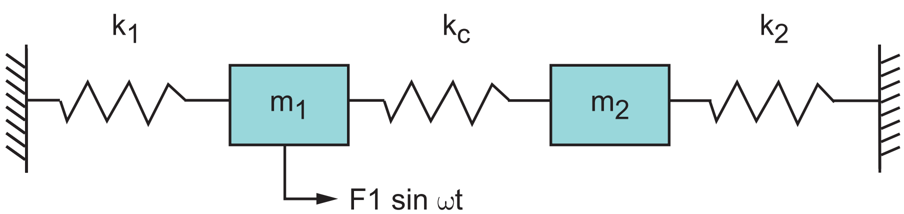
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 178, ex. 6.6-1.
Analysis Type(s):	Harmonic Analysis (**ANTYPE** = 3)
Element Type(s):	Spring-Damper Elements (COMBIN14) Structural Mass Elements (MASS21)
Input Listing:	vm90.dat

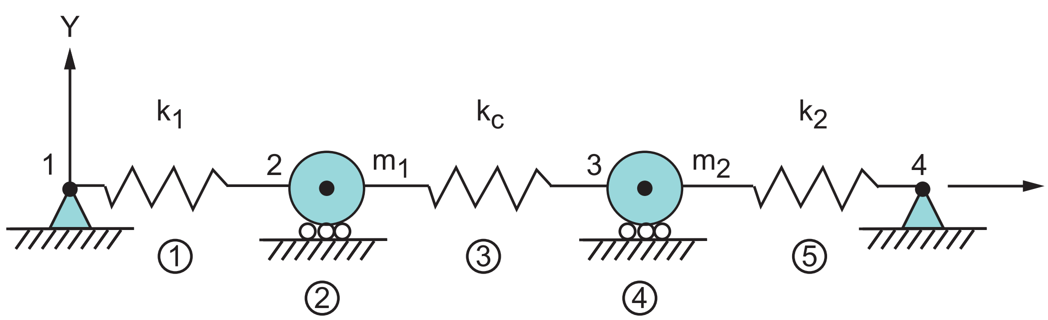
Test Case

Determine the response amplitude (X_i) and phase angle (Φ_i) for each mass (m_i) of the system in Figure 90.1: Two-Mass-Spring System Problem Sketch (p. 245) when excited by a harmonic force ($F_1 \sin \omega t$) acting on mass m_1.

Figure 90.1: Two-Mass-Spring System Problem Sketch



Problem Sketch



Representative Finite Element Model

Material Properties	Loading
$m_1 = m_2 = 0.5$ lb-sec^2/in $k_1 = k_2 = k_c = 200$ lb/in	$F_1 = 200$ lb

Analysis Assumptions and Modeling Notes

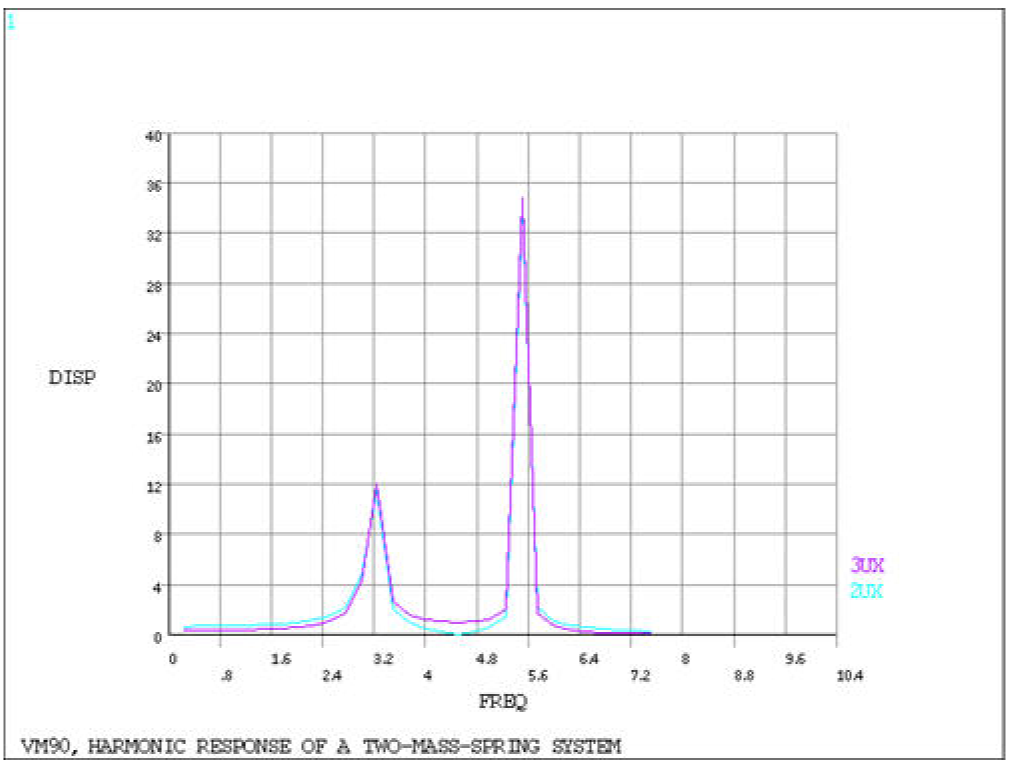
The spring lengths are arbitrarily selected and are used only to define the spring direction. A frequency range from zero to 7.5 Hz with a solution at 7.5/30 = 0.25 Hz intervals is chosen to give an adequate response curve. POST26 is used to get amplitude versus frequency display.

Results Comparison

	Target	Mechanical APDL	Ratio
X_1 , in (f = 1.5 Hz)[1]	0.82272	0.82272	1.000
$Angle_1$, deg (f = 1.5 Hz)	0.0000	0.0000	-
X_2 , in (f = 1.5 Hz)[1]	0.46274	0.46274	1.000
$Angle_2$, deg (f = 1.5 Hz)	0.000	0.0000	-
X_1 , in (f = 4.0 Hz)	0.51145	0.51146	1.000
$Angle_1$, deg (f = 4.0 Hz)	180.00	180.00	1.000
X_2 , in (f = 4.0 Hz)	1.2153	1.2153	1.000
$Angle_2$, deg (f = 4.0 Hz)	180.00	180.00	1.000
X_1 , in (f = 6.5 Hz)	0.58513	0.58512	1.000
$Angle_1$, deg (f = 6.5 Hz)	180.00	180.00	1.000
X_2 , in (f = 6.5 Hz)	0.26966	0.26965	1.000
$Angle_2$, deg (f = 6.5 Hz)	0.0000	0.0000	-

1. X_1 = UX @ m_1 (node 2) X_2 = UX @ m_2 (node 3)

Figure 90.2: Amplitude vs. Frequency



VM91: Large Rotation of a Swinging Pendulum

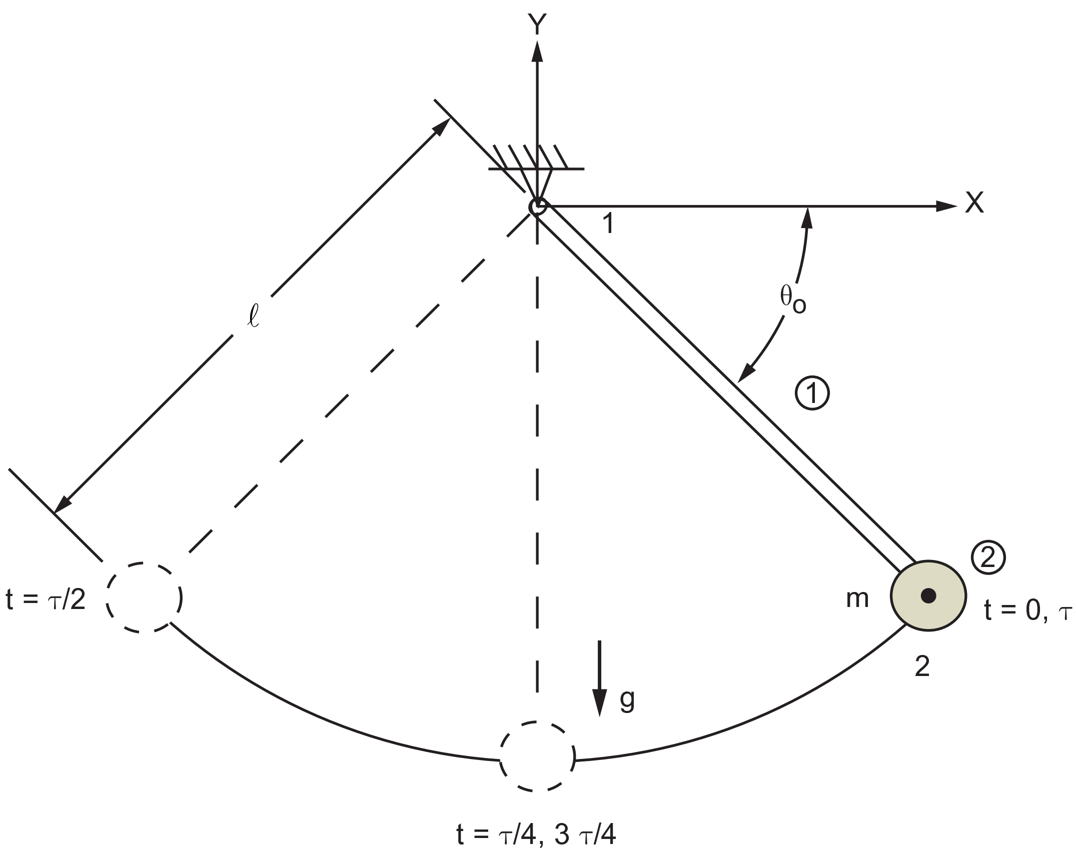
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pg. 138, ex. 5.4-1.
Analysis Type(s):	Full Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	3-D Spar (or Truss) Elements (LINK180) Structural Mass Element (MASS21)
Input Listing:	vm91.dat

Test Case

A pendulum consists of a mass m supported by a rod of length ℓ and cross-sectional area A. Determine the motion of the pendulum in terms of the displacement of the mass from its initial position Θ_o in the x and y directions, δ_x and δ_y, respectively. The pendulum starts with zero initial velocity.

Figure 91.1: Pendulum Swing Problem Sketch



Problem Model

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi	ℓ = 100 in	$g = 386$ in/sec^2

Material Properties	Geometric Properties	Loading
m = 0.5 lb-sec^2/in	Θ_o = 53.135 A = 0.1 in^2	

Analysis Assumptions and Modeling Notes

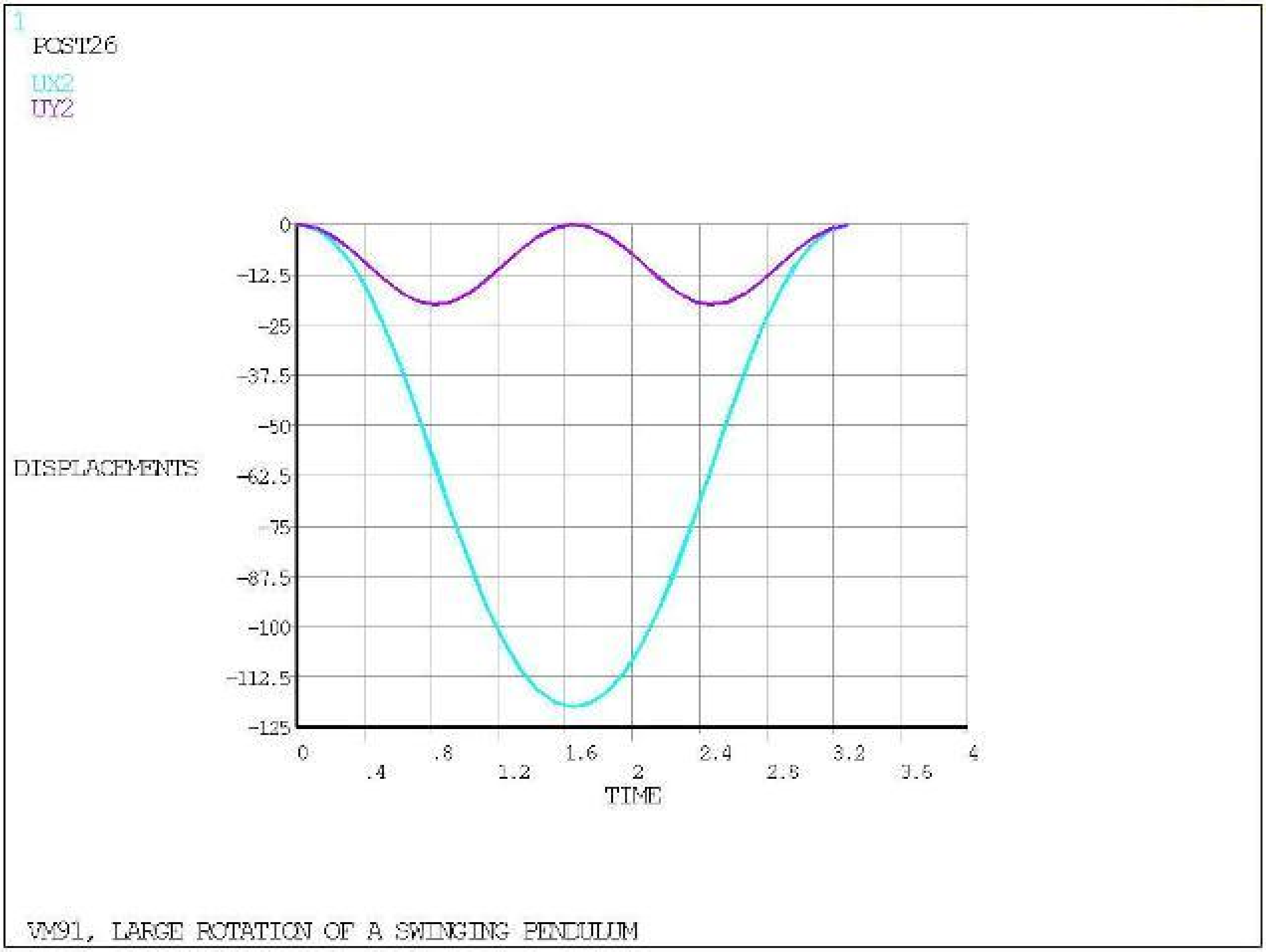
A large deflection solution is required. An initial time step is defined over a small time increment (.01/5 = .002 sec) to allow an initial step change in acceleration to be attained. Subsequent integration time steps (1.64142/8 = .205 sec) are based on $\approx$ 1/24 of the period to allow the initial step change in acceleration to be followed reasonably well.

Several load steps are defined for clearer comparison with theoretical results. POST26 is used to process results from the solution phase.

Results Comparison

	Target	Mechanical APDL	Ratio
Deflection$_x$, in(t=period/4)	-60.000	-59.3738	0.990
Deflection$_y$, in(t=period/4)	-20.000	-20.0040	1.000
Deflection$_x$, in(t=period/2)	-120.00	-119.9106	0.999
Deflection$_y$, in(t=period/2)	0.0000	-0.0662	0.000
Deflection$_x$, in(t=3period/4)	-60.000	-61.8834	1.031
Deflection$_y$, in(t=3period/4)	-20.000	-19.9897	0.999
Deflection$_x$, in(t=period)	0.0000	-0.2302	0.000
Deflection$_y$, in(t=period)	0.0000	-0.1824	0.000

Figure 91.2: Pendulum Swing



VM92: Insulated Wall Temperature

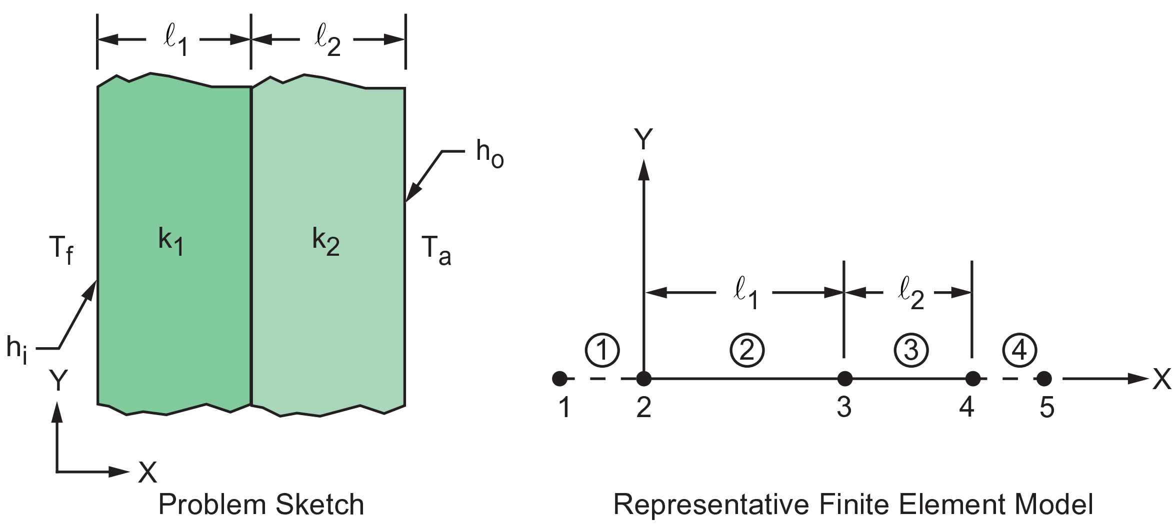
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 32, ex. 2-5.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	Convection Link Elements (LINK34) 3-D Conduction Bar Elements (LINK33)
Input Listing:	vm92.dat

Test Case

A furnace wall consists of two layers, firebrick and insulating brick. The temperature inside the furnace is T_f and the inner surface convection coefficient is h_i. The ambient temperature is T_a and the outer surface convection coefficient is h_o. Neglect the thermal resistance of the mortar joints and determine the rate of heat loss through the wall q, the inner surface temperature T_i, and the outer surface temperature T_o.

Figure 92.1: Insulated Wall Temperature Problem Sketch



Material Properties	Geometric Properties	Loading
k_1 = 0.8 Btu/hr-ft-°F k_2 = 0.1 Btu/hr-ft-°F h_i = 12 Btu/hr-ft^2-°F h_o = 2 Btu/hr-ft^2-°F	ℓ_1 = 9 in = 0.75 ft ℓ_2 = 5 in = 5/12 ft	T_f = 3000°F T_a = 80°F

Analysis Assumptions and Modeling Notes

A 1 ft^2 area is used for the convection and conduction elements. Nodes 1 and 5 are given arbitrary locations. Feet units are input as (inches/12) for convenience. POST1 is used to extract results from the solution phase.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
q, Btu/hr	513.	513.	1.001
T_i , °F	2957.	2957.	1.000
T_o , °F	336.	337.	1.002

1. Rounded-off values (normalized)

VM93: Temperature Dependent Conductivity

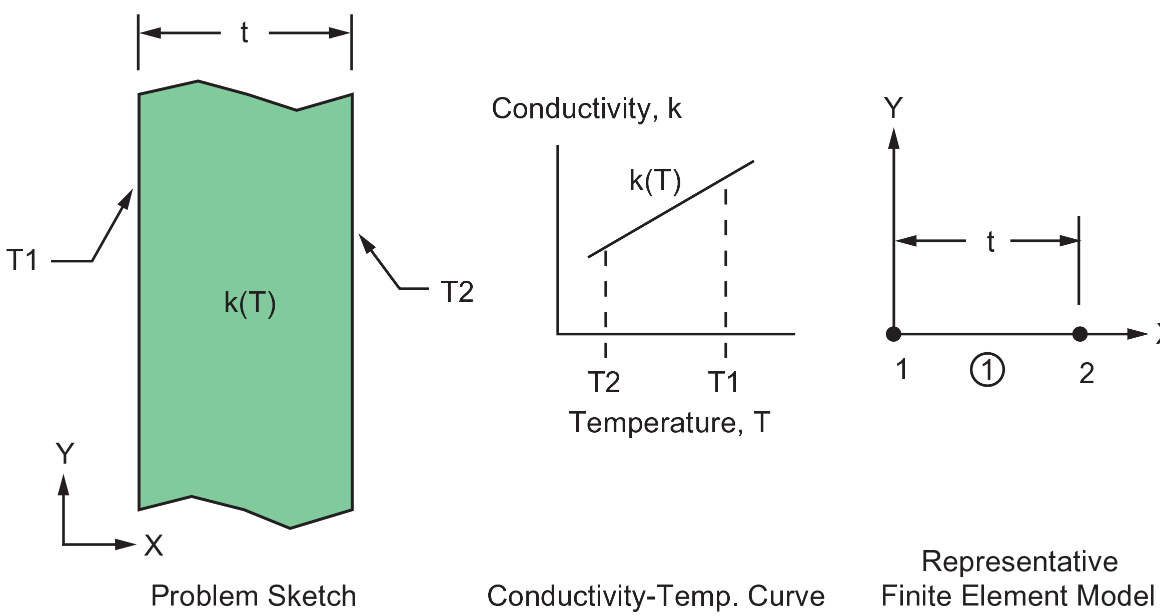
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 25, ex. 2-2
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Conduction Bar Elements (LINK33)
Input Listing:	vm93.dat

Test Case

The conductivity of an 85% magnesia insulating material is given by $k(T) = C_0 + C_1 T$ for $100°F \leq T \leq 300°F$. Determine the rate of heat flow q between these temperatures for a slab of thickness t.

Figure 93.1: Conductivity Problem Sketch



Material Properties	Geometric Properties	Loading
C_0 = 0.031 Btu/hr-ft-°F C_1 = 0.000031 Btu/hr-ft-°F^2	t = 3 in = 0.25 ft	T_1 = 300°F T_2 = 100°F

Analysis Assumptions and Modeling Notes

A 1 ft^2 area is used for the conduction element.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
q, Btu/hr	29.760	29.760	1.000

1. Solution recalculated.

VM94: Heat-generating Plate

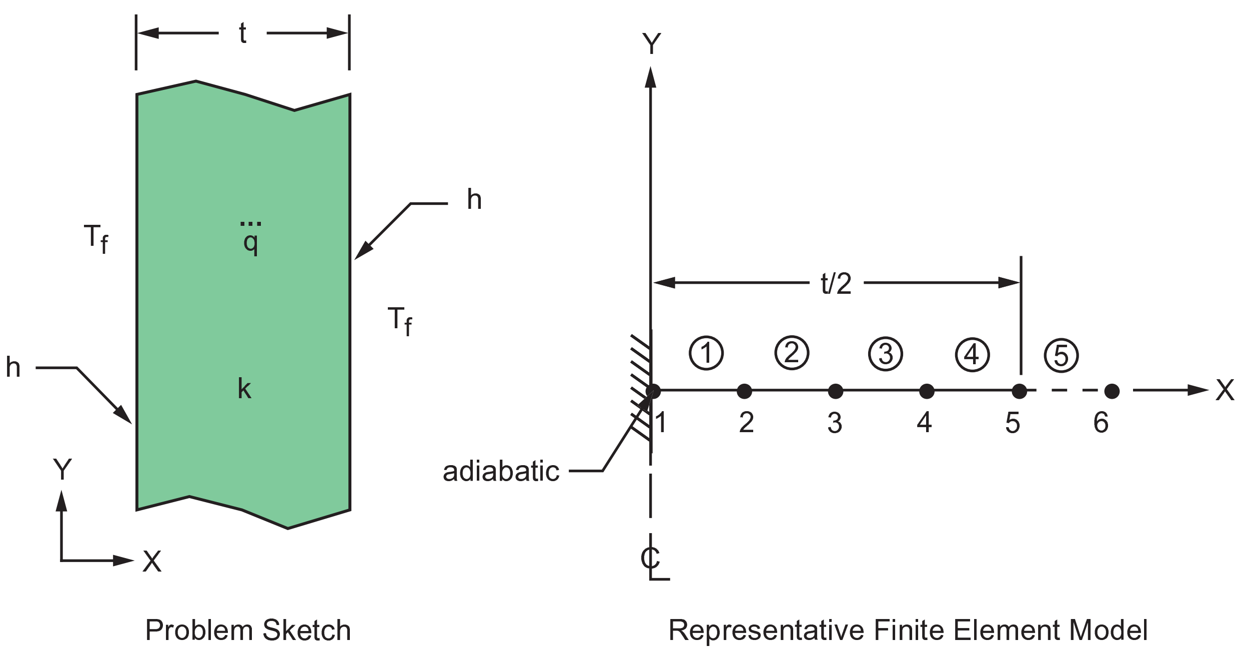
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 42, ex. 2-9.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Conduction Bar Elements (LINK33) Convection Link Elements (LINK34)
Input Listing:	vm94.dat

Test Case

A well-mixed fluid is heated by a long iron plate of conductivity k and thickness t. Heat is generated uniformly in the plate at the rate $\dddot{q}$. If the surface convection coefficient is h and the fluid temperature is T_f, determine the temperature at the center of the plate T_c and the heat flow rate to the fluid q_f.

Figure 94.1: Plate Problem Sketch



Material Properties	Geometric Properties	Loading
k = 25 Btu/hr-ft-°F h = 13.969738 Btu/hr-ft^2-°F	t = 1/2 in = 0.041666 ft	$\dddot{q}$ = 100,000 Btu/hr-ft^3 T_f = 150°F

Analysis Assumptions and Modeling Notes

A 1 ft^2 area is used for the conduction and convection elements. Only one half of the plate is modeled because of symmetry. Node 6 is given an arbitrary location. POST1 is used to process results from the solution phase.

Results Comparison

	Target	**Mechanical APDL**	**Ratio**
q_f,Btu/hr	2083.3	2083.3	1.000
T_c, °F	299.1	300.0	1.003

VM95: Heat Transfer from a Cooling Spine

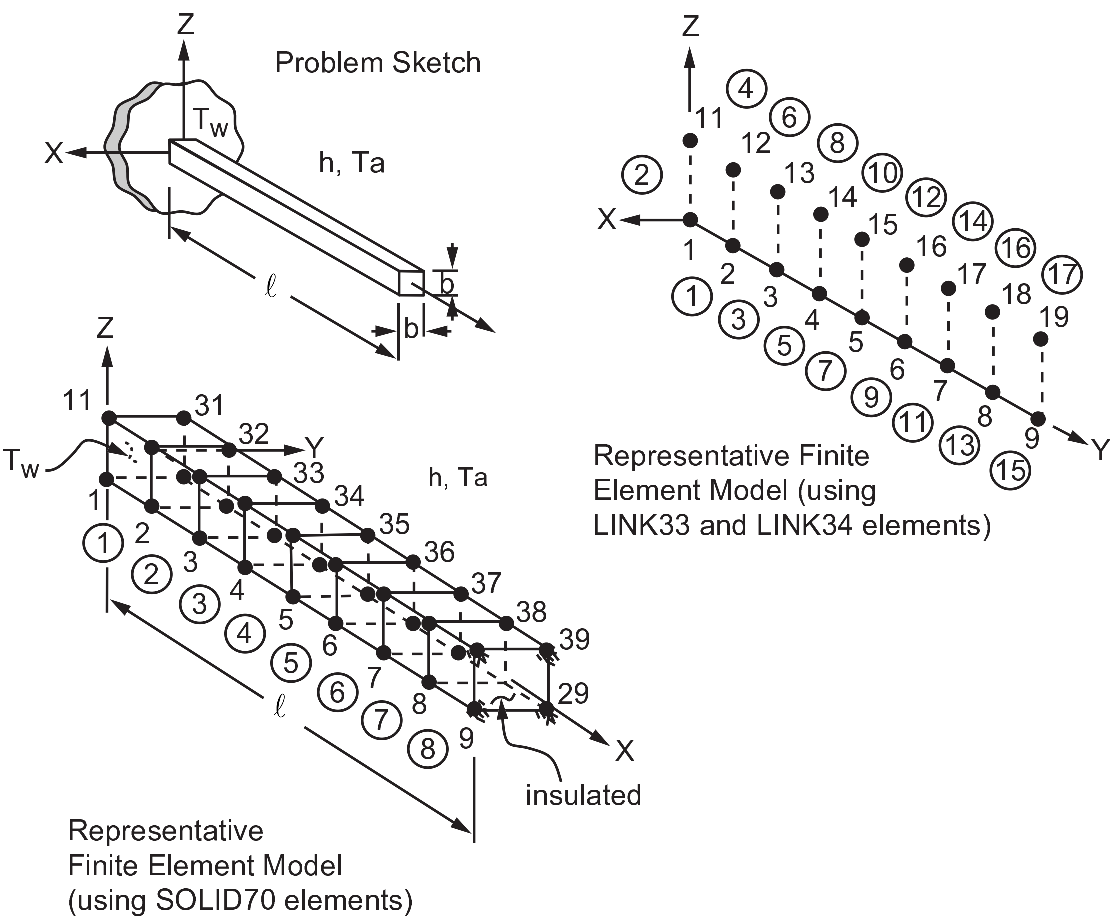
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 48, eq. 2-44, 45.
Analysis Type(s):	Heat Transfer Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Conduction Bar Elements (LINK33) Convection Link Elements (LINK34) 3-D Thermal Solid Elements (SOLID70)
Input Listing:	vm95.dat

Test Case

A cooling spine of square cross-sectional area A, length ℓ, and conductivity k extends from a wall maintained at temperature T_w. The surface convection coefficient between the spine and the surrounding air is h, the air temperature is T_a, and the tip of the spine is insulated. Determine the heat conducted by the spine q and the temperature of the tip T_ℓ.

Figure 95.1: Cooling Spine Problem Sketch



Material Properties	Geometric Properties	Loading
$k = 25$ Btu/hr-ft-°F $h = 1$ Btu/hr-ft^2-°F	$A = 1$ in^2 = (1/144) ft^2 ℓ = 8 in = (2/3) ft b = 1 in = (1/12) ft	T_a = 0°F T_w = 100°F

Analysis Assumptions and Modeling Notes

The problem is solved first using conducting line elements (LINK33) and convection elements (LINK34) and then using conducting solid elements (SOLID70). The surface convection area is 4 in^2 (4/144 ft^2) per inch of length.

In the first case, the convection elements at the end are given half the surface area of the interior convection elements. Nodes 11 through 19 are given arbitrary locations.

In the second case, coupled nodal temperatures are used to ensure symmetry.

Unit conversions are done by input expressions. POST1 is used to process results from the solution phase.

Results Comparison

		Target	Mechanical APDL	Ratio
LINK33 and LINK34	T_{length}, °F	68.594	68.618	1.000
	q, Btu/hr	17.504	17.528	1.001
SOLID70	T_{length}, °F	68.594	68.618	1.000
	q, Btu/hr	17.504	17.528	1.001

VM96: Temperature Distribution in a Short, Solid Cylinder

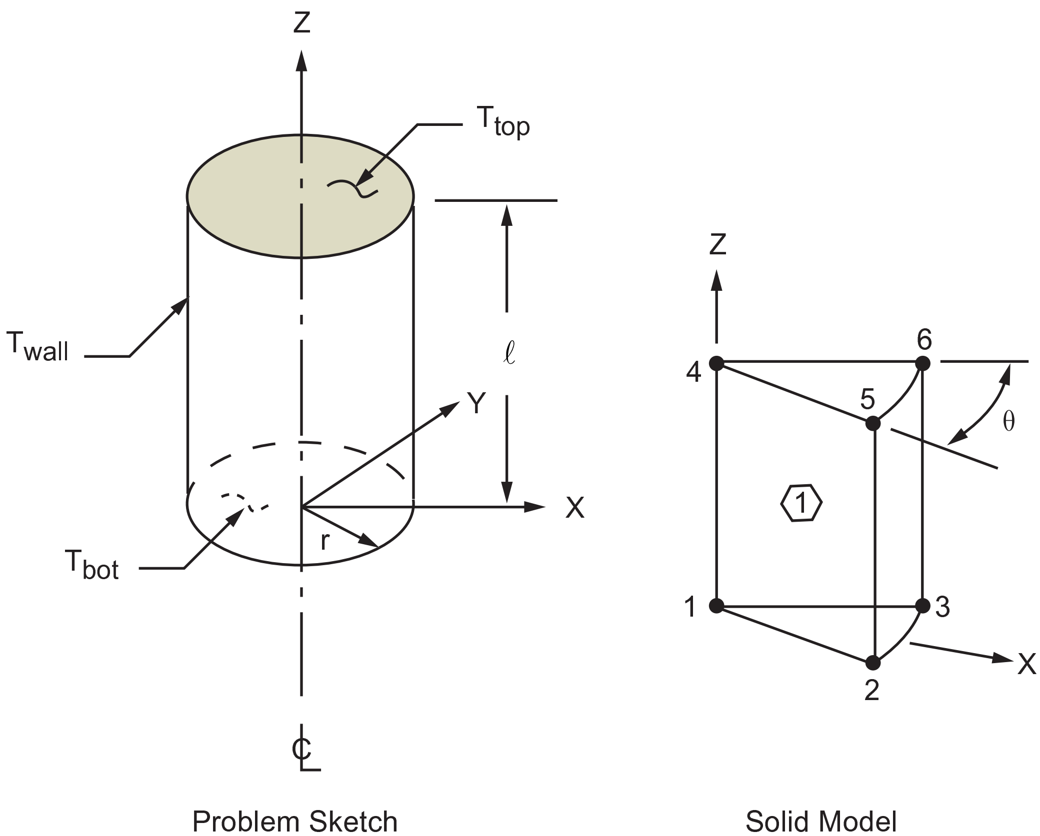
Overview

Reference:	P. J. Schneider, *Conduction Heat Transfer*, 2nd Printing, Addison-Wesley Publishing Co., Inc., Reading, MA, 1957, pg. 134, fig. 6-7.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 10-Node Tetrahedral Thermal Solid Elements (SOLID87)
Input Listing:	vm96.dat

Test Case

A short, solid cylinder is subjected to the surface temperatures shown. Determine the temperature distribution within the cylinder

Figure 96.1: Short, Solid Cylinder Problem Sketch



Material Properties	Geometric Properties	Loading
k = 1.0 Btu/hr-ft-°F	$r = \ell = 0.5$ ft	$T_{top} = 40°F$ $T_{bot} = T_{wall} = 0°F$

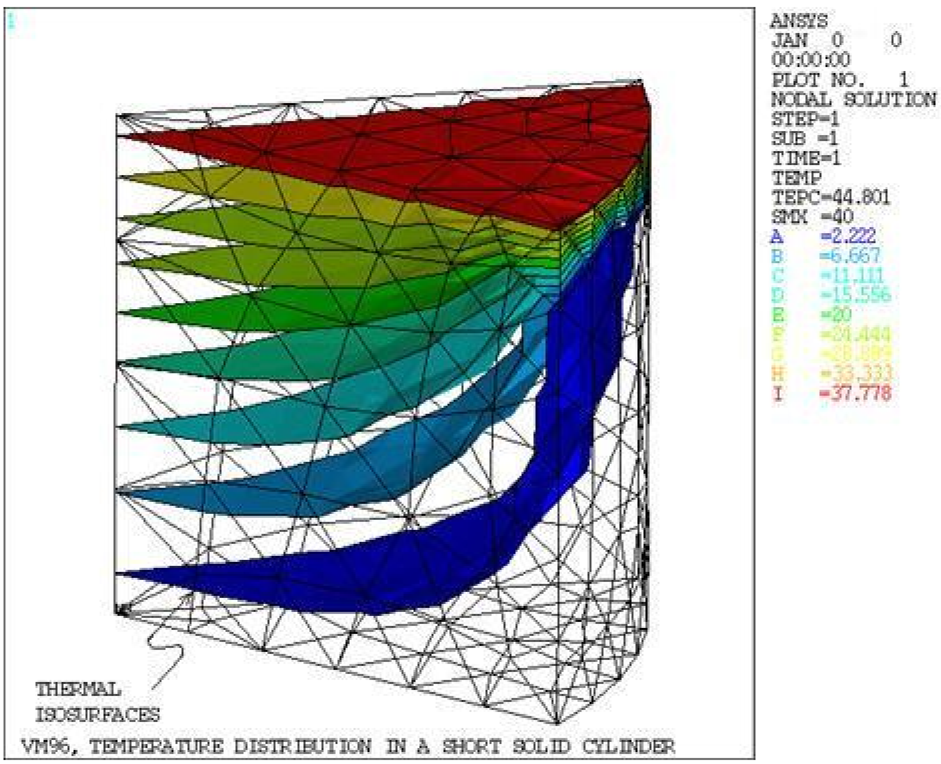
Analysis Assumptions and Modeling Notes

Since the problem is axisymmetric, the entire cylinder geometry is not required. An angle Θ = 45° is arbitrarily chosen. Postprocessing is used to print temperatures at the centerline in geometric order. A finer mesh density (than required for reasonable results) is used to produce a smooth isosurface plot.

Results Comparison

At Centerline		Target	Mechanical APDL	Ratio
z = 0.0 ft	T, °F	0.0	0.0	--
z = 0.125 ft	T, °F	6.8	6.8	1.007
z = 0.25 ft	T, °F	15.6	15.4	0.985
z = 0.375 ft	T, °F	26.8	26.6	0.991
z = 0.5 ft	T, °F	40.0	40.0	1.00

Figure 96.2: Temperature Isosurface Display with Annotation



VM97: Temperature Distribution Along a Straight Fin

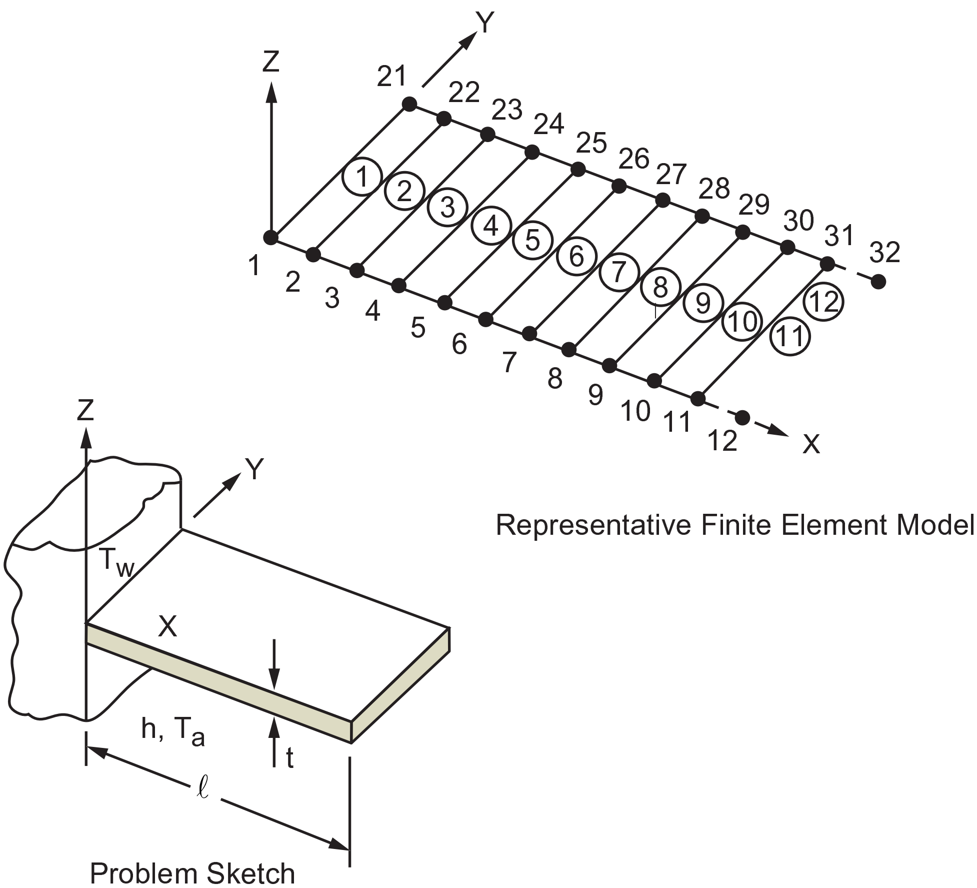
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 57, ex. 2-13.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	4-Node Layered Thermal Shell Elements (SHELL131) Convection Link Elements (LINK34)
Input Listing:	vm97.dat

Test Case

A straight rectangular stainless steel cooling fin dissipates heat from an air-cooled cylinder wall. The wall temperature is T_w, the air temperature is T_a, and the convection coefficient between the fin and the air is h. Determine the temperature distribution along the fin and the heat dissipation rate q.

Figure 97.1: Straight Fin Problem Sketch



Material Properties	Geometric Properties	Loading
k = 15 Btu/hr-ft-°F h = 15 Btu/hr-ft^2-°F	t = 1 in = (1/12 ft) ℓ = 4 in = (4/12) ft	T_w = 1100°F T_a = 100°F

Analysis Assumptions and Modeling Notes

Convection from the tip of the fin is modeled with the two convection elements (LINK34). One half of the cross-sectional area is assigned to each element. The depth of the fin (Y-direction) is arbitrarily selected to be 1 foot. POST1 is used to extract results from the solution phase.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
T, °F (at x/length = 0.0)	1100.	1100.	1.000
T, °F (at x/length = 0.1)	955.	958.	1.00
T, °F (at x/length = 0.2)	835.	838.	1.00
T, °F (at x/length = 0.3)	740.	738.	1.00
T, °F (at x/length = 0.4)	660.	655.	0.99
T, °F (at x/length = 0.5)	595.	587.	0.99
T, °F (at x/length = 0.6)	535.	532.	1.00
T, °F (at x/length = 0.7)	490.	489.	1.00
T, °F (at x/length = 0.8)	460.	456.	0.99
T, °F (at x/length = 0.9)	430.	432.	1.01
T, °F (at x/length = 1.0)	416.	417.	1.00
q, Btu/hr	5820.	5840.	1.00

1. Based on graphical readings

VM98: Temperature Distribution Along a Tapered Fin

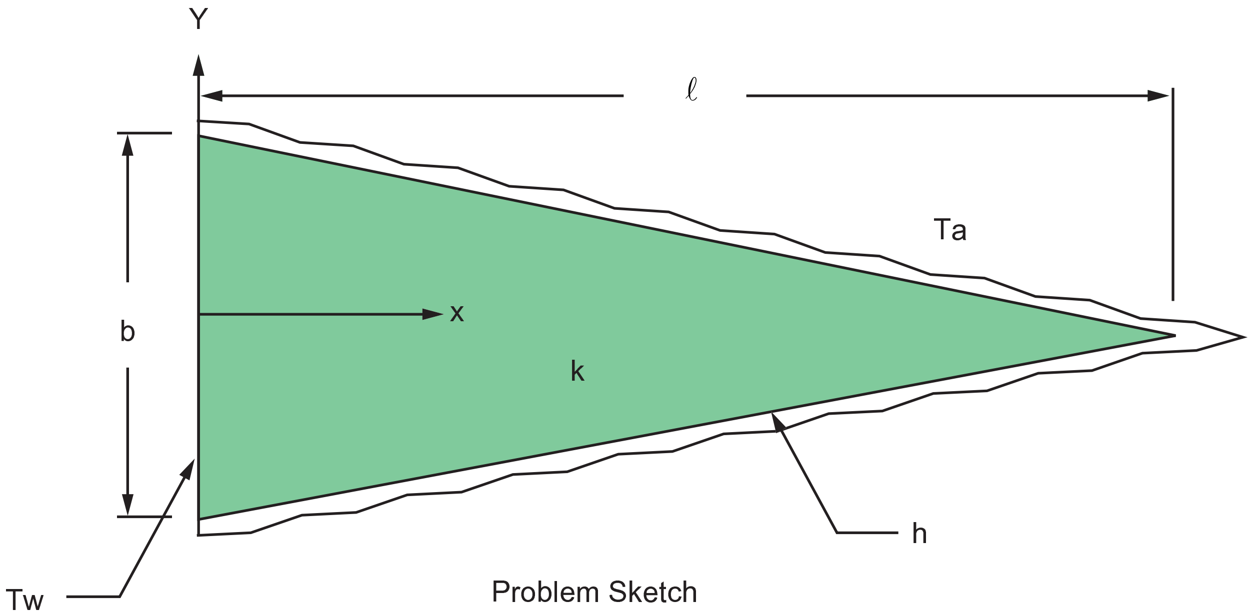
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 57, ex. 2-13.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Thermal Solid Elements (PLANE55)
Input Listing:	vm98.dat

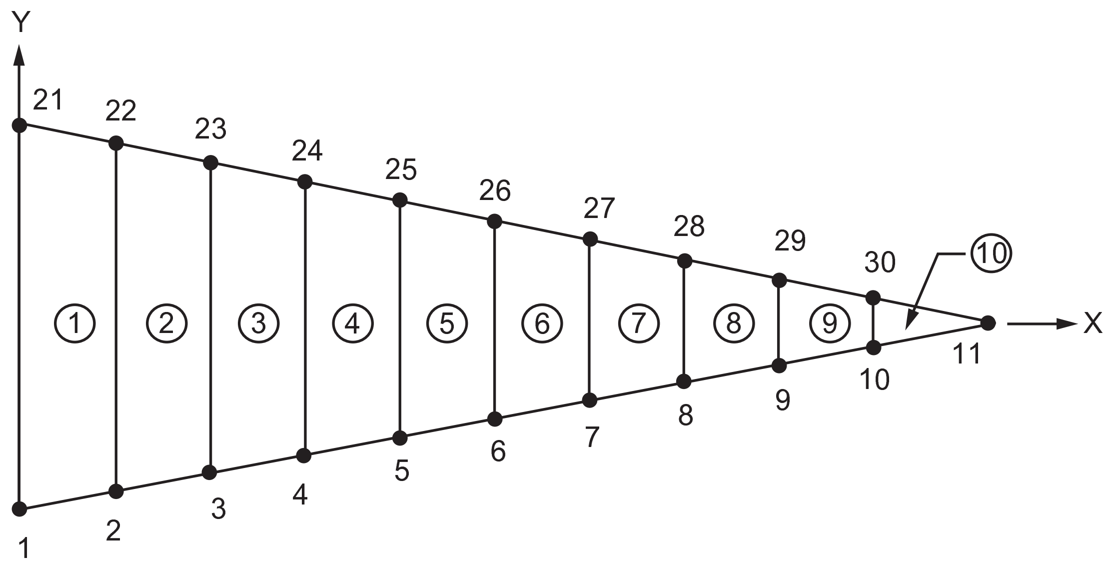
Test Case

A tapered rectangular stainless steel cooling fin dissipates heat from an air-cooled cylinder wall. The wall temperature is T_w, the air temperature is T_a, and the convection coefficient between the fin and the air is h. Determine the temperature distribution along the fin and the heat dissipation rate q.

Figure 98.1: Tapered Fin Problem Sketch



Problem Sketch



Representative Finite Element Model

Material Properties	Geometric Properties	Loading
k = 15 Btu/hr-ft-°F h = 15 Btu/hr-ft^2-°F	b = 1 in = (1/12) ft ℓ = 4 in = (4/12) ft	T_w = 1100°F T_a = 100°F

Analysis Assumptions and Modeling Notes

The solution is based on a fin of unit depth (Z-direction). POST1 is used to extract results from the solution phase.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
T, °F (at x/length = 0.0)	1100.	1100.	1.000
T, °F (at x/length = 0.1)	970.	971.	1.001
T, °F (at x/length = 0.2)	850.	854.	1.004
T, °F (at x/length = 0.3)	750.	748.	0.998
T, °F (at x/length = 0.4)	655.	653.	0.997
T, °F (at x/length = 0.5)	575.	568.	0.988
T, °F (at x/length = 0.6)	495.	492.	0.994
T, °F (at x/length = 0.7)	430.	424.	0.987
T, °F (at x/length = 0.8)	370.	364.	0.984
T, °F (at x/length = 0.9)	315.	311.	0.988
T, °F (at x/length = 1.0)	265.	267.	1.006
q, Btu/hr	5050.	5109.	1.012

1. Based on graphical estimates.

VM99: Temperature Distribution in a Trapezoidal Fin

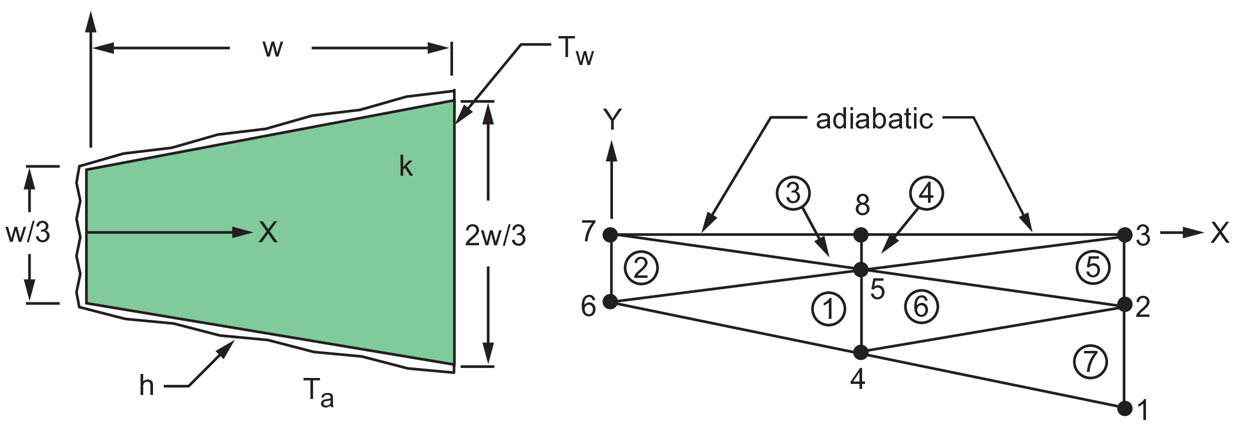
Overview

Reference:	P. J. Schneider, *Conduction Heat Transfer*, 2nd Printing, Addison-Wesley Publishing Co., Inc., Reading, MA, 1957, pg. 164, Article 7-8.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Thermal Solid Elements (PLANE55)
Input Listing:	vm99.dat

Test Case

A rectangular cooling fin with a trapezoidal cross-section dissipates heat from a wall maintained at a temperature T_w. The surrounding air temperature is T_a and the convection coefficient between the fin and the air is h. Determine the temperature distribution within the fin and the heat dissipation rate q.

Figure 99.1: Trapezoidal Fin Problem Sketch



Material Properties	Geometric Properties	Loading
k = 18 Btu/hr-ft-°F h = 500 Btu/hr-ft^2-°F	w = 0.96 in = 0.08 ft	T_w = 100°F T_a = 0°F

Analysis Assumptions and Modeling Notes

The finite element model is made the same as the reference's relaxation model for a direct comparison. The solution is based on a fin of unit depth (Z-direction). Only half of the fin is modeled due to symmetry. POST1 is used to extract results from the solution phase.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
T, °F (at Node 4)	27.6	27.8	1.01

	Target[1]	Mechanical APDL	Ratio
T, °F (at Node 5)	32.7	32.8	1.00
T, °F (at Node 6)	9.5	9.5	1.00
T, °F (at Node 7)	10.7	10.7	1.00
q, Btu/hr	3545.[2]	3482.	0.982

1. Based on a numerical relaxation method.

2. Solution recalculated.

VM100: Heat Conduction Across a Chimney Section

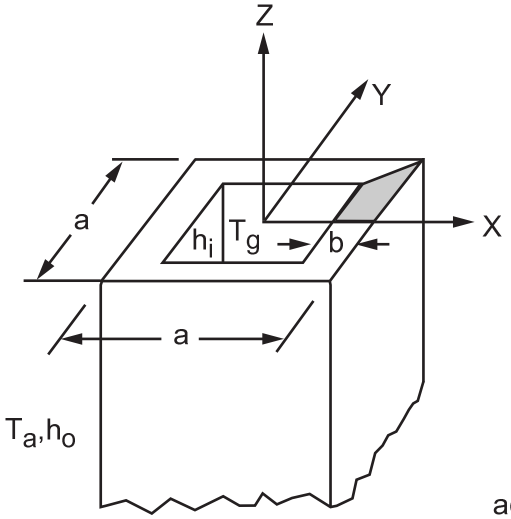
Overview

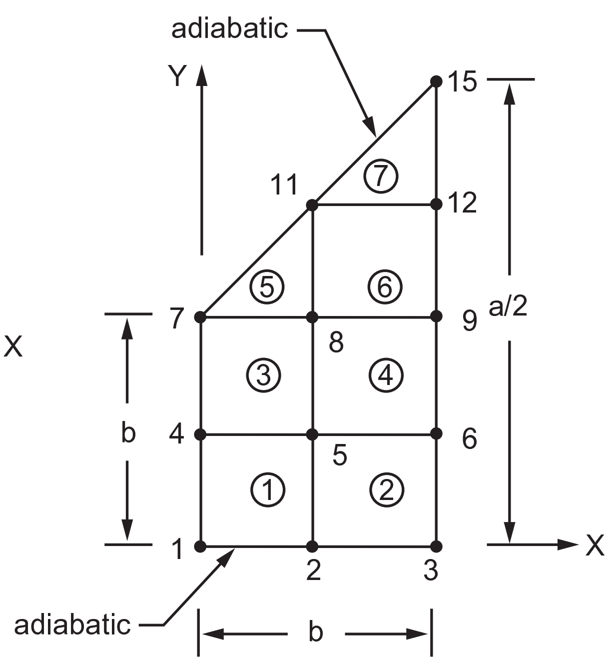
Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 102, ex. 3-4.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Thermal Solid Elements (PLANE55)
Input Listing:	vm100.dat

Test Case

Determine the temperature distribution and the rate of heat flow q per foot of height for a tall chimney whose cross-section is shown in Figure 100.1: Heat Conduction Across a Chimney Section Problem Sketch (p. 269). Assume that the inside gas temperature is T_g, the inside convection coefficient is h_i, the surrounding air temperature is T_a, and the outside convection coefficient is h_o.

Figure 100.1: Heat Conduction Across a Chimney Section Problem Sketch





Material Properties	Geometric Properties	Loading
k = 1.0 Btu/hr-ft-°F h_i = 12 Btu/hr-ft^2-°F h_o = 3 Btu/hr-ft^2-°F	a = 4 ft b = 1 ft	T_g = 100°F T_a = 0°F See Figure 100.2: Temperature Contour Display (p. 270).

Analysis Assumptions and Modeling Notes

Due to symmetry, a 1/8 section is used. The finite element model is made the same as the reference's relaxation model for a direct comparison. The solution is based on a fin of unit depth (Z-direction). POST1 is used to obtain results from the solution phase.

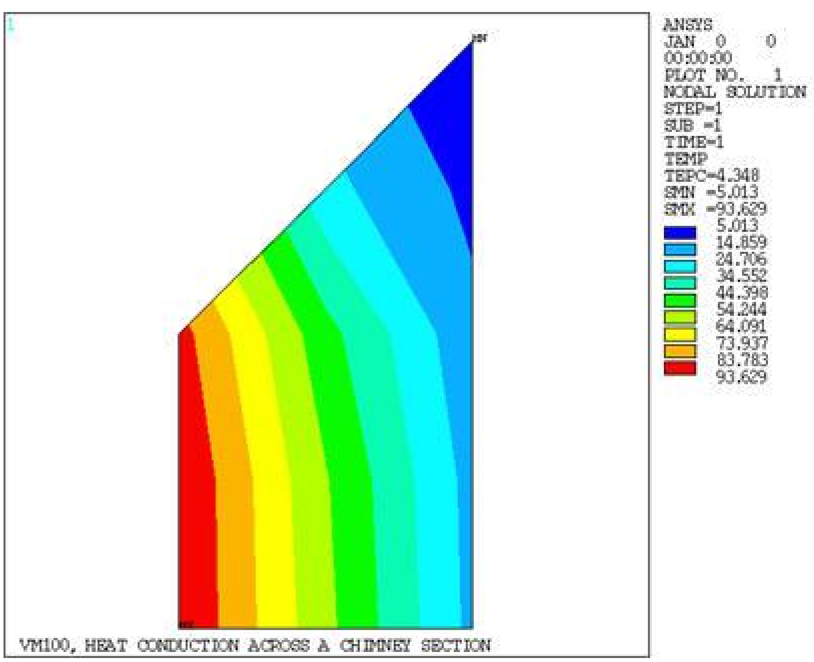
Results Comparison

	Target[1]	Mechanical APDL	Ratio
T, °F (at Node 1)	93.7	93.6	1.00
T, °F (at Node 2)	56.3	56.8	1.01
T, °F (at Node 3)	22.2	22.1	0.99
T, °F (at Node 4)	93.2	93.2	1.00
T, °F (at Node 5)	54.6	54.9	1.01
T, °F (at Node 6)	21.4	21.1	0.98
T, °F (at Node 7)	87.6	87.8	1.00
T, °F (at Node 8)	47.5	47.7	1.01
T, °F (at Node 9)	18.3	17.3	0.95
T, °F (at Node 11)	29.6	27.6	0.93
T, °F (at Node 12)	11.7	12.5	1.07
T, °F (at Node 15)	4.7	5.0	1.07
q, Btu/hr	775.2	773.5[2]	1.00

1. Based on a numerical relaxation method.

2. From heat rates at elements 1 and 3 multiplied by 8.

Figure 100.2: Temperature Contour Display



VM101: Temperature Distribution in a Short Solid Cylinder

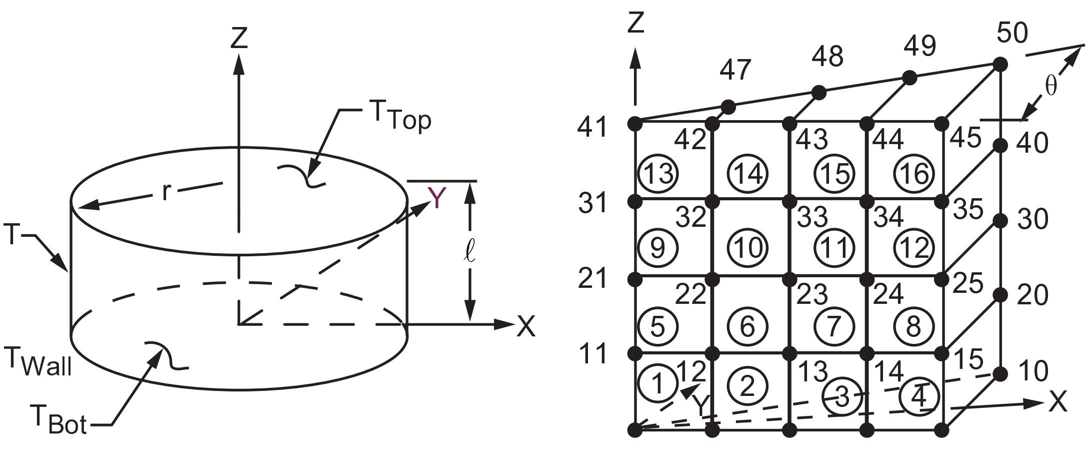
Overview

Reference:	P. J. Schneider, *Conduction Heat Transfer*, 2nd Printing, Addison-Wesley Publishing Co., Inc., Reading, MA, 1957, pg. 134, fig. 6-7.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Thermal Solid Elements (SOLID70)
Input Listing:	vm101.dat

Test Case

A short solid cylinder is subjected to the surface temperatures shown. Determine the temperature distribution within the cylinder.

Figure 101.1: Short Solid Cylinder Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
k = 1.0 Btu/hr-ft-°F	r = ℓ = 6 in = 0.5 ft	T_{Top} = 40°F T_{Bot} = T_{Wall} = 0°F

Analysis Assumptions and Modeling Notes

Since the problem is axisymmetric only a sector (one element wide) is modeled. A small angle Θ=10° is used for approximating the circular boundary with a straight-sided element. Note that circumferential symmetry is automatically ensured due to default adiabatic boundary conditions. POST1 is used to report centerline and mid-radius temperatures to compare results.

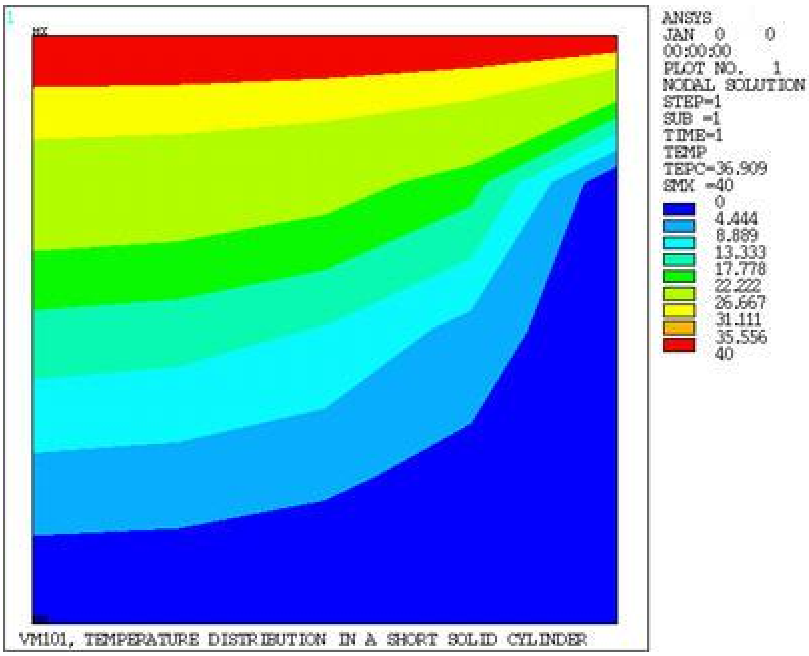
Results Comparison

		Target[1]	Mechanical APDL	Ratio
T, °F	Node 11	6.8	7.4	1.09

		Target[1]	Mechanical APDL	Ratio
(center-line)	Node 21	15.6	16.4	1.05
	Node 31	26.8	27.4	1.02
T, °F	Node 13	5.2	5.3	1.02
(mid-radius)	Node 23	12.8	13.0	1.02
	Node 33	24.0	24.8	1.03

1. Based on a graphical estimate.

Figure 101.2: Temperature Contour Display



VM102: Cylinder with Temperature Dependent Conductivity

Overview

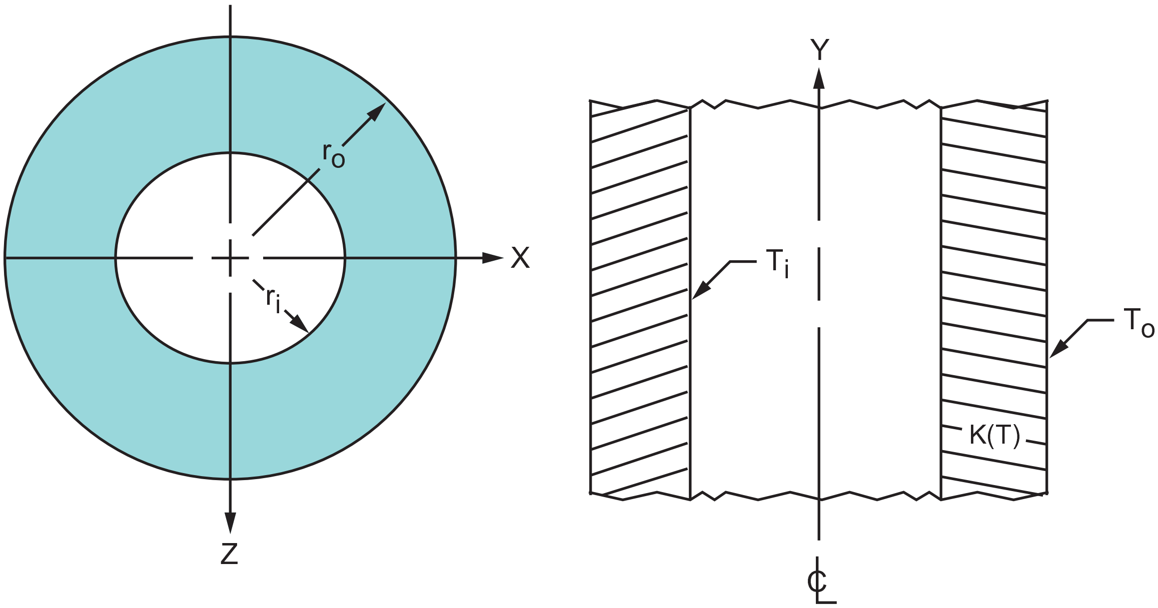
Reference:	P. J. Schneider, *Conduction Heat Transfer*, 2nd Printing, Addison-Wesley Publishing Co., Inc., Reading, MA, 1957, pg. 166, article 7-9.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Thermal Solid Elements (PLANE55)
Input Listing:	vm102.dat

Test Case

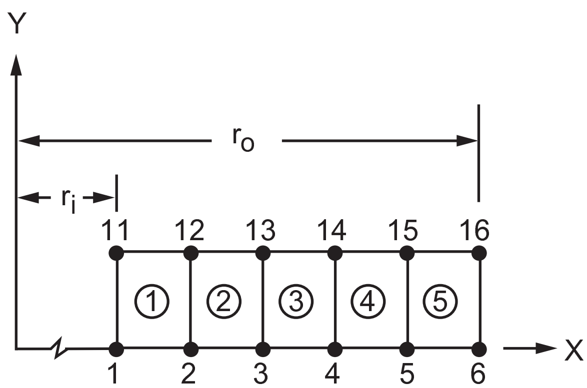
A long hollow cylinder is maintained at temperature T_i along its inner surface and T_o along its outer surface. The thermal conductivity of the cylinder material is known to vary with temperature according to the linear function $k(T) = C_0 + C_1 T$. Determine the temperature distribution in the cylinder for two cases:

- k = constant, (i.e. $C_1 = 0$)
- k = k (T).

Figure 102.1: Cylinder Problem Sketch



Problem Sketch



Representative Finite Element Model

Material Properties	Geometric Properties	Loading
C_0 = 50 Btu/hr-ft-°F C_1 = 0.5 Btu/hr-ft-°F^2	r_i = 1/2 in = (1/24) ft r_o = 1 in = (1/12) ft	T_i = 100°F T_o = 0°F

Analysis Assumptions and Modeling Notes

The axial length of the model is arbitrarily chosen to be 0.01 ft. Note that axial symmetry is automatically ensured by the adiabatic radial boundaries. The problem is solved in two load steps. The first load step uses the constant k. The **MP** command is reissued in the second load step to specify a temperature-dependent k.

Results Comparison

		Target[1]	Mechanical APDL	Ratio
T, °F (k = constant); first load step	Node 2	73.8	73.7	1.000
	Node 3	51.5	51.5	1.000
	Node 4	32.2	32.2	1.000
	Node 5	15.3	15.2	0.99
T, °F (k = k(T)); second load step	Node 2	79.2	79.2	1.000
	Node 3	59.6	59.5	1.000
	Node 4	40.2	40.2	1.000
	Node 5	20.8	20.7	0.99

1. Based on a numerical relaxation method.

VM103: Thin Plate with Central Heat Source

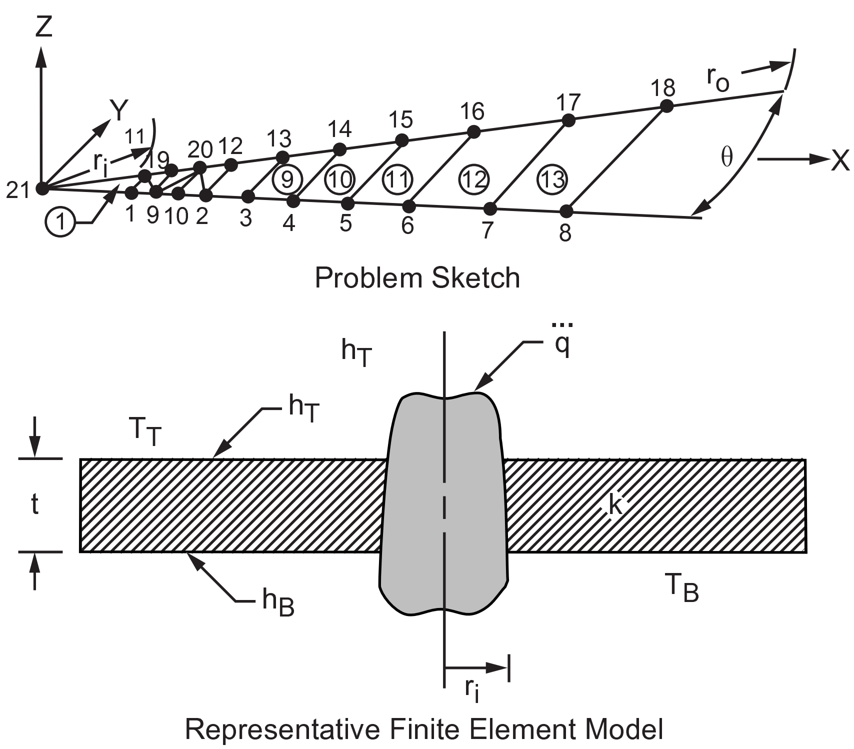
Overview

Reference:	P. J. Schneider, *Conduction Heat Transfer*, 2nd Printing, Addison-Wesley Publishing Co., Inc., Reading, MA, 1957, pg. 173, article 8-1.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	4-Node Layered Thermal Shell Elements (SHELL131) 8-Node Layered Thermal Shell Elements (SHELL132)
Input Listing:	vm103.dat

Test Case

Determine the temperature distribution in the thin infinite plate with a cylindrical heat source $\ddot{q}$ shown in the following table. The plate also gains heat on the top face from an ambient gas at a temperature T_T and loses heat on the bottom face to an ambient gas at temperature T_B. Assume that no temperature gradient exists through the thickness of the plate.

Figure 103.1: Thin Plate Problem Sketch



Material Properties	Geometric Properties	Loading
k = 5 Btu/hr-ft-°F h_T = 30 Btu/hr-ft^2-°F h_B = 20 Btu/hr-ft^2-°F	t = 0.1 ft r_i = 0.1 ft	T_T = 100°F T_B = 0°F $\ddot{q}$ = 250,000 Btu/hr-ft^3

Analysis Assumptions and Modeling Notes

Since the problem is axisymmetric only a one-element sector is needed. A small angle Θ = 10° is used for approximating the circular boundary with a straight-sided element. The outer radius r_o is arbitrarily selected at a point where the heat source should have negligible effect. Small elements are used adjacent to the heat source where the temperature gradient is the largest. Nodal coupling is used to ensure circumferential symmetry. Triangular and quadrilateral elements are used.

Results Comparison

SHELL131			
	Target[1]	Mechanical APDL	Ratio
T, °F (at Node 1)	226.3	227.0	1.00
T, °F (at Node 2)	103.2	102.4	0.99
T, °F (at Node 3)	73.8	73.6	1.00
T, °F (at Node 4)	65.8	64.6	0.98
T, °F (at Node 5)	62.8	61.6	0.98
T, °F (at Node 6)	60.8	60.6	1.00
T, °F (at Node 7)	60.2	60.2	1.00
T, °F (at Node 8)	60.0	60.2	1.00
T, °F (at Node 9)	173.1	164.9	0.95
T, °F (at Node 10)	130.7	126.8	0.97

SHELL132			
	Target[1]	Mechanical APDL	Ratio
T, °F (at Node 1)	226.3	234.8	1.04
T, °F (at Node 2)	103.2	107.2	1.04
T, °F (at Node 3)	73.8	74.4	1.01
T, °F (at Node 4)	65.8	64.7	0.98
T, °F (at Node 5)	62.8	61.6	0.98
T, °F (at Node 6)	60.8	60.6	1.00
T, °F (at Node 7)	60.2	60.4	1.00
T, °F (at Node 8)	60.0	60.4	1.01
T, °F (at Node 9)	173.1	170.5	0.98
T, °F (at Node 10)	130.7	131.7	1.01

1. Based on graphical estimate

VM104: Liquid-Solid Phase Change

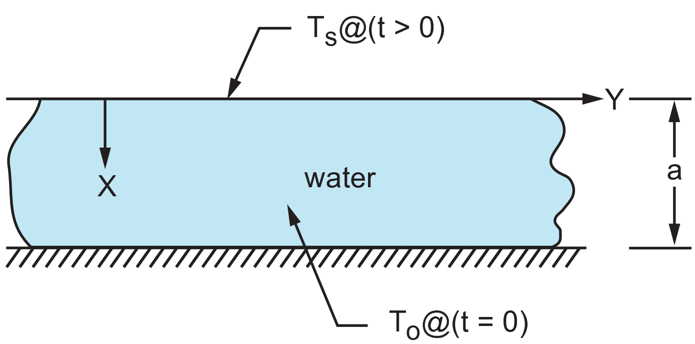
Overview

Reference:	J. A. Dantzig, "Modeling Liquid-Solid Phase Changes with Melt Convection", *Int. Journal Numerical Methods in Engineering*, Vol. 28, 1989, pg. 1774, problem I.
Analysis Type(s):	Thermal Analysis (with phase change) (**ANTYPE** = 4)
Element Type(s):	2-D Thermal Solid Elements (PLANE55)
Input Listing:	vm104.dat

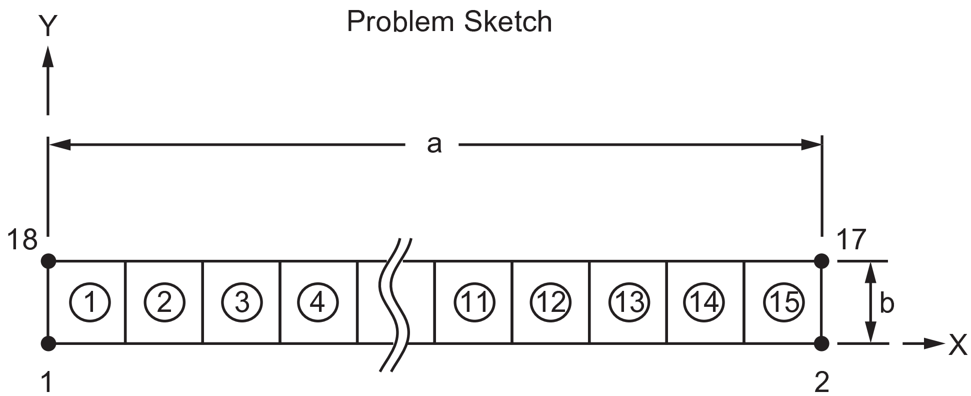
Test Case

A layer of liquid (of depth a), covering an insulated surface and initially at its freezing temperature T_o, is suddenly subjected to a free surface temperature T_s (less than T_o). Determine the time, t_f, taken for the liquid to solidify completely, and the temperature distribution in the solid phase at time t_1 seconds.

Figure 104.1: Liquid-Solid Phase Change Problem Sketch



Problem Sketch



Representative Finite Element Model

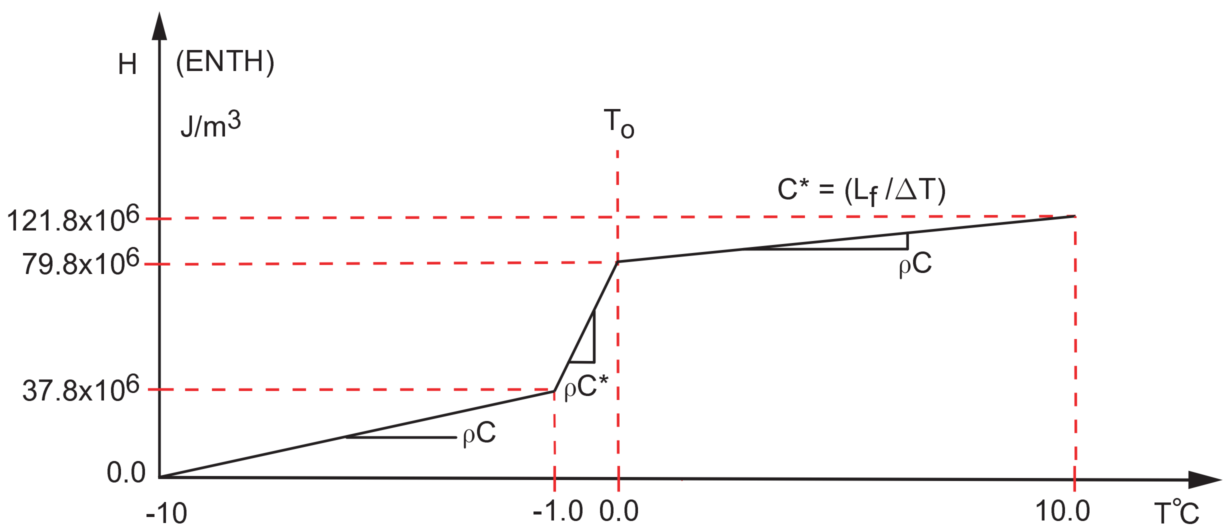
Material Properties	Geometric Properties	Loading
ρ = 1000 kg/m^3 C_p = 4200.0 J/kg-°C k = 0.60 W/m-°C L_f = Latent heat of fusion = 42000. J/kg	a = 0.01 m b = 0.001 m	T_o = 0°C (t = 0) T_s = -5°C (x = 0; t > 0) t_1 = 500 sec

Analysis Assumptions and Modeling Notes

The problem is formulated in two dimensions, with all faces insulated, except the face representing the liquid surface. The latent heat effect (accompanying change in phase from liquid to solid), is approximated by specifying a rapid variation in enthalpy (material property ENTH), over the "mushy" zone in a temperature range of ΔT (taken as 1.0°C). The enthalpy (H) variation is computed from the equation $H = \rho c \int dT$. An adjusted specific heat of $L_f/\Delta T$ = 42000.0 J/kg-°C, is used in the freezing zone, resulting in a slope discontinuity, as shown in Figure 104.3: Temperature Distribution at Time = 501 Seconds (p. 281). For the given case, a time step of 3.0 seconds is found to be adequate to give more than one time step through the freezing zone. Automatic time stepping is used.

POST1 is used to obtain the temperature distribution through the two phases and POST26 is used to display the temperature history of points in each of the phases.

Figure 104.2: Enthalpy vs. Temperature



Enthalpy vs. Temperature

Results Comparison

	Target[1]	Mechanical APDL	Ratio
t_f, seconds	810.0	between (787 to 797) [2]	-
At t = 500 seconds			
T , °C (x = 0.002m)	-3.64	-3.71	1.019
T , °C (x = 0.004m)	-2.32	-2.46	1.059

1. From Equations 20-31, in J. A. Dantzig, "Modeling Liquid-Solid Phase Changes with Melt Convection".

2. Corresponds to the time interval at which Node 2 temperature crosses the ΔT = 1°C freezing zone.

Figure 104.3: Temperature Distribution at Time = 501 Seconds

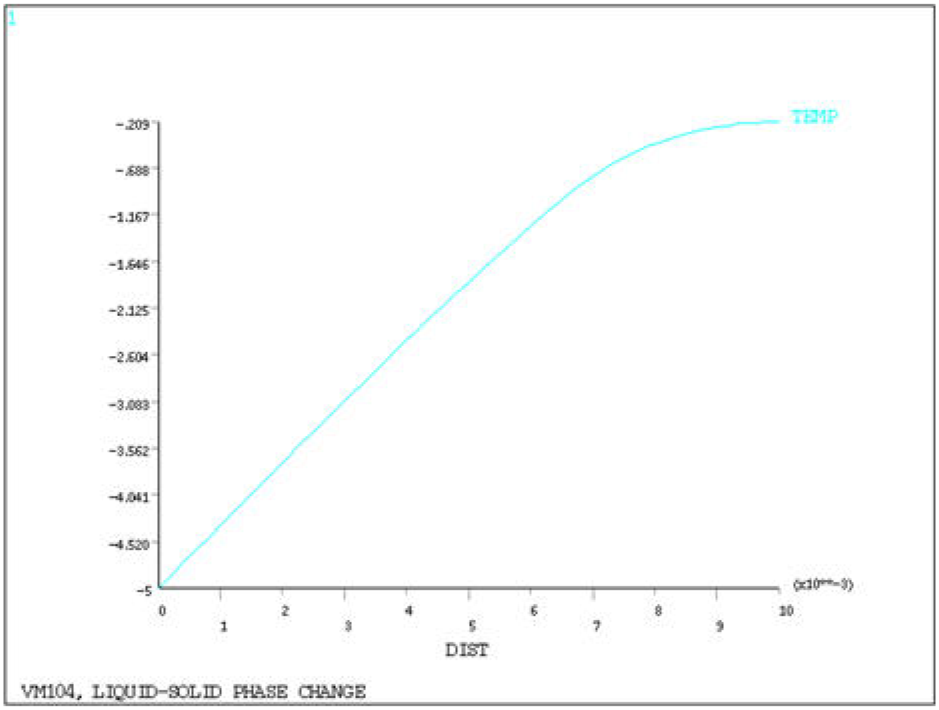
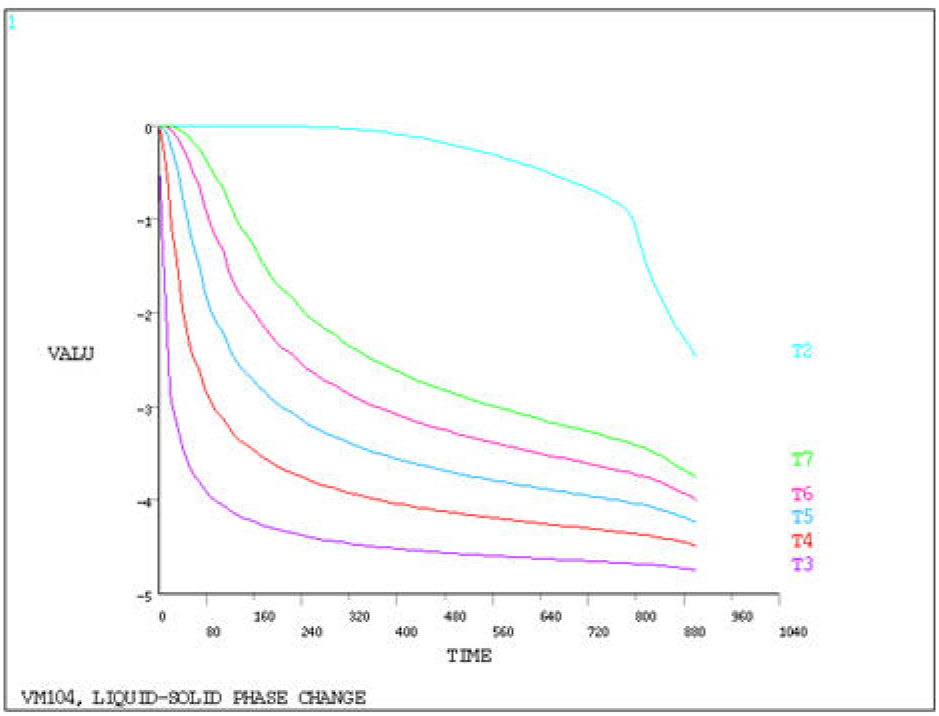


Figure 104.4: Temperature History of Solidification



VM105: Heat Generating Coil with Temperature Conductivity

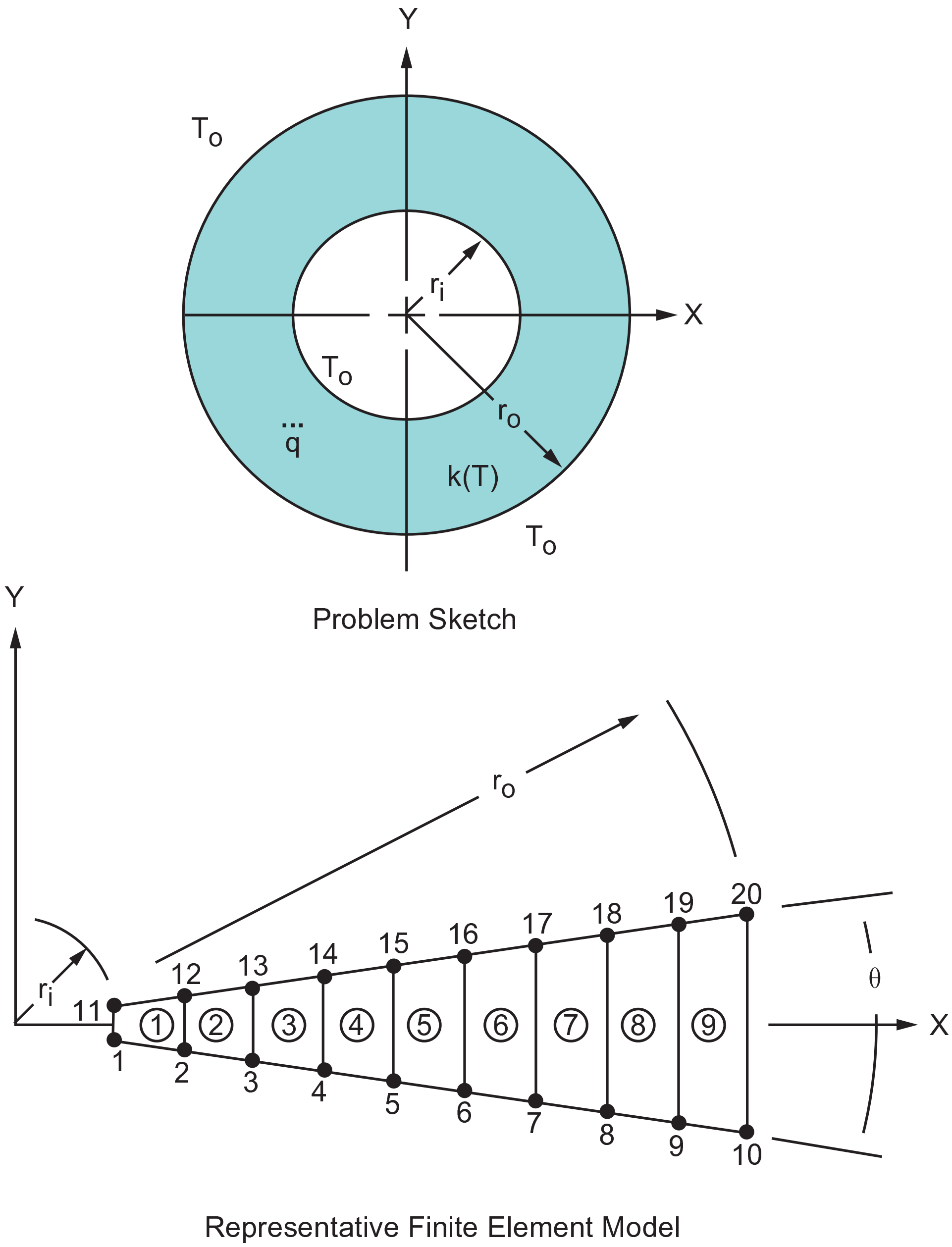
Overview

Reference:	P. J. Schneider, *Conduction Heat Transfer*, 2nd Printing, Addison-Wesley Publishing Co., Inc., Reading, MA, 1957, pg. 193, article 8-8
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Thermal Solid Elements (PLANE55)
Input Listing:	vm105.dat

Test Case

A long hollow generator coil has its inner and outer surface temperatures maintained at temperature T_o while generating Joule heat at a uniform rate $\dddot{q}$. The thermal conductivity of the coil material varies with temperature according to the function $k(T) = C_0 + C_1 T$. Determine the temperature distribution in the coil.

Figure 105.1: Heat Generating Coil Problem Sketch



Material Properties	Geometric Properties	Loading
C_0 = 10 Btu/hr-ft-°F C_1 = 0.075 Btu/hr-ft-°F^2	r_i = 1/4 in = 1/48 ft r_o = 1 in = 1/12 ft	T_o = 0°F $\dddot{q}$ = 1 x 10^6 Btu/hr-ft^3

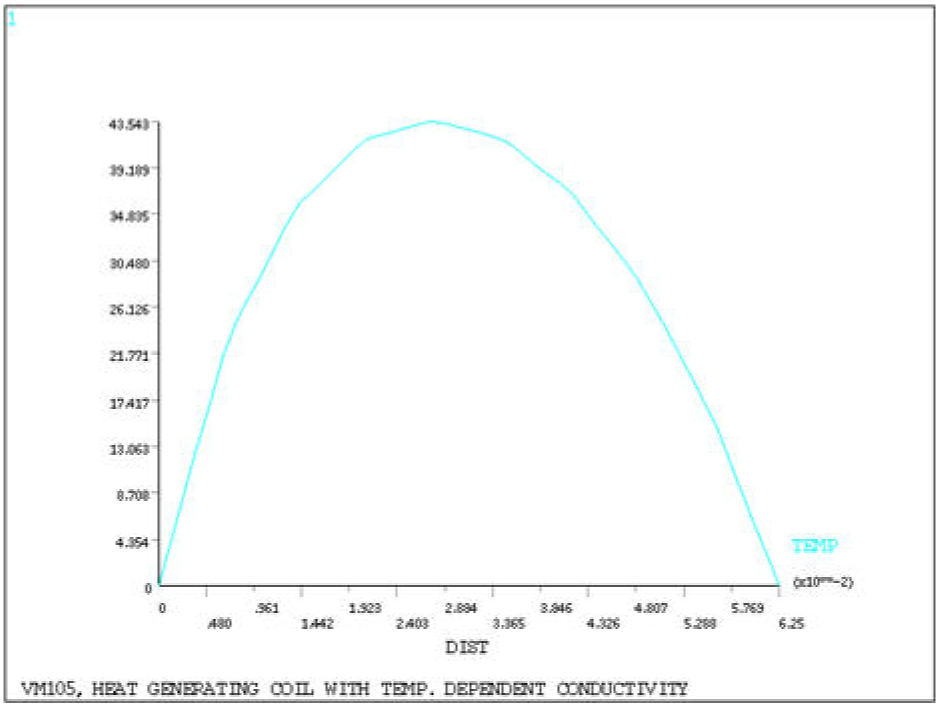
Analysis Assumptions and Modeling Notes

Since the problem is axisymmetric only a symmetry sector (one-element wide) is needed. A small angle (Θ=10°) is used for approximating the circular boundary with a straight-sided element. Adiabatic boundary conditions are assumed at the symmetry edges. The steady-state convergence procedures are used. Note that this problem can also be modeled using the axisymmetric option as in VM102.

Results Comparison

T, °F	Target	Mechanical APDL	Ratio
Node 2	23.3	23.0	0.989
Node 3	35.9	35.5	0.990
Node 4	42.2	41.8	0.991
Node 5	44.0	43.7	0.992
Node 6	42.2	41.9	0.992
Node 7	37.0	36.8	0.993
Node 8	28.6	28.4	0.991
Node 9	16.5	16.4	0.991

Figure 105.2: Variation of Temperature in the Radial Direction



VM106: Radiant Energy Emission

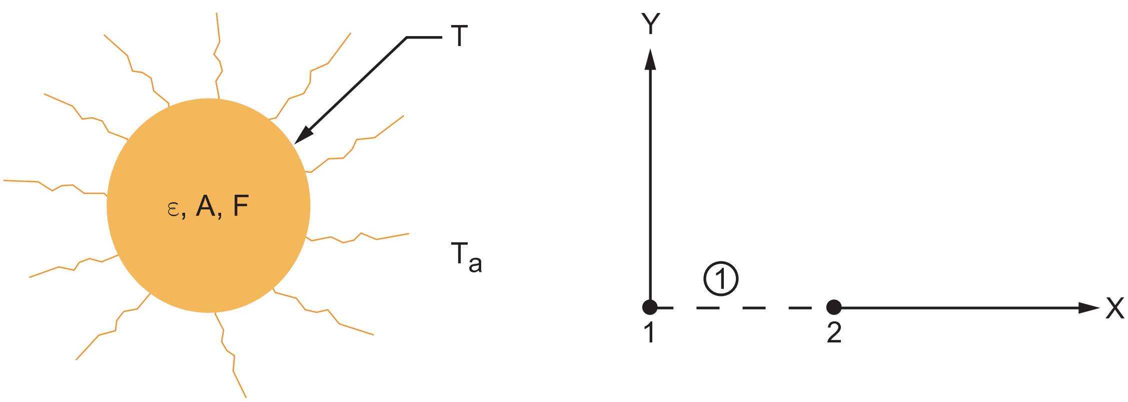
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 22, problem 1-8(b).
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	Radiation Link Elements (LINK31)
Input Listing:	vm106.dat

Test Case

Determine the rate of radiant heat emission q in Btu/hr from a black body of unit area A at a temperature T, when ambient temperature is T_a.

Figure 106.1: Radiant Energy Emission Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
ε = emissivity = 1.0	A = 1 ft^2 F = form factor = 1.0	T = 3000°F T_a = 0°F

Analysis Assumptions and Modeling Notes

A conversion factor of 144 in^2/ft^2 is included in the area input to convert the default Stefan-Boltzmann constant to feet units. The temperature offset of 460°F is required to convert the input Fahrenheit temperature to an absolute (Rankine) temperature. The node locations are arbitrarily selected as coincident.

Results Comparison

	Target	Mechanical APDL [1]	Ratio
q, Btu/hr	2.4559×10^5	2.4552×10^5	1.000

1. Element heat rate

VM107: Thermocouple Radiation

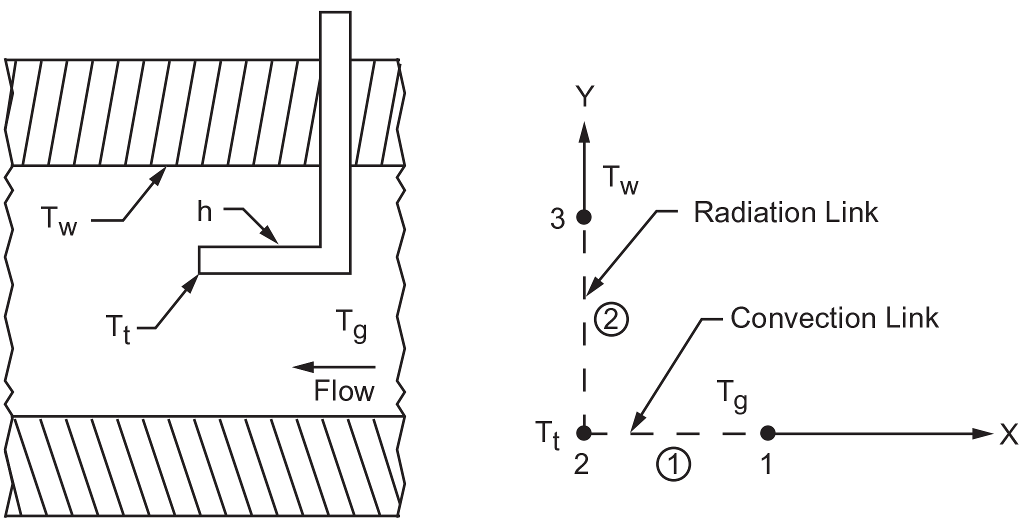
Overview

Reference:	A. J. Chapman, *Heat Transfer*, The Macmillan Co, New York, NY, 1960, pg. 396, article 13.5.
Analysis Type(s):	Thermal analysis (**ANTYPE** = 0)
Element Type(s):	Radiation Link Elements (LINK31) Convection Link Elements (LINK34)
Input Listing:	vm107.dat

Test Case

A thermocouple is used to measure the temperature T_g of a gas flowing within a duct. The duct wall temperature is T_w and the thermocouple is placed at right angles to the flow. If the conduction effects are negligible, determine the thermocouple reading T_t and the heat flow rate q due to convection and radiation.

Figure 107.1: Thermocouple Radiation Problem Sketch



Problem Sketch Representative Finite Element Model

Material Properties	Loading
ε = emissivity = 0.5 h = 11.85 Btu/hr-ft^2-°F Stefan-Boltzmann constant[1] = 0.174 x 10^{-8} Btu/hr-ft^2-°R^4	T_w = 300°F T_g = 1309°F

1. As given in A. J. Chapman, *Heat Transfer*.

Analysis Assumptions and Modeling Notes

The temperature offset of 460°F is required to convert the input Fahrenheit temperatures to absolute (Rankine) temperatures. The node locations are arbitrarily selected (coincident).

Results Comparison

	Target	Mechanical APDL [1]	Ratio
T_t, °F	1000.00	999.95	1.000
q, Btu/hr	3661.65	3662.24	1.000

1. At node 2

VM108: Temperature Gradient Across a Solid Cylinder

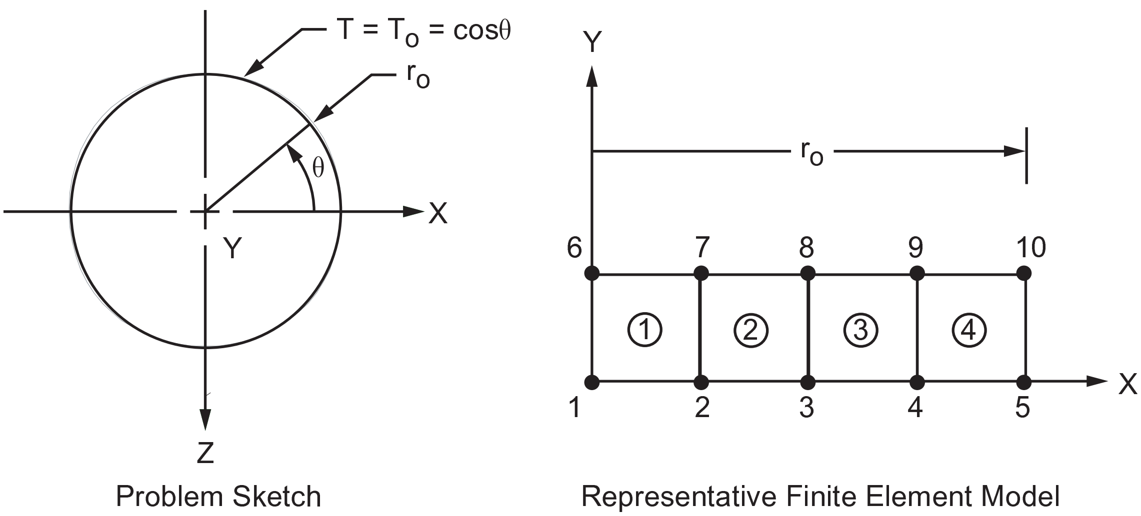
Overview

Reference:	F. B. Hildebrand, *Advanced Calculus for Applications*, 2nd Edition, Prentice-Hall, Inc., Englewood, NJ, 1976, pg. 447, eqs. 38-44.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	Axisymmetric-Harmonic 4-Node Thermal Solid Elements (PLANE75)
Input Listing:	vm108.dat

Test Case

Heat is conducted across the diameter of a long solid cylinder. The temperature loading along the circumference is antisymmetric about the Y-Z plane and varies sinusoidally with peaks occurring at Θ = 0° and Θ = 180°. Determine the temperature distribution along the radius at Θ = 0°.

Figure 108.1: Solid Cylinder Problem Sketch



Material Properties	Geometric Properties	Loading
k = 1 Btu/hr-ft-°F	r_o = 20 ft	T_o = 80°F

Analysis Assumptions and Modeling Notes

The axial length of the model is arbitrarily chosen to be 5 ft. The temperature loading is applied as a harmonic function (mode = 1) around the periphery of the cylinder. To obtain the theoretical solution, equations 43 and 44 in F. B. Hildebrand, *Advanced Calculus for Applications* are used. Applying the temperature boundary condition and the requirement that T(r,Θ) should be finite and single-valued leads to the following solution: $T(r,\Theta) = T_0 * (r/r_0) * \cos\Theta$.

Results Comparison

Mode = 1 (angle =0°)	Target	Mechanical APDL	Ratio
Node 1 T, °F	0.0	0.0	-
Node 2 T, °F	20.0	20.0	1.00
Node 3 T, °F	40.0	40.0	1.00
Node 4 T, °F	60.0	60.0	1.00

VM109: Temperature Response of a Suddenly Cooled Wire

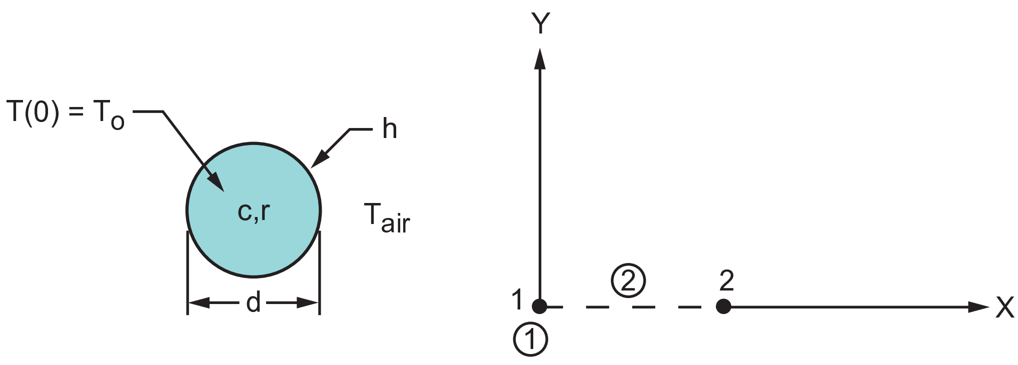
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 120, ex. 4-1.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 4)
Element Type(s):	Convection Link Elements (LINK34) Thermal Mass Elements (MASS71)
Input Listing:	vm109.dat

Test Case

Determine the temperature response of a copper wire of diameter d, originally at temperature T_o, when suddenly immersed in air at temperature T_{air}. The convection coefficient between the wire and the air is h.

Figure 109.1: Cooled Copper Wire Problem Sketch



Problem Sketch   Representative Finite Element Model

Material Properties	Geometric Properties	Loading
ρ = 558 lb/ft^3 c = 0.091 Btu/lb-°F h = 2 Btu/hr-ft^2-°F	d = 1/32 in	T_{air} = 100°F T_o = 300°F (at t=0)

Analysis Assumptions and Modeling Notes

The node locations are arbitrary (coincident). The final time of 0.05 hr (180 sec) is sufficient for the theoretical response comparison. An initial integration time step of 0.05/40 = 0.00125 hr is used. Automatic time stepping is used. The thermal capacitance C, and the surface area of the wire A_s, are calculated based on a unit length as follows:

$$C = \rho c V = 558 \times 0.091 \times \frac{\pi}{4} \times \left(\frac{1}{32 \times 12}\right)^2 = 2.7046 \times 10^{-4} \text{BTU} / {}^\circ\text{F}$$

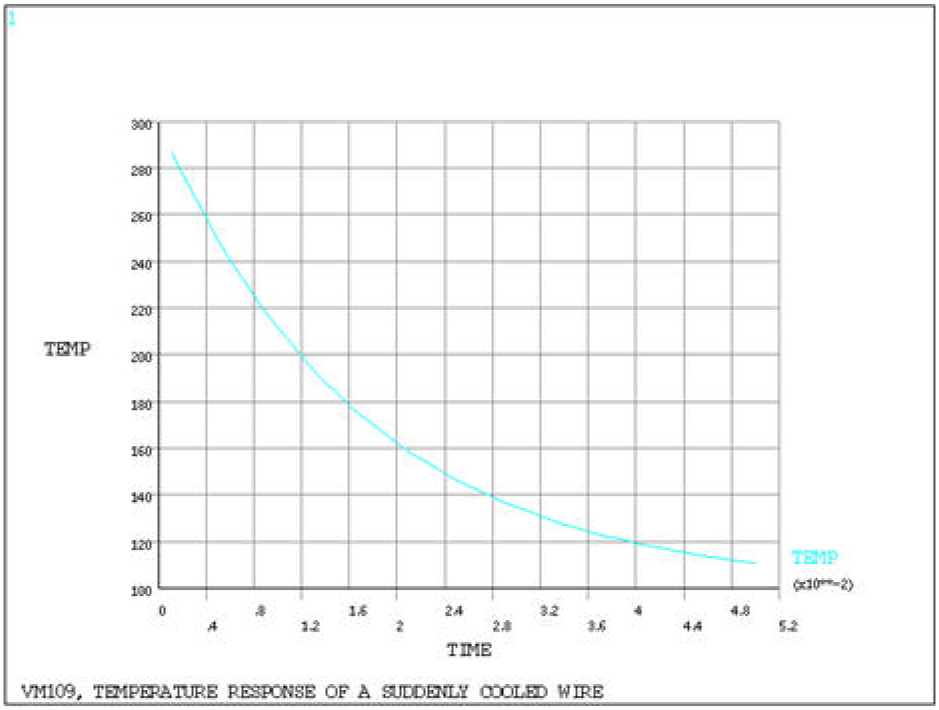
$$A = \pi d = \frac{\pi}{32 \times 12} = 8.1812 \times 10^{-3} \text{ft}^2$$

Results Comparison

	Target	Mechanical APDL	Ratio
T, °F @ 0.0125hr	193.89	196.48	1.013
T, °F @ 0.0325hr	128.00	130.05	1.016
T, °F @ 0.05hr	109.71	110.83	1.010

1. POST26, Node 1 temperature history

Figure 109.2: Temperature vs. Time Display



VM110: Transient Temperature Distribution in a Slab

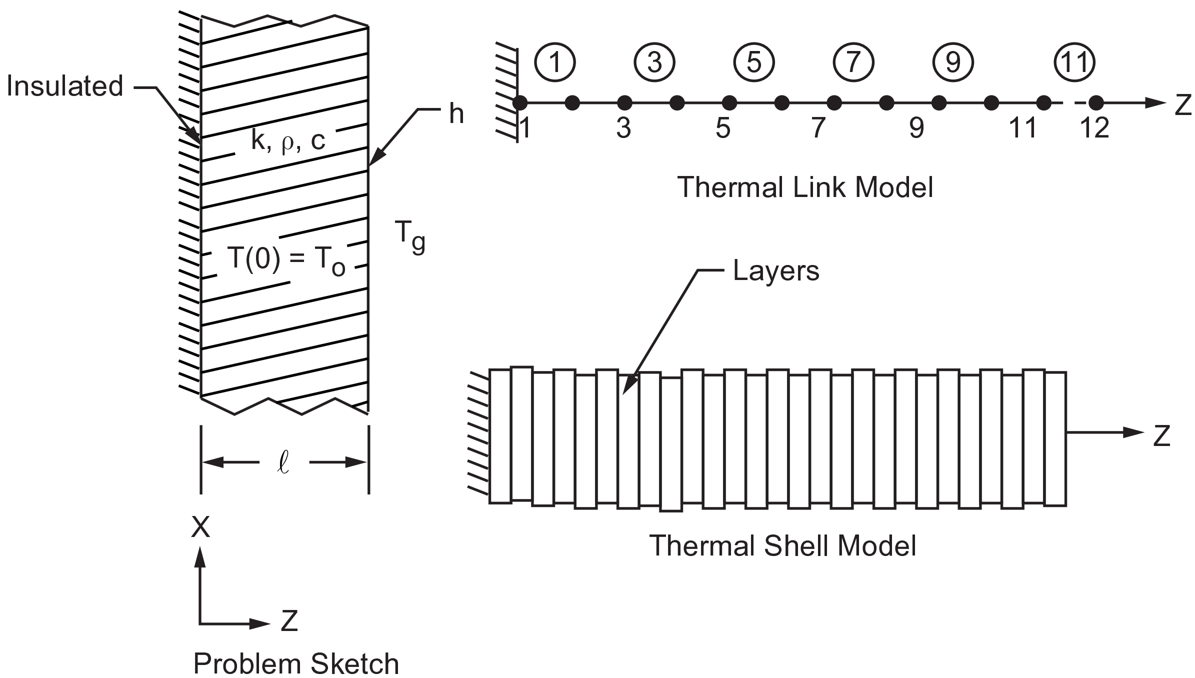
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 140, ex. 4-4.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 4)
Element Type(s):	3-D Conduction Bar Elements (LINK33) Convection Link Elements (LINK34)
Input Listing:	vm110.dat

Test Case

A concrete wall, originally at temperature T_o, is suddenly exposed on one side to a hot gas at temperature T_g. If the convection coefficient on the hot side is h and the other side is insulated, determine the temperature distribution in the slab after 14.5 hours, and the total heat Q transferred to the wall per square foot of surface area.

Figure 110.1: Slab Problem Sketch



Material Properties	Geometric Properties	Loading
k = 0.54 Btu/hr-ft-°F ρ = 144 lb/ft^3 c = 0.2 Btu/lb-°F h = 5 Btu/hr-ft^2-°F	ℓ = 1 ft	T_o = 100°F T_g = 1600°F

Analysis Assumptions and Modeling Notes

The problem is first solved using LINK33 elements. A 1 ft^2 area is used for the convection and conduction elements. Node 12 is given an arbitrary location. Automatic time stepping is used. The initial integration time step (ITS) chosen (14.5/80 = 0.18125 hr) is larger than the minimum ITS recommended; ITS $\approx \delta^2/4\alpha$, where δ is the conduction element length (0.1 ft) and a is the thermal diffusivity (k/ρc = 0.01875 ft^2/hr). POST26 is used to obtain the total heat transferred to the wall.

Results Comparison

Time = 14.5 hr	**Target[1]**	**Mechanical APDL**	**Ratio[1]**
T, °F (node 1)	505.	507.	1.00
T, °F (node 3)	550.	549.	1.00
T, °F (node 5)	670.	675.	1.01
T, °F (node 7)	865.	874.	1.01
T, °F (node 9)	1135	1134.	1.00
T, °F (node 11)	1435.	1433.	1.00
Q[2], BTU/ft^2	-20,736.	-20,662.	1.00

1. Based on graphical estimates

2. Q = $\int$ q dt, from POST26

VM111: Cooling of a Spherical Body

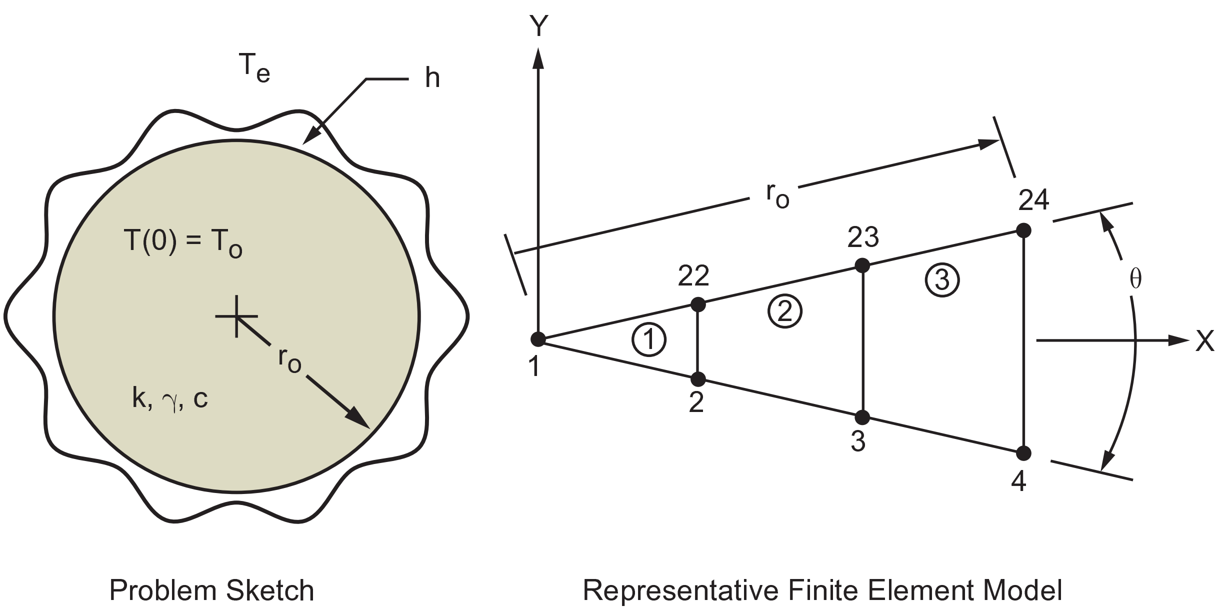
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 143, ex. 4-5.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 4)
Element Type(s):	2-D Thermal Solid Elements (PLANE55)
Input Listing:	vm111.dat

Test Case

Determine the temperature at the center of a spherical body, initially at a temperature T_o, when exposed to an environment having a temperature T_e for a period of 6 hours. The surface convection coefficient is h.

Figure 111.1: Spherical Body Problem Sketch



Material Properties	Geometric Properties	Loading
K=(1/3) BTU/hr-ft-°F γ = 62 lb/ft^3 c = 1.075 Btu/lb-°F h = 2 Btu/hr-ft^2-°F	r_o = 2 in = (1/6) ft	T_o = 65°F T_e = 25°F

Analysis Assumptions and Modeling Notes

Since the problem is axisymmetric, only a one-element sector is needed. A small angle Θ = 15° is used for approximating the circular boundary with a straight-side element. Nodal coupling is used to ensure circumferential symmetry. Automatic time stepping is used. The initial integration time step (6/40 =

0.15 hr) is based on ≈ $\delta^2/4\,\alpha$, where δ is the element characteristic length (0.0555 ft) and α is the thermal diffusivity ($k/\gamma c$ = 0.005 ft^2/hr). POST1 is used to extract results from the solution phase.

Results Comparison

Time = 6 hr	Target[1]	Mechanical APDL	Ratio
T, °F	28.0	28.66	1.024

1. Based on graphical estimates.

VM112: Cooling of a Spherical Body

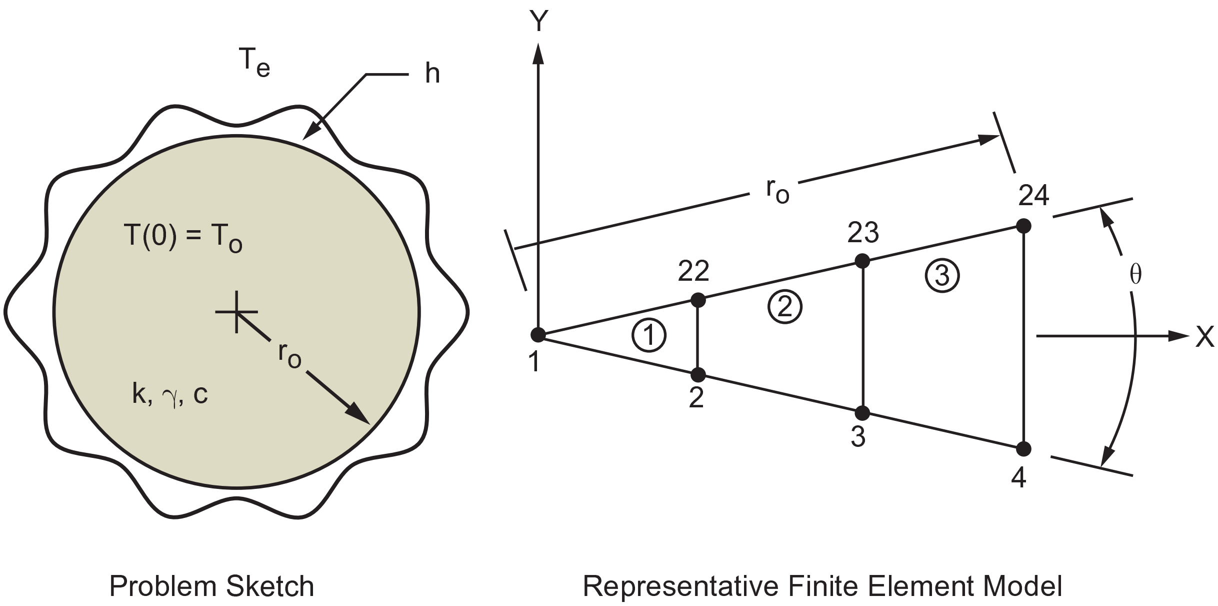
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 143, ex. 4-5.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 4)
Element Type(s):	2-D 8-Node Thermal Solid Elements (PLANE77)
Input Listing:	vm112.dat

Test Case

See VM111 for test case description, geometric and material properties, and loading.

Figure 112.1: Spherical Body Problem Sketch



Analysis Assumptions and Modeling Notes

Since the problem is axisymmetric, only a one-element sector is needed. A small angle Θ = 15° is used for approximating the circular boundary with a curved-side element. Nodal coupling is used to ensure circumferential symmetry. Automatic time stepping is used. The initial integration time step (6/40 = 0.15 hr) is based on ≈ $\delta^2/4\ \alpha$, where δ is the element characteristic length (0.0555 ft) and α is the thermal diffusivity (k/γc = 0.005 ft^2/hr). POST1 is used to extract results from the solution phase.

Results Comparison

Time = 6 hr.	Target[1]	Mechanical APDL	Ratio
T, °F	28.0	29.0	1.035

1. Based on graphical estimates.

VM113: Transient Temperature Distribution in an Orthotropic Metal Bar

Overview

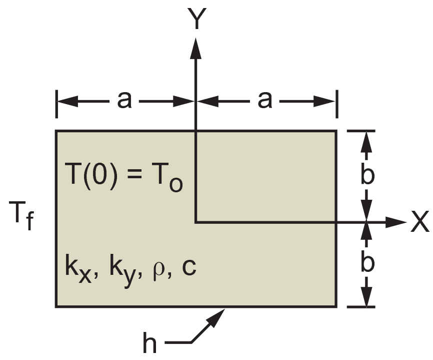
Reference:	P. J. Schneider, *Conduction Heat Transfer*, 2nd Printing, Addison-Wesley Publishing Co., Inc., Reading, MA, 1957, pg. 261, ex. 10-7.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 4)
Element Type(s):	2-D Thermal Solid Elements (PLANE55)
Input Listing:	vm113.dat

Test Case

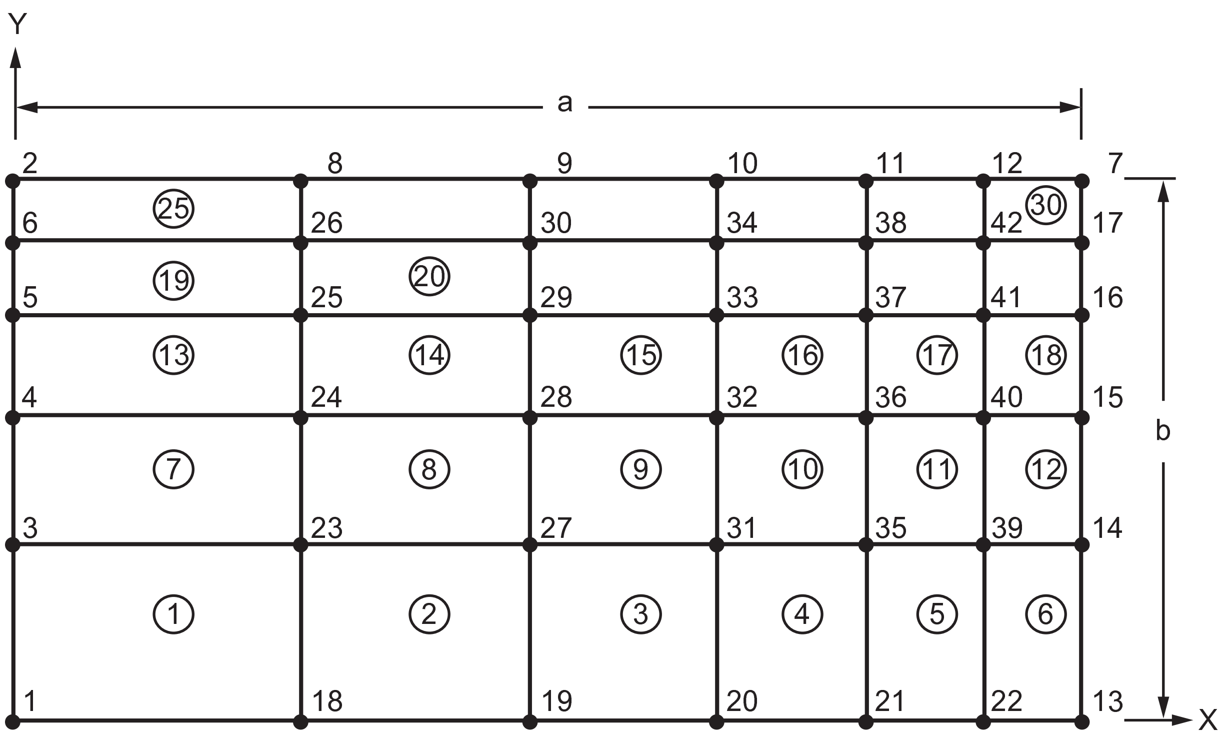
A long metal bar of rectangular cross-section is initially at a temperature T_o and is then suddenly quenched in a large volume of fluid at temperature T_f. The material conductivity is orthotropic, having different X and Y directional properties. If the surface convection coefficient is h, determine the temperature distribution in the slab after 3 seconds in the following locations of the bar:

- center
- corner edge
- face centers of the bar

Figure 113.1: Orthotropic Metal Bar Problem Sketch



Problem Sketch



Representative Finite Element Model

Material Properties	Geometric Properties	Loading
k_x = 20 Btu/hr-ft-°F k_y = 3.6036 Btu/hr-ft-°F γ = 400 lb/ft^3 c = 0.009009 Btu/lb-°F h = 240 Btu/hr-ft^2-°F	a = 2 in = (2/12) ft b = 1 in = (1/12) ft	T_o = 500°F T_f = 100°F

Analysis Assumptions and Modeling Notes

A nonuniform grid (based on a geometric progression) is used in both X and Y directions to model a quarter of the bar cross-section. Automatic time stepping is used. The initial integration time step = (3/3600)(1/40) is greater than ($\delta^2/4\alpha$), where δ is the shortest element length (0.0089 ft) and α is the thermal diffusivity ($k_y/\gamma c$ = 1.0 ft^2/hr).

Results Comparison

Time = 3 sec. (=0.0008333 hr.)	**Target[1]**	**Mechanical APDL**	**Ratio**
T, °F (Node 1)	459.	457.	1.00
T, °F (Node 7)	151.	158.	1.05
T, °F (Node 13)	279.	288.	1.03
T, °F (Node 2)	202.	204.	1.01

1. Based on graphical estimates.

VM114: Temperature Response to Increasing Temperature

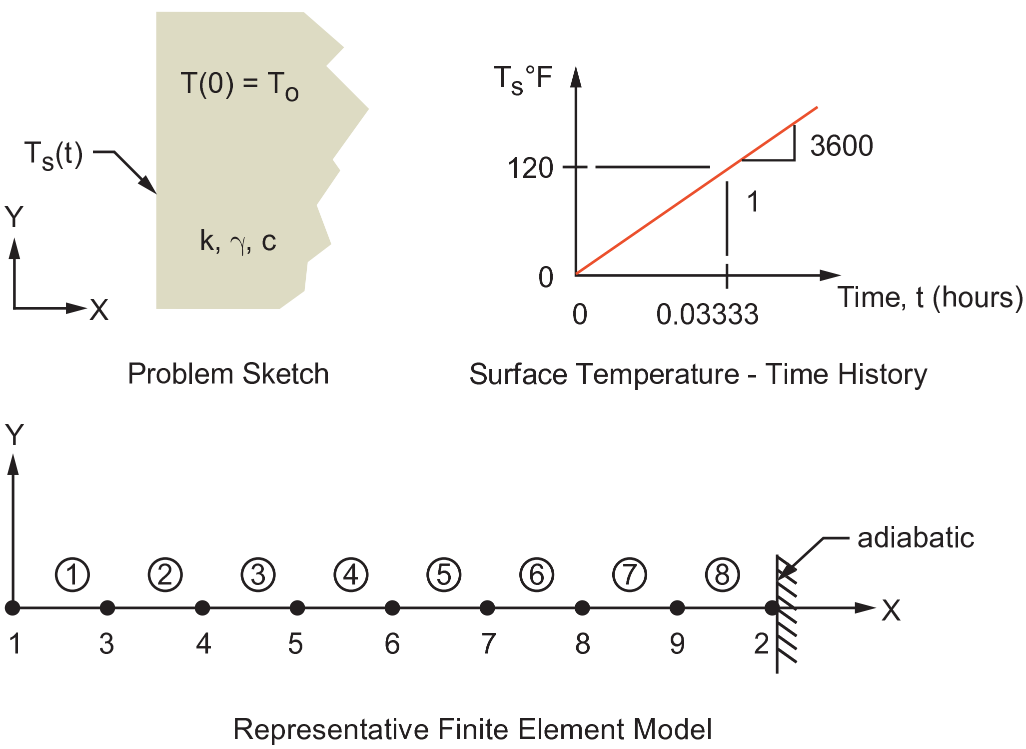
Overview

Reference:	P. J. Schneider, *Conduction Heat Transfer*, 2nd Printing, Addison-Wesley Publishing Co., Inc., Reading, MA, 1957, pp. 274-275, article 11-2, eq. 11-9.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 4)
Element Type(s):	3-D Conduction Bar Elements (LINK33)
Input Listing:	vm114.dat

Test Case

A semi-infinite solid, initially at a temperature T_o, is subjected to a linearly rising surface temperature T_s = 3600 t, where T_s is in °F and t is time in hours. Determine the temperature distribution in the solid at t = 2 min.

Figure 114.1: Linearly-rising Surface Temperature Problem Sketch



Material Properties	Loading
k = 10 Btu/hr-ft-°F γ = 500 lb/ft^3 c = 0.2 Btu/lb-°F	T_o = 0°F @ t = 0 T_s = 120°F @ t = 2 (ramped) (see Figure 114.2: Temperature vs. Time Plot (p. 306))

Analysis Assumptions and Modeling Notes

A nonuniform mesh is used to model the nonlinear thermal gradient through the solid. An arbitrary area of 1 ft^2 is used for the elements. The length of the model is taken as 0.3 ft assuming that no significant temperature change occurs at the interior end point (Node 2) during the time period of interest (2 min). This assumption is validated by the temperature of node 2 at the end of the transient analysis.

Automatic time stepping is used with an initial integration time step (0.03333/20 = 0.001666 hr) greater than $\delta^2/4\alpha$, where δ = minimum element conducting length (0.0203 ft) and α = thermal diffusivity (= $k/\gamma c$ = 0.1 ft^2/hr).

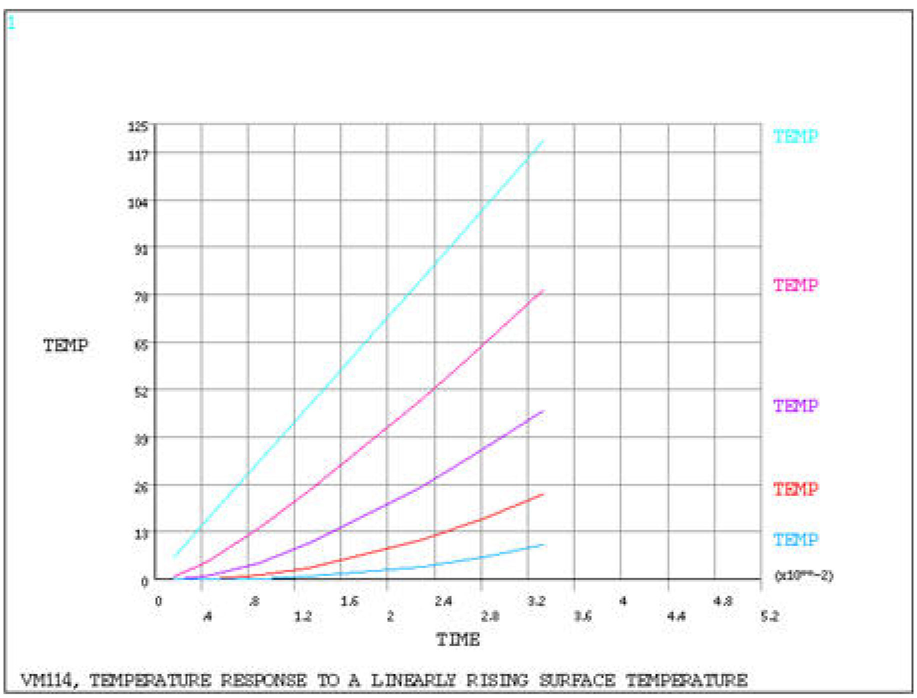
Note that the KBC key (not input) defaults to zero, resulting in the surface temperature load being ramped linearly to its final value.

POST26 and POST1 are used to obtain the temperature history at the node locations, and the temperature distribution at t = 0.03333 hr, respectively.

Results Comparison

Time = 0.03333 hr		Target	Mechanical APDL	Ratio
T, °F (Node 1)	@ x = 0.0 ft	120.00	120.00	1.000
T, °F (Node 3)	@ x = 0.0203 ft	79.32	79.07	0.997
T, °F (Node 4)	@ x = 0.0441 ft	46.62	46.35	0.994
T, °F (Node 5)	@ x = 0.0719 ft	23.44	23.25	0.992
T, °F (Node 6)	@ x = 0.1044 ft	9.51	9.52	1.001
T, °F (Node 2)	@ x = 0.3 ft	0.0	0.03	-

Figure 114.2: Temperature vs. Time Plot



VM115: Thermal Response of a Heat-generating Slab

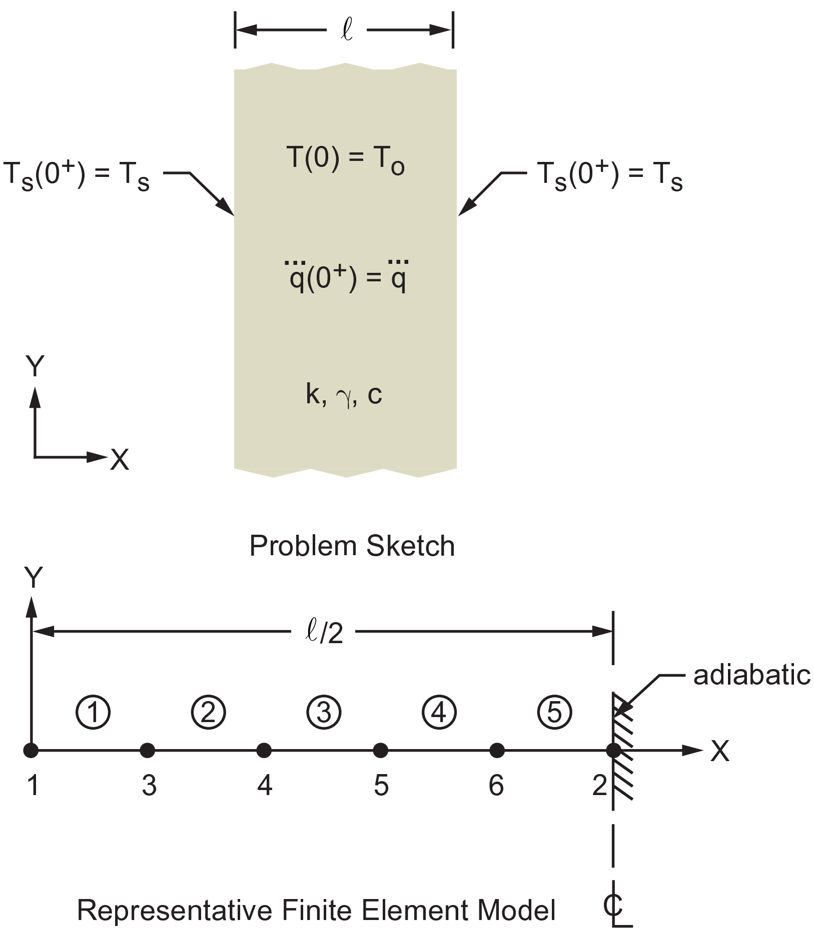
Overview

Reference:	P. J. Schneider, *Conduction Heat Transfer*, 2nd Printing, Addison-Wesley Publishing Co., Inc., Reading, MA, 1957, pg. 283, article 11-4, eq. (11-21) and pg. 309, article 12-8.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 4)
Element Type(s):	3-D Conduction Bar Elements (LINK33)
Input Listing:	vm115.dat

Test Case

An infinite plate of thickness ℓ, initially at a uniform temperature T_o, is subjected to a sudden uniformly distributed heat generation rate $\dddot{q}$ and a surface temperature T_s. Determine the temperature distribution in the plate after 12 minutes.

Figure 115.1: Heat-Generating Slab Problem Sketch



Material Properties	Geometric Properties	Loading
k = 20 Btu/hr-ft-°F	ℓ = 1 ft	T_o = 60°F

Material Properties	Geometric Properties	Loading
γ = 500 lb/ft^3 c= 0.2 Btu/lb-°F		T_s = 32°F (t>0) $\dddot{q}$ = 4 x 10^4 Btu/hr-ft^3

Analysis Assumptions and Modeling Notes

A 1 ft^2 area is used for the conduction elements. Due to symmetry only half of the plate is modeled. Automatic time stepping is used. The initial integration time step (0.01 hr) is based on $\approx \delta^2/4\alpha$, where δ is the element length (0.1 ft) and α is the thermal diffusivity (k/γc = 0.2 ft^2/hr).

Results Comparison

Time = 0.2 hr	Target	Mechanical APDL	Ratio
T, °F (Node 1)	32.00	32.00	1.000
T, °F (Node 3)	75.75	75.37	0.995
T, °F (Node 4)	103.99	103.26	0.993
T, °F (Node 5)	120.80	119.79	0.992
T, °F (Node 6)	129.46	128.27	0.991
T, °F (Node 2)	132.10	130.85	0.991

Using up to three terms of the infinite series solution in equation 11-21 of P. J. Schneider, *Conduction Heat Transfer*.

VM116: Heat Conducting Plate with Sudden Cooling

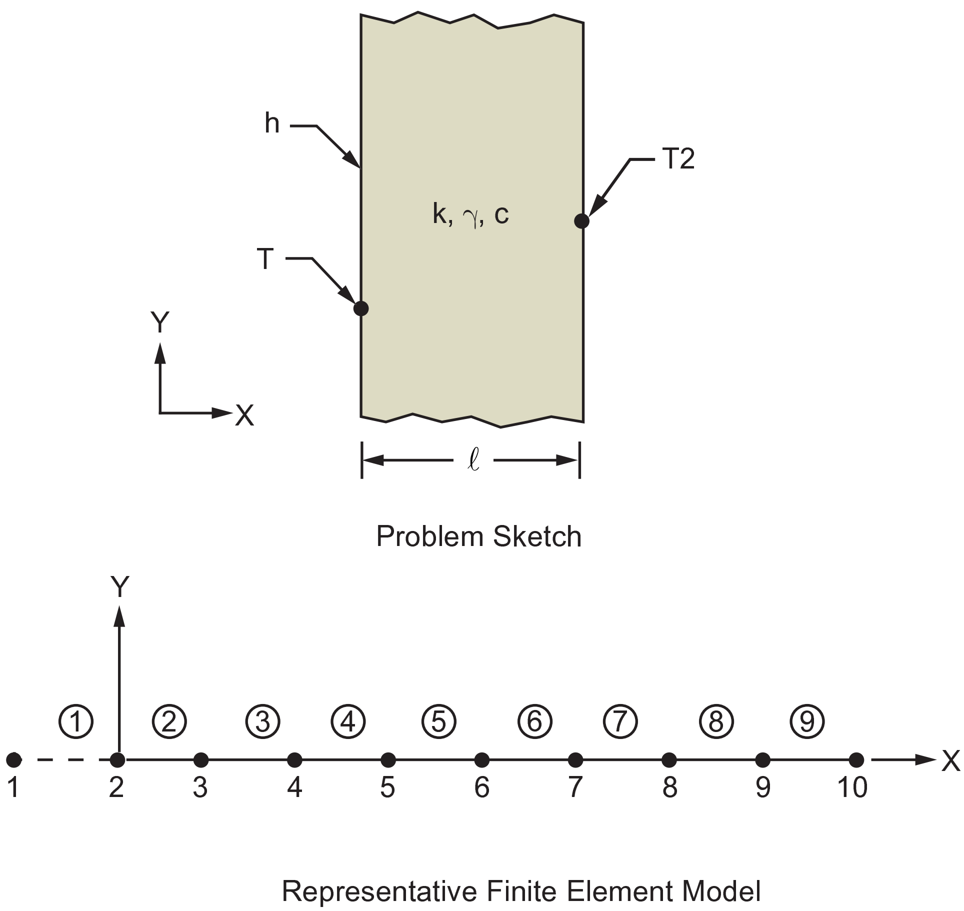
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 161, ex. 4-11.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 4)
Element Type(s):	Convection Link Elements (LINK34) 3-D Conduction Bar Elements (LINK33)
Input Listing:	vm116.dat

Test Case

A large plate of thickness ℓ initially has its left surface at temperature T_1 and the other surface at temperature T_2. The left surface is suddenly subjected to an environment temperature of $T_\infty = T_2$. The convection coefficient on this side is given by h = 2.0 + 0.02 $(T - T_\infty)$ where T is the surface temperature (function of time). Determine T after 7 hours. Graphically display the variation of T with time and the temperature distribution across the plate at 7 hours.

Figure 116.1: Heat Conducting Plate Problem Sketch



Material Properties	Geometric Properties	Loading
$k = 2$ Btu/hr-ft-°F $\gamma = 800$ lb/ft^3 $c = 0.833$ Btu/lb-°F	$\ell = 8$ in = (8/12) ft	$T_1 = 500$°F $T_2 = 100$°F

Analysis Assumptions and Modeling Notes

A 1 ft^2 area is assumed for the conduction elements. The length of the convection element is taken as zero (arbitrarily selected). The finite element model is made the same as the theoretical model for a direct comparison. A steady-state solution is done in the first load step. Automatic time stepping is used. The initial integration time step (7/20 = 0.35 hr) is based on $\approx \delta^2/4\alpha$, where δ is the nodal distance within the element (1/12 ft), and α is the thermal diffusivity $k/\gamma c$ = 0.003 ft^2/hr). POST26 and POST1 are used to obtain the surface temperature history and the temperature distribution at the final time step, respectively.

Results Comparison

Time = 7 hr	Target	Mechanical APDL	Ratio
T, °F (at X = 0.0 in)	285.[1]	293.[2]	1.03

1. Based on graphical estimates

2. Temperature at Node 2

Figure 116.2: Surface Temperature History Plot

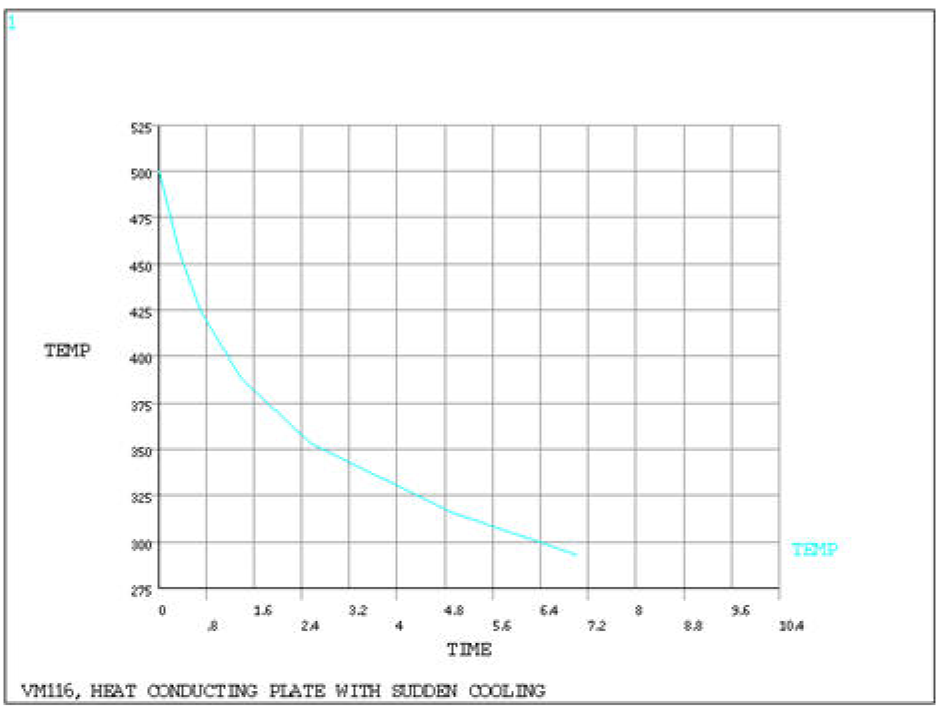
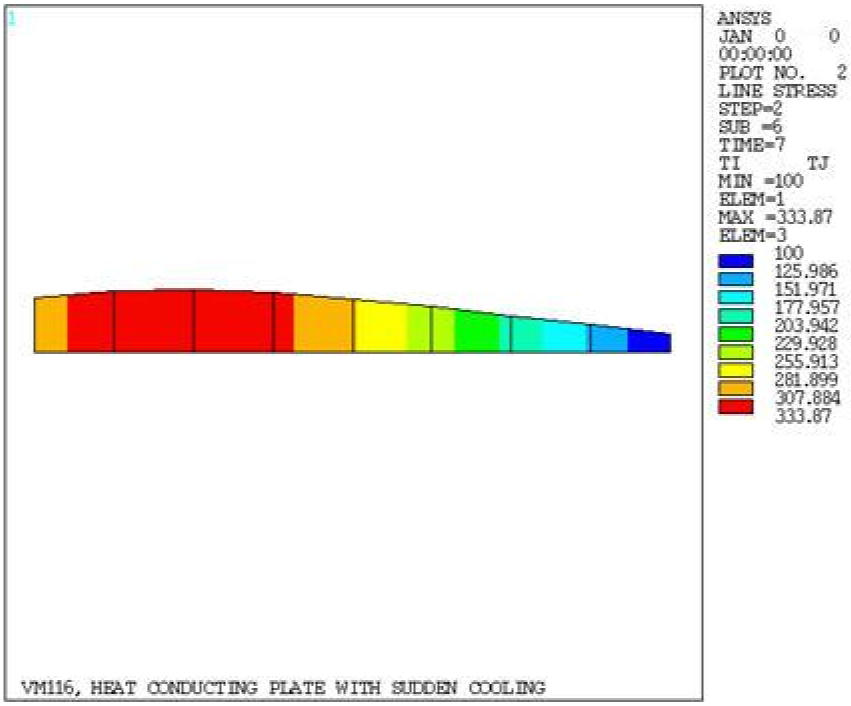


Figure 116.3: Temperature Distribution Across Thickness Plot



VM117: Electric Current Flowing in a Network

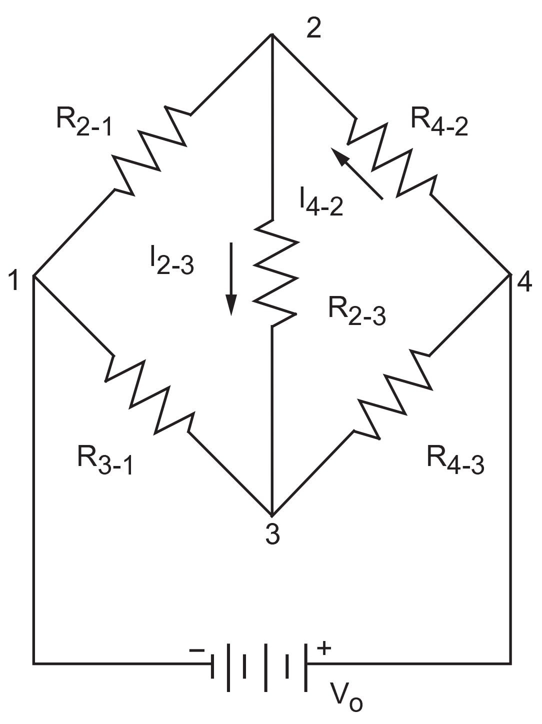
Overview

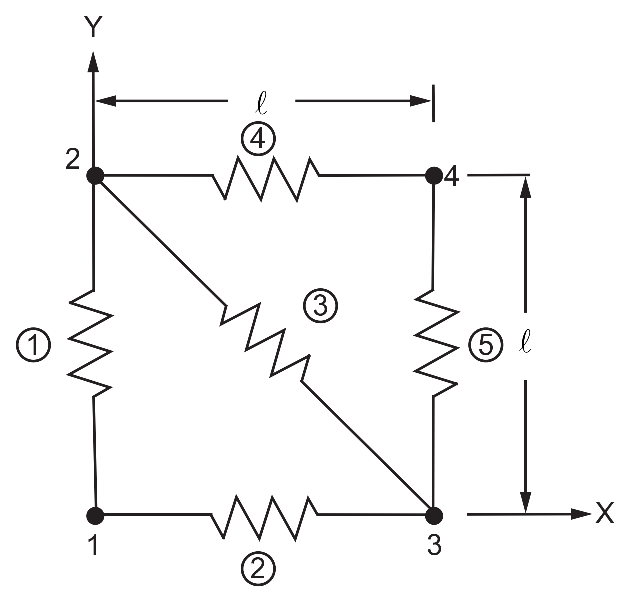
Reference:	A. E. Fitzgerald, D. E. Higginbotham, *Basic Electrical Engineering*, 2nd Edition, McGraw-Hill Book Co., Inc., New York, NY, 1957, pg. 22, ex. 1-11.
Analysis Type(s):	Thermal (electrical) Analysis (**ANTYPE** = 0)
Element Type(s):	Coupled Thermal-Electric Line Elements (LINK68) Electric Circuit Element (CIRCU124)
Input Listing:	vm117.dat

Test Case

The network shown below is that of an unbalanced bridge used in measuring resistance. With the circuit parameters as specified, determine the current $I_{a\text{-}b}$ flowing in each branch (from a to b) and the voltage at each node.

Figure 117.1: Electric Current Problem Sketch





Material Properties	Loading
$R_{2\text{-}1}$ = 20 Ω $R_{3\text{-}1}$ = 10 Ω $R_{2\text{-}3}$ = 9 Ω $R_{4\text{-}2}$ = 30 Ω $R_{4\text{-}3}$ = 90 Ω	V_o = 100 volts

Analysis Assumptions and Modeling Notes

The branch resistance is implicitly input as the element area (real constant). A convenient geometric configuration is assumed (ℓ = 1 ft) and the material resistivity is taken as 1 ohm-ft (input as material property RSVX). The areas are calculated from the relation: $A = \rho\ell/R$, where A = area of element (ft^2), ℓ = length of element (ft), ρ = resistivity (ohm-ft), R = given resistance (ohm).

Node 1 is assumed to be the ground node for reference. POST1 is used to extract the currents in each branch. A negative value indicates that current flow is opposite to the assumed direction (Node I to J of the element).

Results Comparison

LINK68	Target	Mechanical APDL	Ratio
V_1, volts	0.0	0.0	-
V_2, volts	28.0	28.0	1.00
V_3, volts	19.0	19.0	1.00
V_4, volts	100.0	100.0	1.00
I_{2-1}, amps	1.4	1.4	1.00
I_{3-1}, amps	1.9	1.9	1.00
I_{2-3}, amps	1.0	1.0	1.00
I_{4-2}, amps	2.4	2.4	1.00
I_{4-3}, amps	0.9	0.9	1.00
I_{1-4}, amps	3.3	3.3	1.00

CIRCU124	Target	Mechanical APDL	Ratio
V_1, volts	0.0	0.0	-
V_2, volts	28.0	28.0	1.00
V_3, volts	19.0	19.0	1.00
V_4, volts	100.0	100.0	1.00
I_{2-1}, amps	1.4	1.4	1.00
I_{3-1}, amps	1.9	1.9	1.00
I_{2-3}, amps	1.0	1.0	1.00
I_{4-2}, amps	2.4	2.4	1.00
I_{4-3}, amps	0.9	0.9	1.00
I_{1-4}, amps	3.3	3.3	1.00

VM118: Centerline Temperature of a Heat-generating Wire

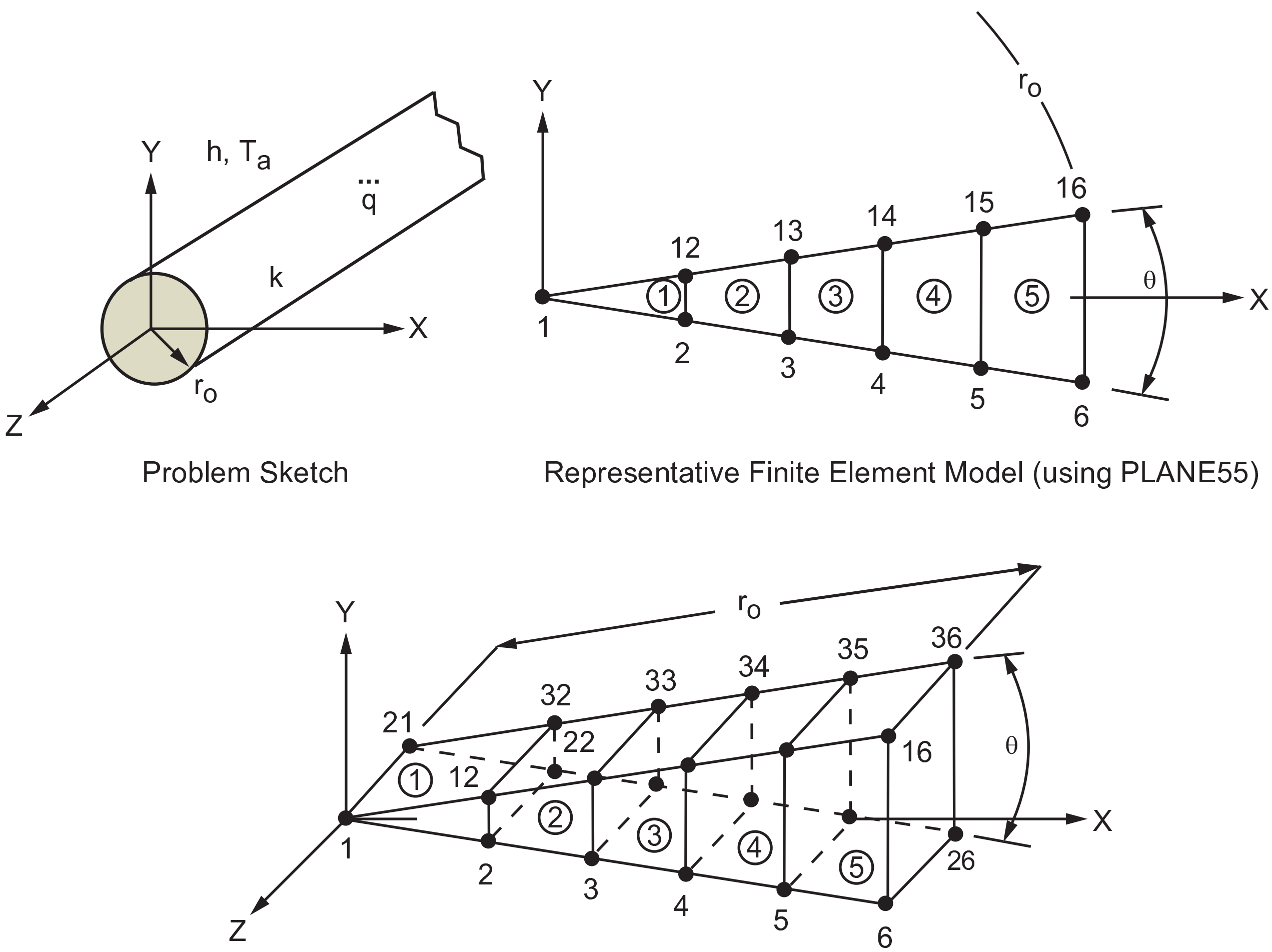
Overview

Reference:	W. M. Rohsenow, H. Y. Choi, *Heat, Mass and Momentum Transfer*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1963, pg. 106, ex. 6.5.
Analysis Type(s):	Thermal Analysis (CIRCU124 = 0)
Element Type(s):	2-D Thermal Solid Elements (PLANE55) 3-D Thermal Solid Elements (SOLID70)
Input Listing:	vm118.dat

Test Case

Determine the centerline temperature $T_{℄}$ and the surface temperature T_s of a bare steel wire generating heat at the rate $\dddot{q}$. The surface convection coefficient between the wire and the air (at temperature T_a) is h. Also determine the heat dissipation rate q.

Figure 118.1: Heat-generating Wire Problem Sketch



Problem Sketch

Representative Finite Element Model (using PLANE55)

Representative Finite Element Model (using SOLID70)

Material Properties	Geometric Properties	Loading
$k = 13$ Btu/hr-ft-°F $h = 5$ Btu/hr-ft^2-°F	$r_o = 0.375$ in = 0.03125 ft	$T_a = 70$°F $\dddot{q} = 111311.7$ Btu/hr-ft^3

Analysis Assumptions and Modeling Notes

The problem is solved first using conducting area elements (PLANE55) and then using conducting solid elements (SOLID70). Since the problem is axisymmetric, only a one-element sector is needed. A small angle Θ = 10° is used for approximating the circular boundary with a straight-sided element. Nodal coupling is used to ensure circumferential symmetry. The solution is based on a wire 1 foot long (Z-direction). POST1 is used to extract results from the solution phase. Total heat dissipation is computed parametrically at the outer surface as HRATE using q = h.area.(T_s - T_a).

Results Comparison

		Target	Mechanical APDL	Ratio
PLANE55	Centerline Temperature, °F	419.9	418.6	0.997
	T_s, °F	417.9	416.5	0.997
	q, Btu/hr	341.5	339.8	0.995
SOLID70	Centerline Temperature, °F	419.9	418.6	0.997
	T_s, °F	417.9	416.5	0.997
	q, Btu/hr	341.5	339.8	0.995

VM119: Centerline Temperature of an Electrical Wire

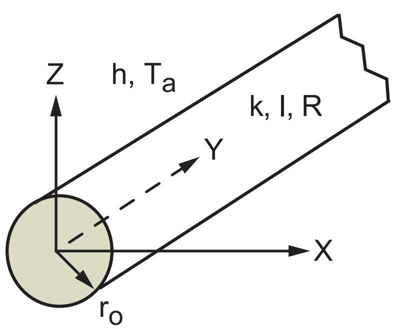
Overview

Reference:	W. M. Rohsenow, H. Y. Choi, *Heat, Mass and Momentum Transfer*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1963, pg. 106, ex. 6.5.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Coupled-Field Solid Elements (PLANE223) 3-D Coupled-Field Solid Elements (SOLID226)
Input Listing:	vm119.dat

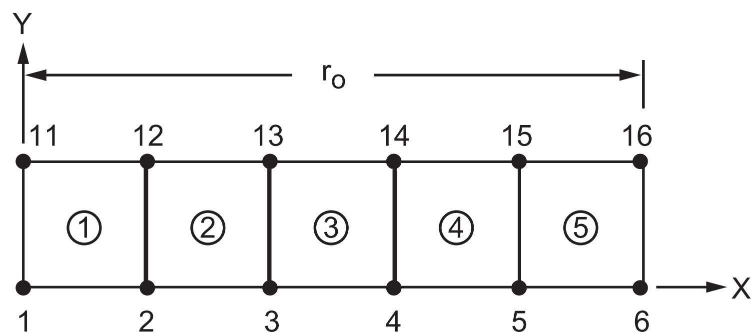
Test Case

Determine the centerline temperature $T_{℄}$ and the surface temperature T_s of a bare steel wire carrying a current I and having a resistance R. The surface convection coefficient between the wire and the air (at temperature T_a) is h. Also determine the heat dissipation rate q.

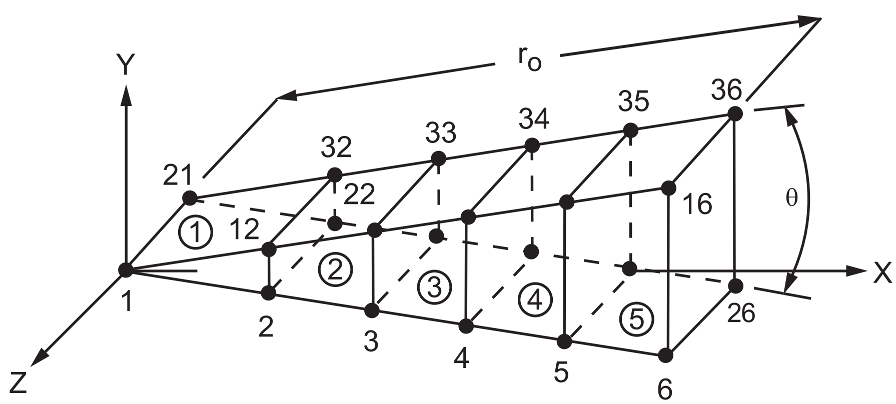
Figure 119.1: Electrical Wire Problem Sketch



Problem Sketch



Representative Finite Element Model (using PLANE223)



Representative Finite Element Model (using SOLID226)

Material Properties	Geometric Properties	Loading
k = 13 Btu/hr-ft °F h = 5 Btu/hr-ft^2-°F R = 0.0001 Ω/ft	r_o = 0.375 in = 0.03125 ft	T_a = 70°F I = 1000 A

Analysis Assumptions and Modeling Notes

The problem is solved first using thermal-electric axisymmetric elements (PLANE223) and then using thermal-electric solid elements (SOLID226).

A 1 foot axial length is chosen for convenience. The voltage drop per foot is IR = 0.1 volt/ft. The resistivity ρ is calculated as ρ = RA/L = (0.0001)(π)$(0.03125)^2$/(1) = 3.06796 x 10^{-7} Ω-ft.

A conversion factor 3.415 (Btu/hr)/W must be included in the resistivity ρ so that the Joule heat units match the thermal units ρ/3.415 = 8.983782 x 10^{-8}. Current printout is divided by 3.415 to get electrical (amp) units. The steady-state convergence procedures are used.

The solution is based on a unit radian model. Since the problem is axisymmetric, only a one-element sector is needed. A small angle Θ = 10° is used for approximating the circular boundary with a straight-sided element.

POST1 is used to extract results from the solution phase. Total heat dissipation is computed parametrically at the outer surface as HRATE using q = h.area.(T_s-T_a).

Results Comparison

		Target	Mechanical APDL	Ratio
PLANE223	Centerline Temperature, °F	419.9	420.0	1.000
	T_s, °F	417.9	417.8	1.000
	q, Btu/hr	341.5	341.5	1.000
SOLID226	Centerline Temperature, °F	419.9	422.2	1.006
	T_s, °F	417.9	420.1	1.005
	q, Btu/hr	341.5	343.2	1.005

VM120: Microstrip Transmission Line Capacitance

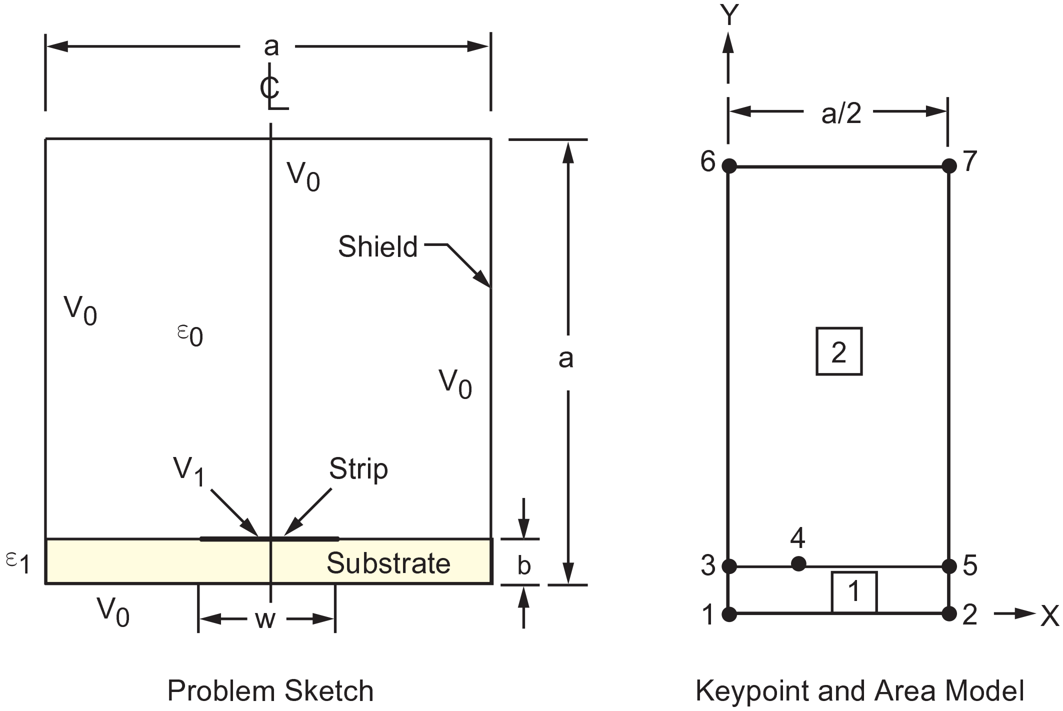
Overview

Reference:	J. Beren, R. Kaires, "EMGAP Solves Electromagnetic Problems Using Finite Element Analysis", *Tektronix Internal Publication*, Beaverton, OR, May 1983.
Analysis Type(s):	Electrostatic Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 8-Node Electrostatic Solid Element (PLANE121)
Input Listing:	vm120.dat

Test Case

A shielded microstrip transmission line consists of a substrate, microstrip, and a shield. The strip is at a potential V_1, and the shield is at a potential V_0. Determine the capacitance of the transmission line.

Figure 120.1: Microstrip Transmission Line Problem Sketch



Material Properties	Geometric Properties	Loading
$\varepsilon_0 = 8.85 \times 10^{-12}$ F/m $\varepsilon_1 = 8.85 \times 10^{-11}$ F/m	a = 10 cm b = 1 cm w = 1 cm	$V_1 = 1.5$ v $V_0 = 0.5$ v

Analysis Assumptions and Modeling Notes

The capacitance of the device can be calculated from electrostatic energy and the applied potential difference as $W_e = 1/2\ C\ (V_1\text{-}V_o)^2$ where W_e is the electrostatic energy and C is the capacitance. The electrostatic energy is available by summing the energies for all the elements in the model in POST1. Additional postprocessing includes displaying equipotential lines and the electric field as vectors.

Results Comparison

	Target	Mechanical APDL	Ratio
Capacitance, pF/m	178.1	179.2	1.006

VM121: Voltage Forced Coil

Overview

Reference:	P.J. Leonard and D. Rodger, "*Voltage Forced Coils for 3-D Finite-Element Electromagnetic Models*", IEEE Transactions on Magnetics, Vol. 24, No. 6 (1988).
Analysis Type(s):	Transient Analysis (**ANTYPE**=4)
Element Type(s):	3-D 20-Node Electromagnetic Solid (SOLID236)
Input Listing:	vm121.dat

Test Case

A circular coil of rectangular cross-section is modeled between two aluminum plates (first solution) and in free-space (second solution). A transient analysis is performed with a 20 volt step excitation. The total current flowing through the coil is calculated.

Material Properties	Geometric Properties	Loading
μr = 1.0 (air) μr = 1.0 (plate) μr = 1.0 (coil) R= 3 x 10^{-8} Ω-m (Resistivity of plate)	Coil: n=700 turns Ri=0.087m(inner radius) H=0.116m(height) Ro=0.116m(outer radius) Plate: 0.24 x 0.24 x 0.0127 m^3	V=20 Volt

Analysis Assumptions and Modeling Notes

This model solves the voltage forced coil problem using 20-node electromagnetic SOLID236 elements with different key options:

- SOLID236 elements with KEYOPT (1) = 0 for air (AZ).
- SOLID236 elements with KEYOPT (1) = 1 for plate (AZ, VOLT)
- SOLID236 elements with KEYOPT (1) = 2 for stranded coil (AZ, VOLT, EMF)

A 1/8 symmetric 3-D model is constructed (Figure 121.1: Finite Element Mesh of the Coil and Plate (p. 322)). The step voltage input is applied on the coil. The current source density in the coil and the plate are shown in Figure 121.3: Current Density in the Plate (p. 323) and Figure 121.4: Coil Current vs. Time (p. 323).

The target data is obtained from Figure 4 in the reference paper.

Figure 121.1: Finite Element Mesh of the Coil and Plate

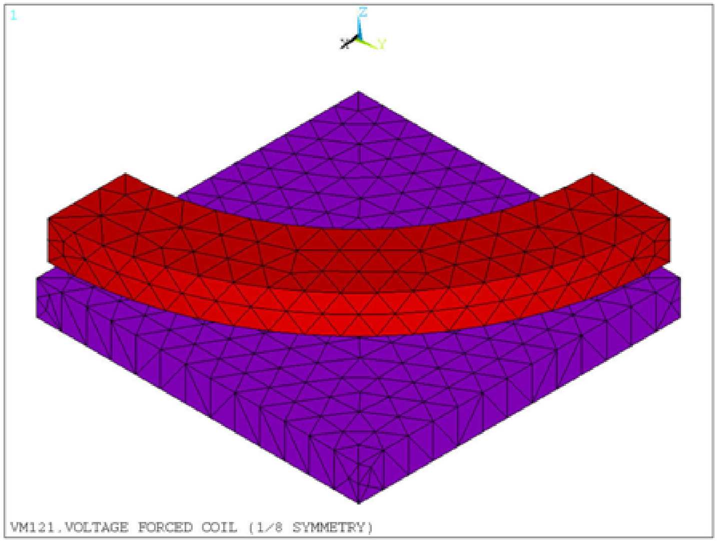


Figure 121.2: Current Density in the Coil

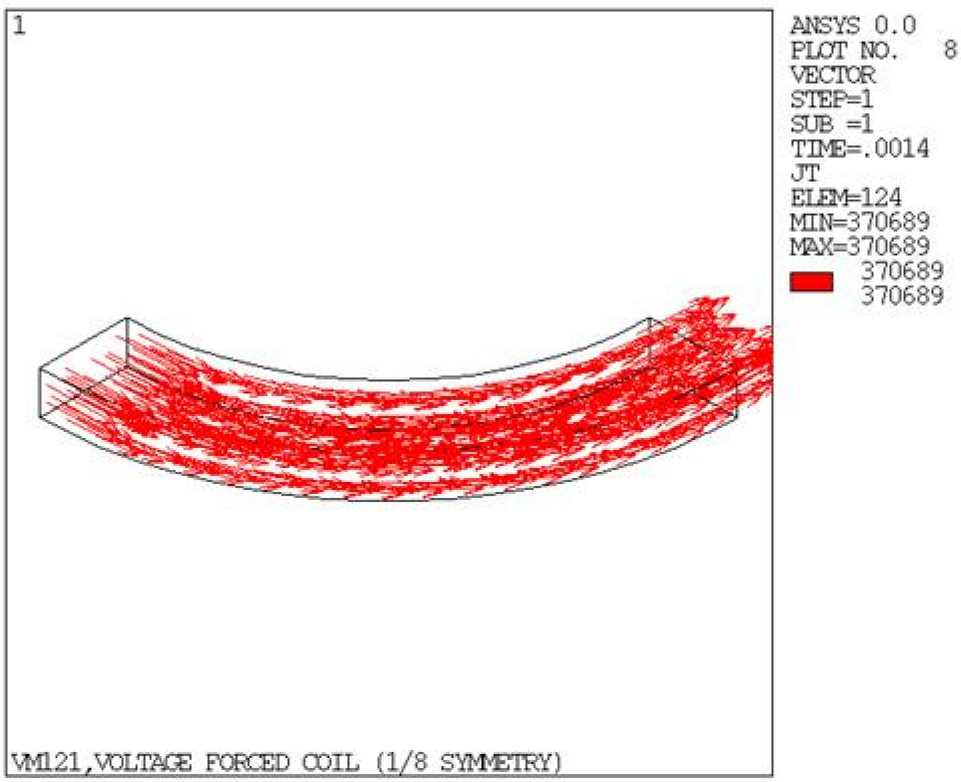


Figure 121.3: Current Density in the Plate

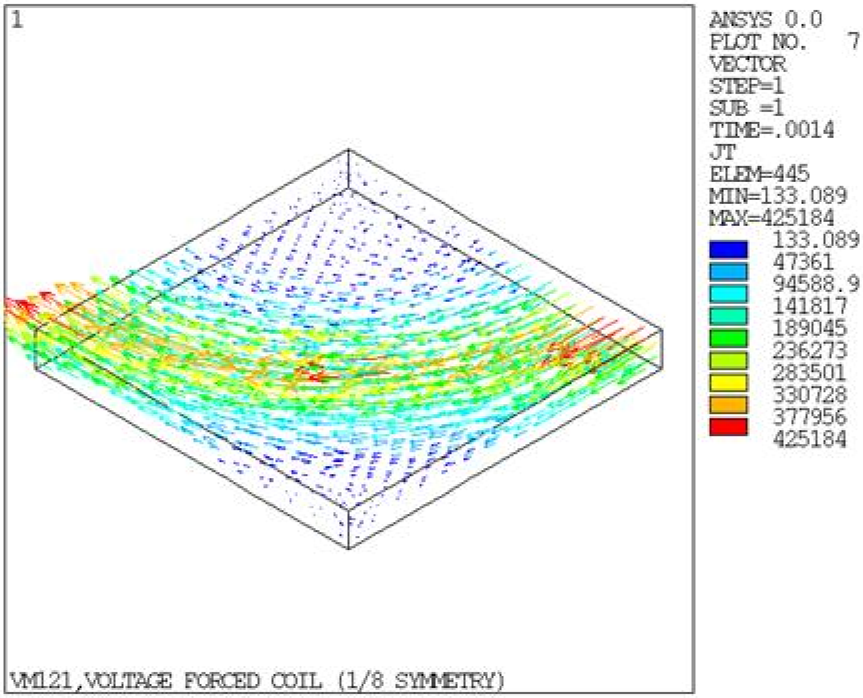
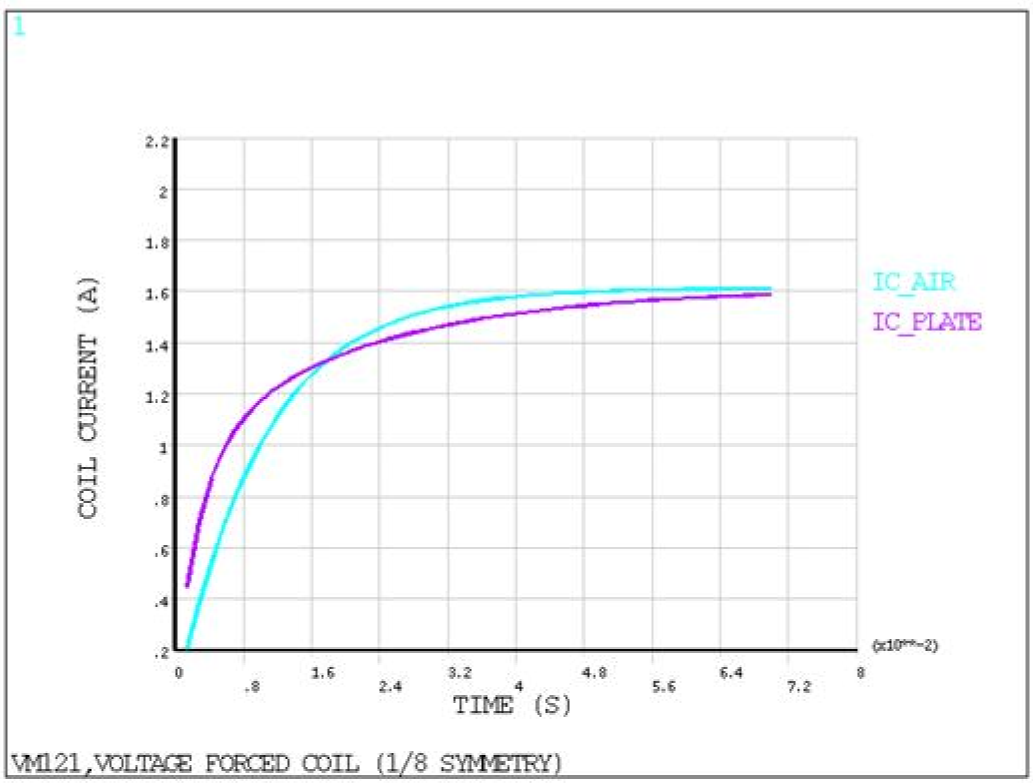


Figure 121.4: Coil Current vs. Time



Results Comparison

Time=1x10^{-2} sec	**Target**	**Mechanical APDL**	**Ratio**

Current in coil with plate (A)	1.160	1.156	0.997
Current in coil in free space (A)	0.970	0.975	1.005

Time=4x10^{-2} sec	**Target**	**Mechanical APDL**	**Ratio**
Current in coil with plate (A)	1.510	1.512	1.002
Current in coil in free space (A)	1.570	1.578	1.005

Time=7x10^{-2} sec	**Target**	**Mechanical APDL**	**Ratio**
Current in coil with plate (A)	1.580	1.586	1.004
Current in coil in free space (A)	1.610	1.611	1.000

VM122: Pressure Drop in a Turbulent Flowing Fluid

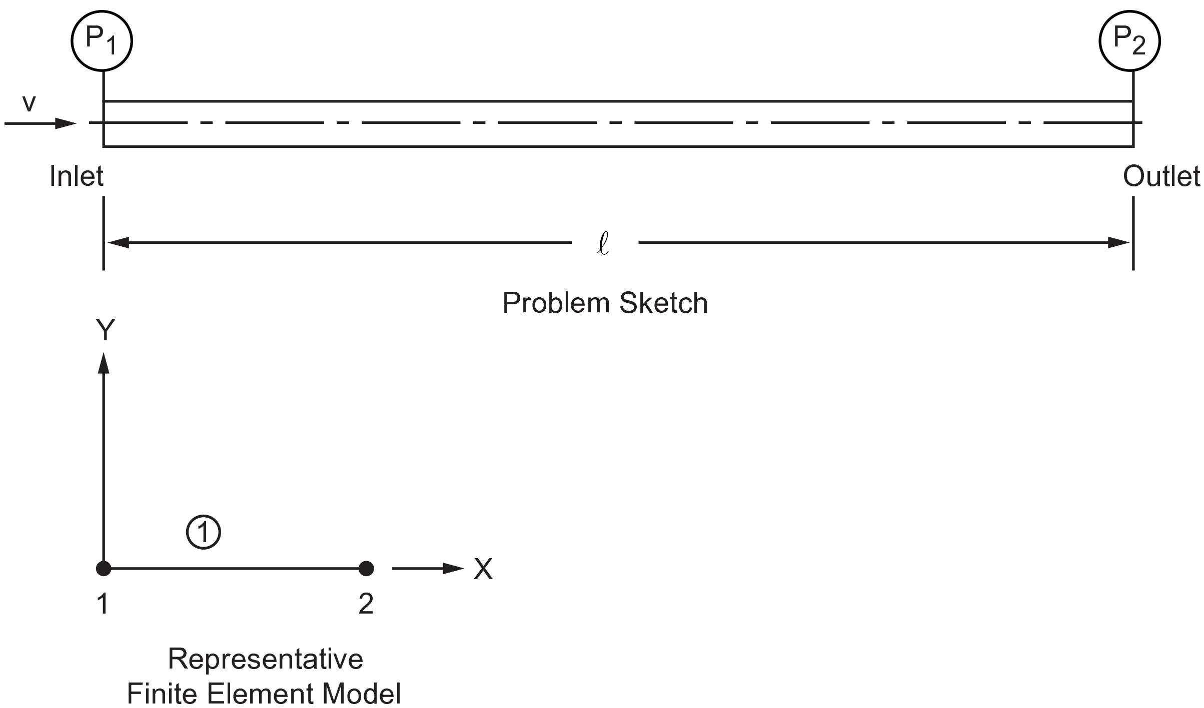
Overview

Reference:	R. C. Binder, *Fluid Mechanics*, 3rd Edition, 3rd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1956, pg. 118, article 8-6.
Analysis Type(s):	Thermal (pressure) Analysis (**ANTYPE** = 0)
Element Type(s):	Coupled Thermal-Fluid Pipe Elements (FLUID116)
Input Listing:	vm122.dat

Test Case

Benzene at 50°F flows through a horizontal commercial steel pipe of diameter d, with an average velocity v. Determine the pressure drop, Δp, in a length ℓ of pipe. The pipe friction factor is f.

Figure 122.1: Turbulent Flowing Fluid Problem Sketch



Material Properties	Geometric Properties	Loading
f = 0.016 sp. gr. (specific gravity) = 0.9	ℓ = 200 ft = 2400 in d = 6 in	v = 132 in/sec

Analysis Assumptions and Modeling Notes

The inlet flow rate w is input as a nodal quantity. The outlet pressure is defined to be zero for reference. An iterative solution is required to find the pressure drop. The following quantities are required for input and are calculated from the given data:

ρ = mass density = sp. gr. x ρH_20 = 0.9 x 62.4
= /(386.4 x 12^3) = 8.411 x 10^{-5} lb_f-sec^2/in^4

w = mass flow rate = ρvA = 8.411 x 10^{-5} x 132 x π x 6 2/4
= .3138 lb_f/sec/in

Results Comparison

	Target	Mechanical APDL	Ratio
Pressure Drop , psi	4.69	4.69[1]	1.00

1. Pressure drop Δp is given by PRES degree of freedom at node 1.

VM123: Laminar Flow in a Piping System

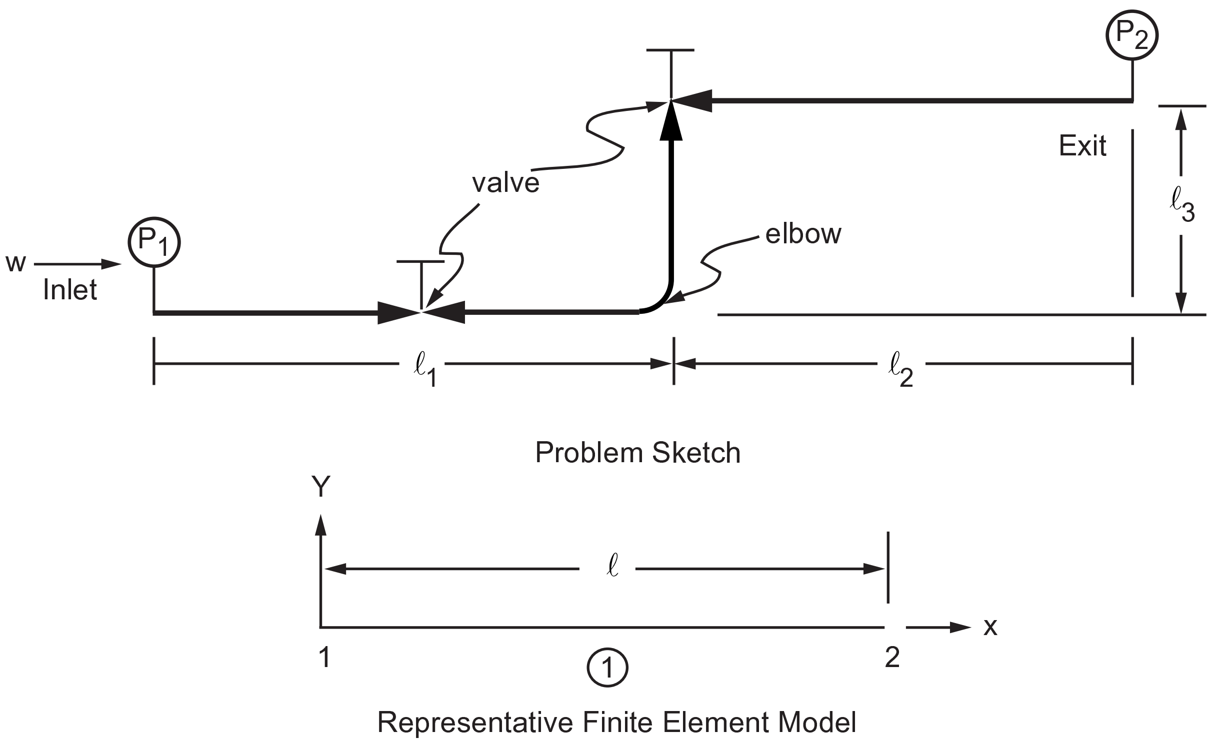
Overview

Reference:	Crane Company Engineering Division, "Flow of Fluids through Valves, Fittings, and Pipe", Technical Paper No. 410, Chicago, IL, 1969, pg. 4-5, ex. 4-9.
Analysis Type(s):	Thermal (pressure) Analysis (**ANTYPE** = 0)
Element Type(s):	Coupled Thermal-Fluid Pipe Elements (FLUID116)
Input Listing:	vm123.dat

Test Case

S.A.E. 70 lube oil at 0°F is flowing through a horizontal 5″ schedule 40 piping system (of diameter d) at a flow rate w. Determine the pressure drop, Δp, and the Reynold's number Re. Assume that the friction factor is determined by the laminar flow relationship for smooth pipes. The equivalent length of elbow and valves to account for flow losses is ℓ_a.

Figure 123.1: Laminar Flow Problem Sketch



Material Properties	Geometric Properties	Loading
μ = viscosity = 0.010032 lb-sec/ft^2 ρ = 1.7546 lb-sec^2/ft^4	d = 0.4206 ft ℓ_1 = 175 ft ℓ_2 = 75 ft ℓ_3 = 50 ft ℓ_a = 53 ft	w = 2.345 slugs/se/sec

Analysis Assumptions and Modeling Notes

The piping system is modeled using a single element of length $\ell = \ell_1 + \ell_2 + \ell_3 = 300$ ft. The flow, w, is input at the inlet node. The exit pressure is defined to be zero for reference. An iterative solution is required. A friction factor of 0.05 (input for MU) is assumed for a starting value.

Results Comparison

	Target	Mechanical APDL	Ratio
Pressure Drop, lb/ft^2	6160.	6164.[1]	1.001
Re	708.	708.	1.000

1. Pressure drop Δp is given by the PRES degree of freedom at node 1.

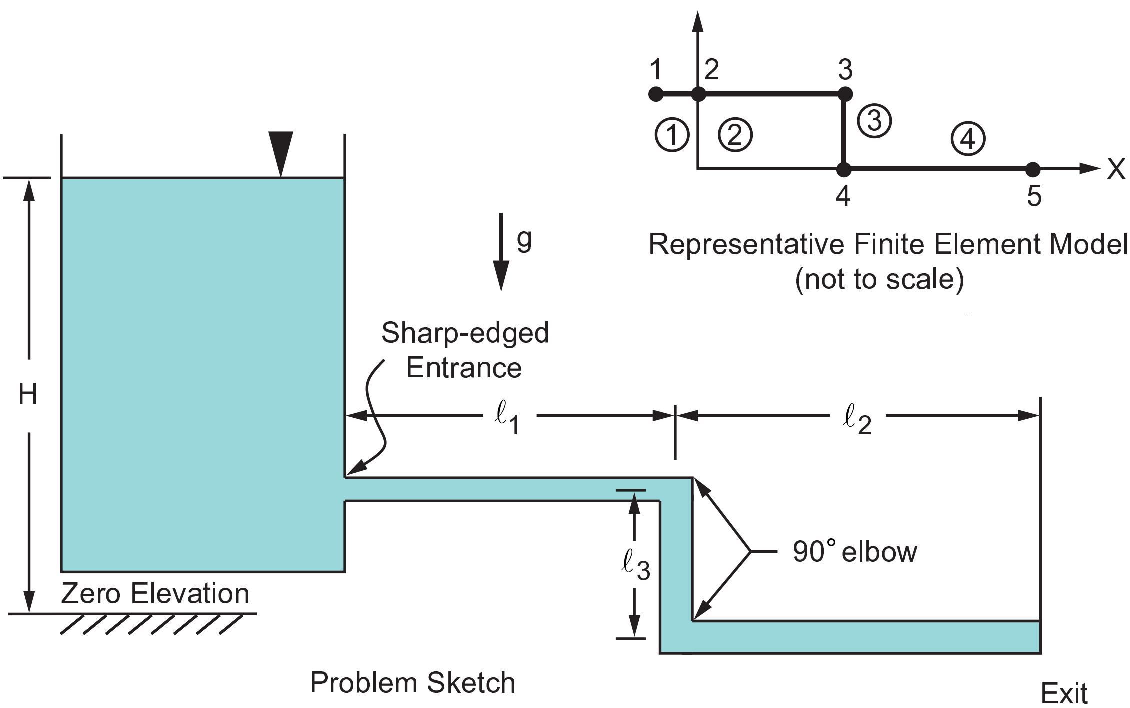
VM124: Discharge of Water from a Reservoir

Overview

Reference:	K. Brenkert, Jr., *Elementary Theoretical Fluid Mechanics*, John Wiley and Sons, Inc., New York, NY, 1960, pg. 224, ex. 4.
Analysis Type(s):	Thermal (pressure) Analysis (**ANTYPE** = 0)
Element Type(s):	Coupled Thermal-Fluid Pipe Elements (FLUID116)
Input Listing:	vm124.dat

Test Case

Water (density ρ, viscosity μ) flows from a large reservoir into a long piping system. Determine the Reynold's number Re and the flow rate w for pipes of friction factor f and diameter d. The loss coefficients for the sharp-edged entrance and 90° elbow are K_1 and K_2, respectively.



Material Properties	Geometric Properties	Loading
ρ = 1.94 lb-sec^2/ft^4 μ = 2.36 x 10^{-5} lb-sec/ft^2	H = 20 ft ℓ_1 = 20 ft ℓ_2 = 70 ft ℓ_3 = 10 ft d = 0.25 ft	K_1 = 0.5 K_3 = 0.9 f = 0.028 for 10^5 < Re < 10^6 g = 32.2 ft/sec^2

Analysis Assumptions and Modeling Notes

The reservoir head is given by (H - ℓ_3) = 10 ft. This is applied as a pump head within a short (0.01 ft, to minimize friction) horizontal element. The acceleration input accounts for the vertical flow. The exit pressure and the water surface pressure is defined to be zero. An iterative solution is required. A friction factor of 0.025 (input for MU) is assumed for a starting value.

Results Comparison

	Target	Mechanical APDL	Ratio
w, lb_fsec/ft	0.898	0.930[1]	1.036
Re	1.94×10^5	2.01×10^5	1.035

1. w is given by nodal flow at node 1.

VM125: Radiation Heat Transfer Between Concentric Cylinders

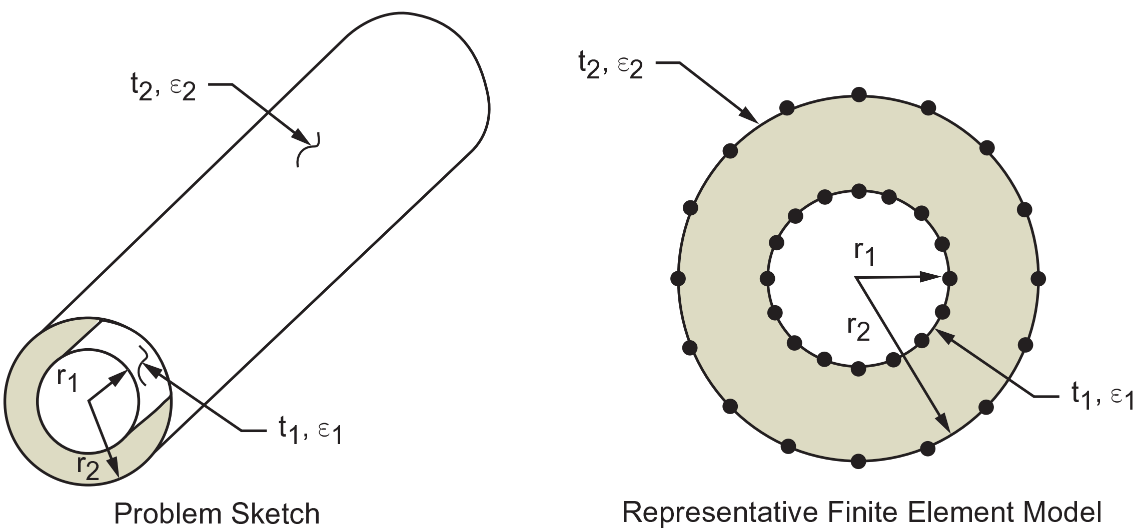
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 260.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0) AUX12 (Radiation View Factor Utility)
Element Type(s):	3-D Conduction Bar Elements (LINK33) Superelement (or Substructure) (MATRIX50)
Input Listing:	vm125.dat

Test Case

Two long concentric cylinders are held at constant temperatures T_1 and T_2. Determine the rate of radiative heat transfer between the cylinders.

Figure 125.1: Concentric Cylinders Problem Sketch



Material Properties	Geometric Properties	Loading
ε_1 = 0.7	r_1 = 1 in	T_1 = 1000°R
ε_2 = 0.5	r_2 = 2 in	T_2 = 460°R

Analysis Assumptions and Modeling Notes

The cylinders are assumed to be sufficiently long enough to neglect end losses. A 2-D model is used to determine the heat transfer rate per unit depth. The thermal conductivity and cross-sectional areas of the conducting bars are arbitrarily set equal to 1. The Stefan-Boltzmann constant defaults to 0.119 x 10^{-10} Btu/hr-in^2-°R^4 (value given in reference).

Results Comparison

	Target	Mechanical APDL	Ratio
Q, Btu/hr-in	37.0[1]	36.4	0.984

1. Based on two cylinders 100 inches long.

VM126: Heat Transferred to a Flowing Fluid

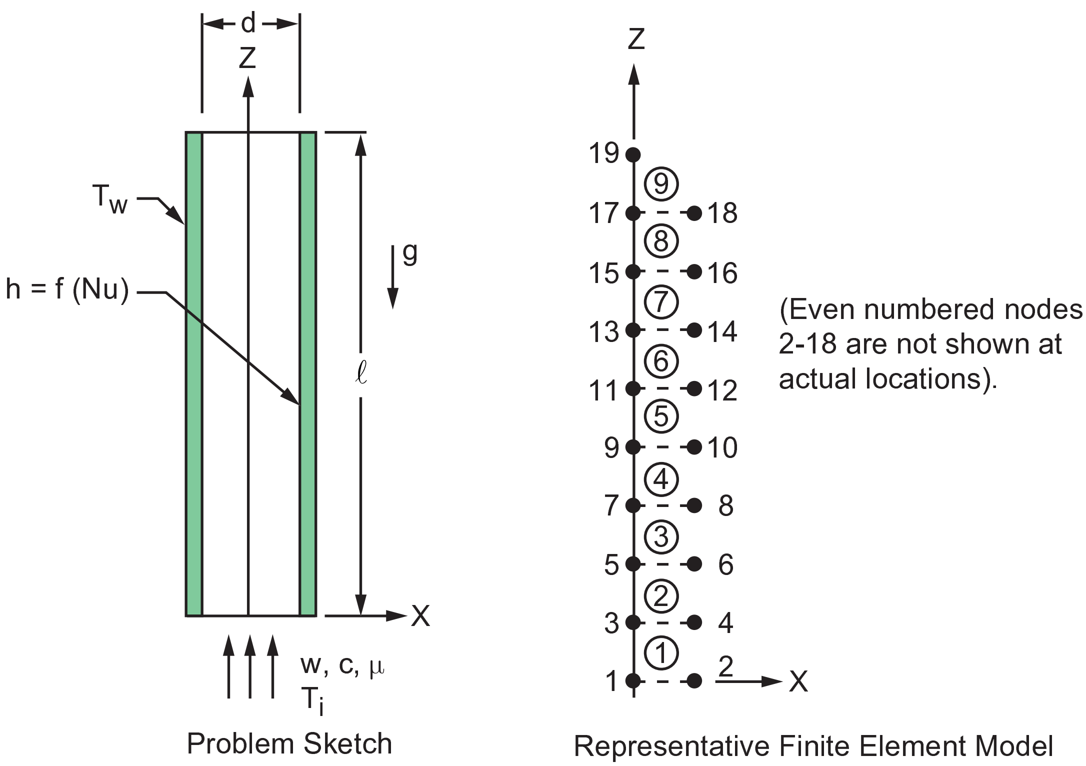
Overview

Reference:	W. M. Rohsenow, H. Y. Choi, *Heat, Mass and Momentum Transfer*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1963, pg. 168, ex. 7.5
Analysis Type(s):	Thermal (fluid flow) Analysis (**ANTYPE** = 0)
Element Type(s):	Coupled Thermal-Fluid Pipe Elements (FLUID116)
Input Listing:	vm126.dat

Test Case

Heat is transferred to air at 14.7 psi, and temperature T_i, flowing at a rate w inside a round tube of length ℓ and diameter d having a uniform tube wall temperature T_w. Determine the heat flow in terms of the inlet (q_{in}) and outlet (q_{out}) heat transport rates. Also determine the air outlet temperature T_o. The convection coefficient is given by the expression Nu = 0.08 $Re^{0.7}$ $Pr^{0.35}$ + 1.63. The tube is nearly frictionless.

Figure 126.1: Flowing Fluid Problem Sketch



Material Properties	Geometric Properties	Loading
k = 0.017 BTU/hr-ft-°F c = 1.002 x 18^8 BTU - ft/lb_f-hr^2-°F	d = 1 in = (1/12) ft ℓ = 5 in = (5/12) ft	T_i = 100°F T_w = 200°F w = 1.131 x 10^{-8} lb_f hr/ft

Material Properties	Geometric Properties	Loading
$\mu = 1.17418 \times 10^{-10}$ lb_f hr/ft^2 $\rho = 1.4377 \times 10^{-10}$ lb_f-hr^2/ft^4 f = 0.001 for 0 < Re < 5 x 10^4		

Analysis Assumptions and Modeling Notes

The convection node locations are arbitrarily selected as coincident. The flow rate (w) is input as a real constant, so MU is not required to be input. The nonlinear material property table is used to input the friction factor table and the flow-dependent film coefficient. Since the heat transport rate is calculated at the element inlet, an extra element is extended beyond the tube exit to obtain q_{out}. POST1 is used to report the required quantities.

Results Comparison

	Target	Mechanical APDL	Ratio
T_o , °F	123.0	122.55[1]	0.996
q_{in} , Btu/hr	113.28	113.44[2]	1.001
q_{out} , Btu/hr	139.33	139.02[2]	0.998

1. Temperature at Node 17.

2. q_{in} and q_{out} are obtained from the heat transport rates of elements 1 and 9, respectively.

VM127: Buckling of a Bar with Hinged Ends (Line Elements)

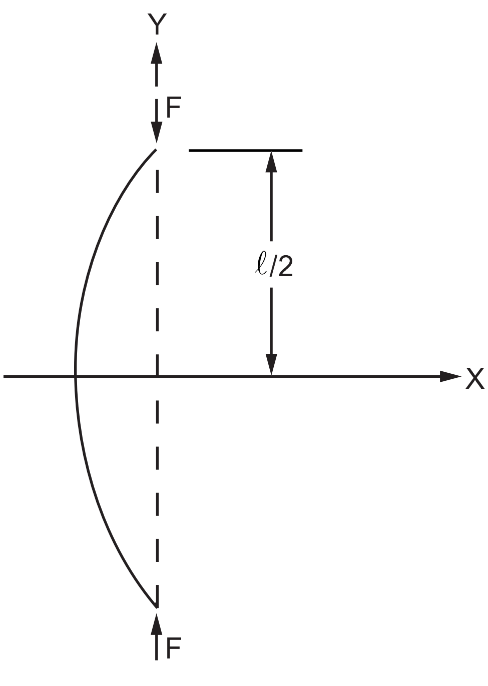
Overview

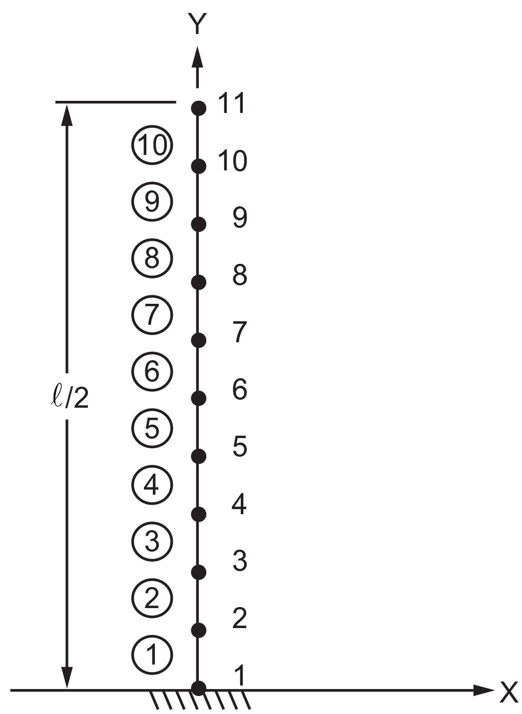
Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pg. 148, article 29.
Analysis Type(s):	Linear Perturbed Buckling Analysis (**ANTYPE** = 1)
Element Type(s):	3-D 2 Node Beam (BEAM188)
Input Listing:	vm127.dat

Test Case

Determine the critical buckling load of an axially loaded long slender bar of length ℓ with hinged ends. The bar has a square cross-section with width and height set to 0.5 inches.

Figure 127.1: Buckling Bar Problem Sketch





Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi	ℓ = 200 in I= 0.5 in	F = 1 lb

Analysis Assumptions and Modeling Notes

Only the upper half of the bar is modeled because of symmetry. The boundary conditions become free-fixed for the half symmetry model. The linear buckling analysis is solved using **PSTRES** command and using Linear Perturbation method.

Results Comparison

	Target	Mechanical APDL	Ratio
Using **PSTRES** command			
F_{cr}, lb	38.553	38.553[1]	1.000
Using Linear Perturbation Method			
F_{cr}, lb	38.553	38.553[1]	1.000

1. F_{cr} = Load Factor (1st mode).

VM128: Buckling of a Bar with Hinged Ends (Area Elements)

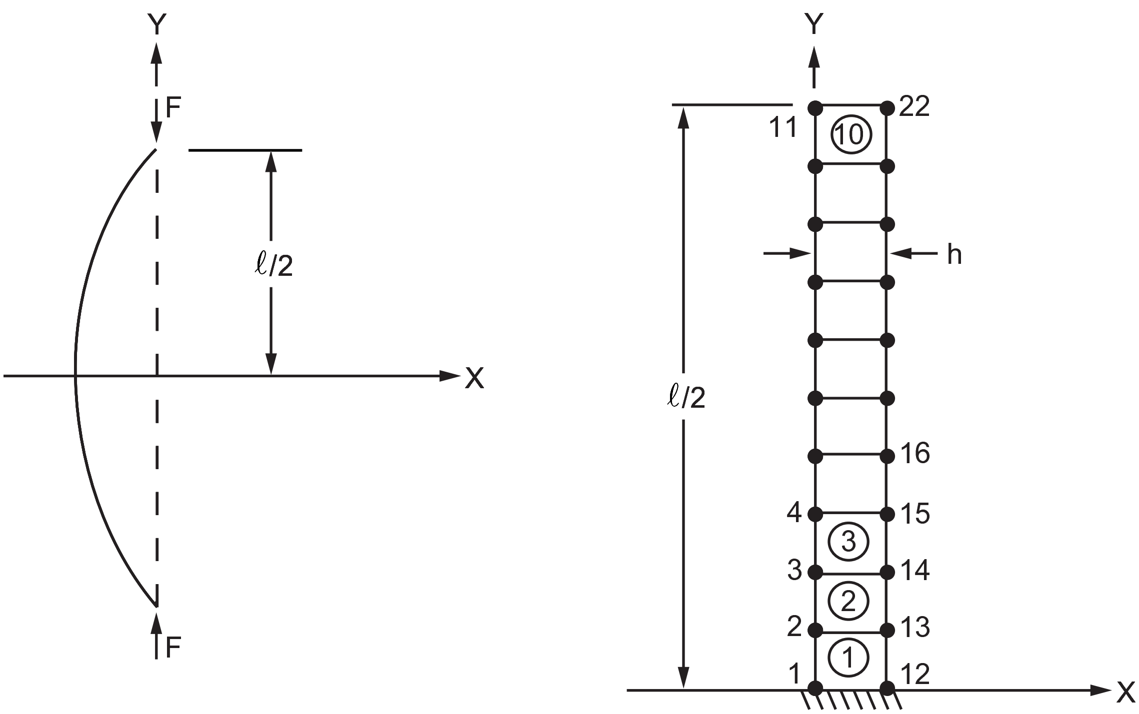
Overview

Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pg. 148, article 29.
Analysis Type(s):	Linear Perturbed Buckling Analysis (**ANTYPE** = 1)
Element Type(s):	2-D 4-Node Structural Solid Elements (PLANE182)
Input Listing:	vm128.dat

Test Case

Determine the critical buckling load of an axially loaded long slender bar of length ℓ with hinged ends. The bar has a cross-sectional height h, and area A.

Figure 128.1: Buckling Bar Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
E = 30 x 10^6 psi	ℓ = 200 in A = 0.25 in 2 h = 0.5 in	F = 1 lb

Analysis Assumptions and Modeling Notes

Only the upper half of the bar is modeled because of symmetry. The model is meshed using PLANE182 elements with enhanced strain formulation. The boundary conditions become free-fixed for the half symmetry model. The bar is assumed to have a rectangular cross-section (thickness = A/h = 0.5 in).

Results Comparison

	Target	Mechanical APDL	Ratio
F_{cr}, lb Subspace	38.553	38.755 [1]	1.005

1. F_{cr} = Load Factor (1st mode).

VM129: Numerical Differentiation and Integration

Overview

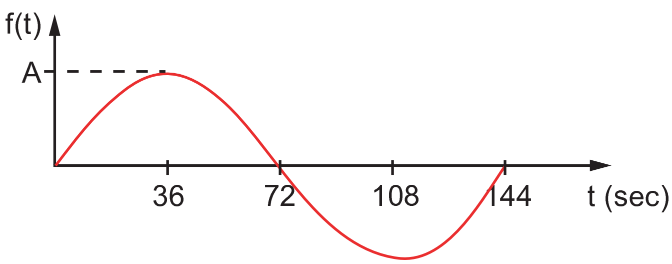
Reference:	Any Basic Calculus Book
Analysis Type(s):	First and Second Derivatives and Integrals Using APDL
Element Type(s):	None
Input Listing:	vm129.dat

Test Case

Given a sine wave f(t) = A sin ωt, find the maximum value of the first and second derivatives. For the same sine wave, find the values of the two integrals:

$$I_1 = \int_0^{36} f(t)dt \quad \text{and} \quad I_2 = \int_0^{36} \left[\int f(t)dt \right] dt$$

Figure 129.1: Numerical Differentiation and Integration



Problem Sketch

Definitions:

A = 1.2732
ω = frequency = π/72 rad/sec

Analysis Assumptions and Modeling Notes

Arrays for one cycle of 145 data points (one data point per second) are generated, starting from a value of 0 up to 144 (representing time, t, in sec). The ***VOPER** command is used to obtain the first and second derivatives, and the single and double integrals.

Results Comparison

	Target	Mechanical APDL	Ratio
df/dt (Max)	5.555×10^{-2}	5.554×10^{-2}	1.000
d^2f/dt^2 (Max)	2.424×10^{-3}	2.422×10^{-3}	0.999
I_1	29.18	29.17	1.000

	Target	Mechanical APDL	Ratio
I_2	381.7	381.6562	1.000

max df/dt is obtained as DERIV1 array parameter E.

max d^2f/dt^2 is obtained as DERIV2 array parameter G

$$I_1 = \int_0^{36} f\,dt \qquad \text{and} \qquad I_2 = \int_0^{36} \left[\int f\,dt \right] dt$$

I_1 and I_2 are obtained from array parameters F and H (at row 37 corresponding to t = 36 sec)

VM130: Fourier Series Generation for a Saw Tooth Wave

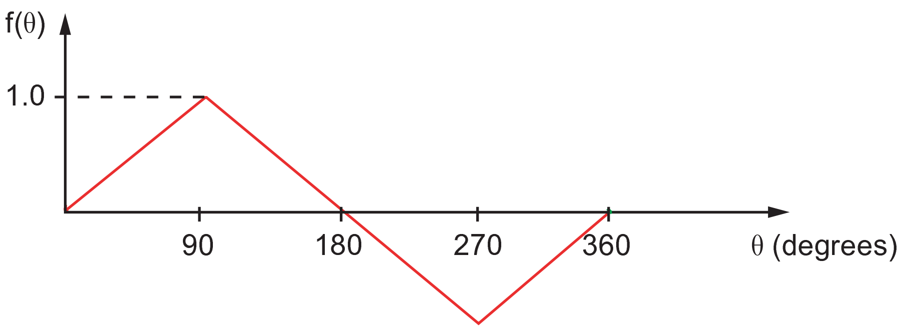
Overview

Reference:	S. Timoshenko, D. H. Young, *Vibration Problems in Engineering*, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 102, problem 2.
Analysis Type(s):	Fourier Coefficients Generated and Series Evaluated Using APDL
Element Type(s):	None
Input Listing:	vm130.dat

Test Case

For the saw tooth wave shown below, determine the coefficients of the Fourier series approximating this wave. Plot both the given wave and the wave as evaluated from the calculated series.

Figure 130.1: Saw Tooth Wave Problem Sketch



Problem Sketch

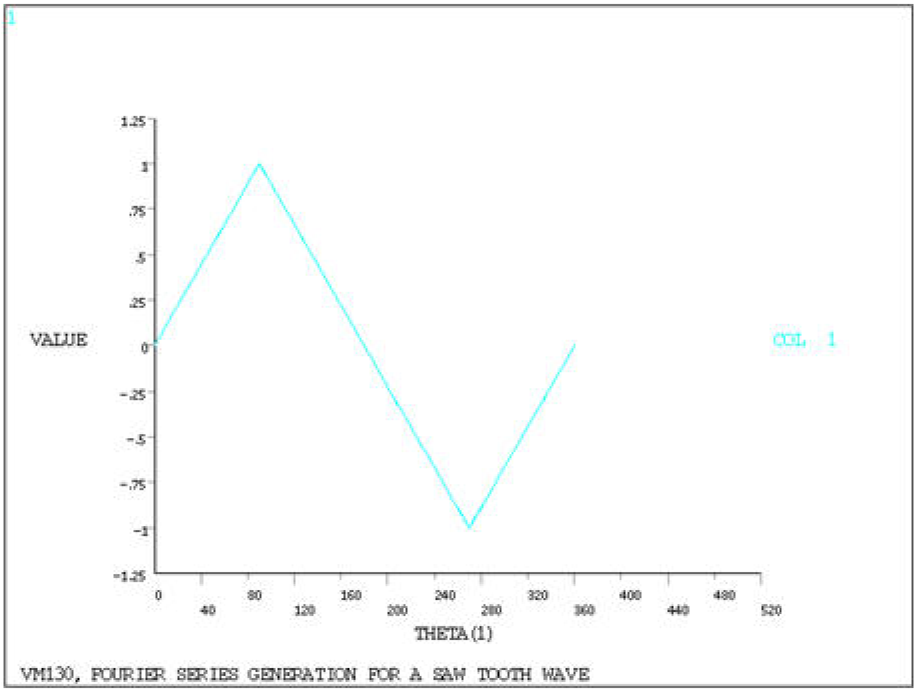
Analysis Assumptions and Modeling Notes

The wave is described by 121 points (arbitrary). Twenty four terms are assumed to be sufficient for the series. Since the wave is antisymmetric, only sine terms with odd modes are chosen.

Results Comparison

	Target	Mechanical APDL	Ratio
Mode 1 Coefficient	0.811	0.811	1.000
Mode 3 Coefficient	-0.901×10^{-1}	-0.902×10^{-1}	1.002
Mode 5 Coefficient	0.324×10^{-1}	0.326×10^{-1}	1.006
Mode 7 Coefficient	-0.165×10^{-1}	-0.167×10^{-1}	1.014

Figure 130.2: Fourier Display



VM131: Acceleration of a Rotating Crane Boom

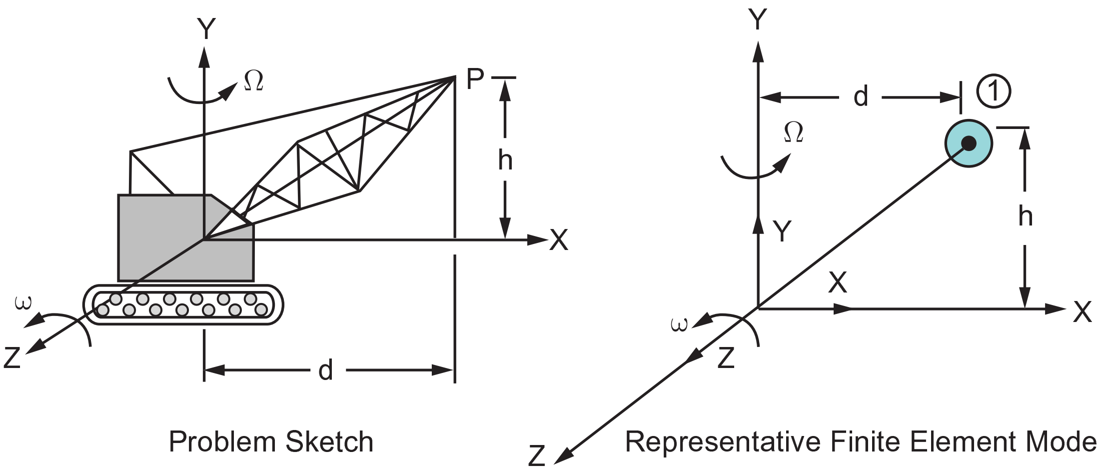
Overview

Reference:	F. P. Beer, E. R. Johnston, Jr., *Vector Mechanics for Engineers, Statics and Dynamics*, 5th Edition, McGraw-Hill Book Co., Inc., New York, NY, 1962, pg. 616, problem 15.13.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Structural Mass Elements (MASS21)
Input Listing:	vm131.dat

Test Case

Determine the acceleration at the tip P of a crane boom that has a constant angular velocity cab rotation (Ω) while being raised with a constant angular velocity (ω).

Figure 131.1: Rotating Crane Boom Problem Sketch



Geometric Properties	Loading
d = 34.64 ft h = 20 ft	Ω = 0.3 rad/sec ω = 0.5 rad/sec

Analysis Assumptions and Modeling Notes

Consider X', Y', Z' as the fixed reference coordinate system. The global Cartesian coordinate system (XYZ) is taken as attached to the cab which rotates at an angular velocity of Ω about the Y'-axis of the reference coordinate system. The boom angular velocity ω is applied about the global Z-axis. The Coriolis effect due to the rotation of the cab is modeled by putting a mass of 1 lb-sec^2/ft (without rotary inertia) at point P, and constraining its degrees of freedom. The reaction forces at the mass then give the acceleration components.

Results Comparison

	Target	Mechanical APDL [1]	Ratio
a_x , ft/sec^2	-11.78	-11.78	1.00
a_y , ft/sec^2	-5.00	-5.00	1.00
a_z , ft/sec^2	6.00	6.00	1.00

1. a_x , a_y , a_z are given by the reaction forces at node 1 (FX, FY, FZ respectively).

VM132: Stress Relaxation of a Tightened Bolt Due to Creep

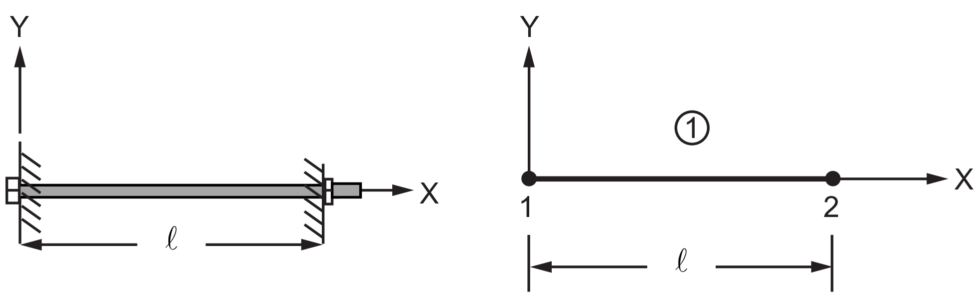
Overview

Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pg. 531, article 93.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0) (with creep properties and initial strain)
Element Type(s):	3D Spar (or Truss) Elements (LINK180)
Input Listing:	vm132.dat

Test Case

A bolt of length ℓ and cross-sectional area A is tightened to an initial stress σ_o. The bolt is held for a long period of time t_1 at an elevated temperature T_o. The bolt material has a creep strain rate given by $d\varepsilon/dt = k\sigma^n$. Determine the stress σ in the bolt at various times during creep relaxation.

Figure 132.1: Tightened Bolt Problem Sketch



Problem Sketch Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $n = 7$ $k = 4.8 \times 10^{-30}$/hr	$\ell = 10$ in $A = 1$ in^2	$\sigma_o = 1000$ psi $T_o = 900°F$ $t_1 = 1000$ hr

Analysis Assumptions and Modeling Notes

An integration time step of 10 hours over the 1000 hour time range (i.e., 100 iterations) is used. The initial strain is calculated by $\sigma_o/E = (1000 \text{ psi})/(30 \times 10^6 \text{ psi}) = 1/30000$.

Results Comparison

	Target	Mechanical APDL (1)	Ratio
Stress, psi @ t = 190 hr	975.	975.	1.00

	Target	Mechanical APDL (1)	Ratio
Stress, psi @ t = 420 hr	950.	950.	1.00
Stress, psi @ t = 690 hr	925.	925.	1.00
Stress, psi @ t = 880 hr	910.	910.	1.00
Stress, psi @ t = 950 hr	905.	905.	1.00

1. Stress (σ) corresponds to the quantity SIG in POST26 listing.

VM133: Motion of a Rod Due to Irradiation Induced Creep

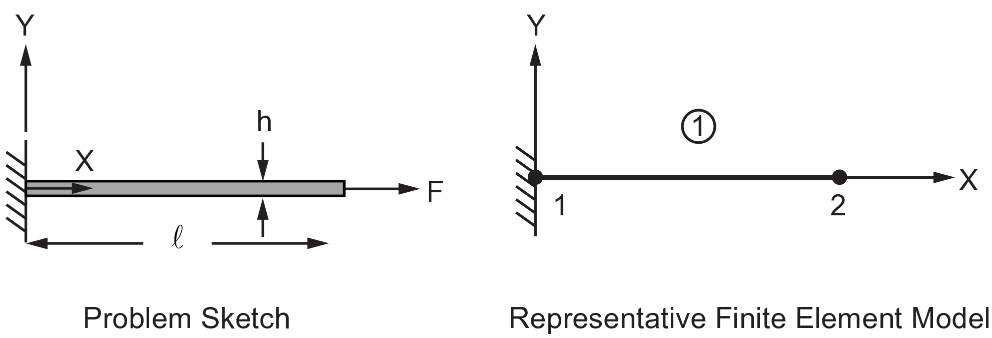
Overview

Reference:	Any basic calculus book
Analysis Type(s):	Static Analysis (with creep properties) (**ANTYPE** = 0)
Element Type(s):	3-D 2 Node Beam (BEAM188)
Input Listing:	vm133.dat

Test Case

A rod of length ℓ and square cross-sectional area A is held at a constant stress σ_o at a temperature T_o. The rod is also subjected to a constant neutron flux Φ. The rod material has an irradiation induced creep strain rate given by the relationship $d\varepsilon_{cr} / dt = k_1\sigma\Phi e - (\Phi t / k_2)$. Determine the amount of creep strain ε_{cr} accumulated up to 5 hours.

Figure 133.1: Rod Motion Problem Sketch



Material Properties	Geometric Properties	Loading
E = 300 psi k_1 = 0.5 x 10^{-12} in^4/lb neutron k_2 = 1 x 10^{10} neutron/in^2 Φ = 1 x 10^{10} neutron/in^2-hr C1 = $0.5e^{-2}$ C2 = 1 C3 = 0 C4 = 0 C5 = 1	ℓ = 1 in A = 0.25 in^2 h = 0.5 in	σ_o = 1 psi T_o = 1000°F

Analysis Assumptions and Modeling Notes

The implicit creep strain is defined using the **TB**,CREEP command. The constants, C1, C2, C3, C4, and C5 are derived from the generalized exponential creep equation and creep strain rate relationship.

Generalized exponential creep = $\dot{\varepsilon}_{cr} = C_1 \sigma^{C2} r e^{-rt}$, $r = C_5 \sigma^{C3} e^{-C4/T}$

An integration time step of 0.1 hr is assumed over the 5 hour time range (50 substeps). POST26 is used to obtain the variation of creep strain with time. The following quantities are required for input:

Maximum fluence = 5 Φ = 5 x 10^{10} neutron/in^2
F = σ_o
A = 0.25 lb
$h = \sqrt{A}$
I = moment of inertia = $A^2/12$ = 0.0052083 in^4

Results Comparison

	Target	Mechanical APDL	Ratio
Creep Strain (t = 0.0 hr)	0.00000	0.00000	0.000
Creep Strain (t = 0.5 hr)	0.00197	0.00187	0.950
Creep Strain (t = 1.0 hr)	0.00316	0.00301	0.951
Creep Strain (t = 5.0 hr)	0.00497	0.00472	0.950

VM134: Plastic Bending of a Clamped I-Beam

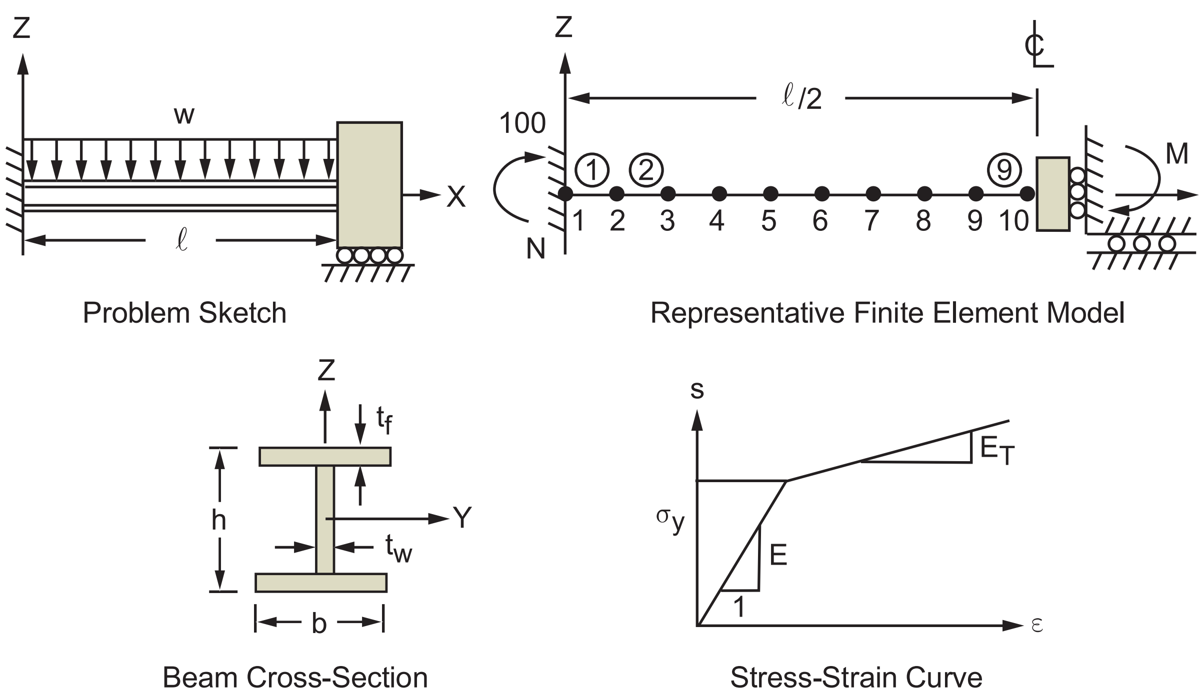
Overview

Reference:	N. J. Hoff, *The Analysis of Structures*, John Wiley and Sons, Inc., New York, NY, 1956, pg. 388, article 4.5.
Analysis Type(s):	Static, Plastic Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 2 node Beam Elements (BEAM188)
Input Listing:	vm134.dat

Test Case

A wide-flanged I-beam of length ℓ, with clamped ends, is uniformly loaded as shown. Investigate the behavior of the beam at load w_1 when yielding just begins at the ends, at load w_2, when the midpoint begins to yield, and at load w_3, when pronounced plastic yielding has occurred. The beam's cross-section is shown in Figure 134.1: Clamped I-Beam Problem Sketch (p. 349) (the cross-section is not show to scale)).

Figure 134.1: Clamped I-Beam Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 29 \times 10^6$ psi $E_T = 5.8 \times 10^6$ psi $\sigma_y = 38,000$ psi	$\ell = 144$ in $b = 95.95$ in $h = 10.6$ in $t_f = 0.1$ in $t_w = 0.0001$ in	$w_1 = 2190$ lb/in $w_2 = 3771$ lb/in $w_3 = 9039$ lb/in

Analysis Assumptions and Modeling Notes

The beam cross-section is modeled as an idealized section to compare with the assumptions of the analytical solution. The loading is assumed to be applied through the centroid of the element cross-section (the neutral axis). Only half the beam is modeled, taking advantage of symmetry. Classical bilinear kinematic hardening behavior is used.

Results Comparison

		Target	Mechanical APDL	Ratio
w_1 = 2190 lb/in	Midspan Deflection , in	-0.160	-0.160	1.00
	End Moment N, in-lb	-3.784×10^6	-3.784×10^6	1.00
	Mid Moment M, in-lb	-1.892×10^6	-1.892×10^6	1.00
	End Status	At Yield	At Yield	-
	Mid Status	Elastic	Elastic	-
w_2 = 3771 lb/in	Midspan Deflection , in	-0.357	-0.354	0.99
	End Moment N, in-lb	-5.98×10^6	-6.01×10^6	1.01
	Mid Moment M, in-lb	-3.78×10^6	-3.76×10^6	1.00
	End Status	Plastic	Plastic	-
	Mid Status	At Yield	At Yield	-
w_3 = 9039 lb/in	Midspan Deflection , in	-2.09	-2.08	1.00
	End Moment N, in-lb	-1.51×10^7	-1.50×10^7	1.00
	Mid Moment M, in-lb	-8.36×10^6	-8.36×10^6	1.00
	End Status	0.0200	0.0196	0.98
	Mid Status	0.0089	0.0087	0.98

Note

δ_{mid} (midspan deflection) is UZ at node 10.

N (fixed-end moment and M (midspan moment) are obtained from the reaction moments MY at nodes 1 and 10 respectively. The end and mid status are determined by comparing SAXL to the yield stress (σ_y).

The total end strain is obtained y adding the quantities EPELAXL and EPPLAXL for element 1 (end I). The total mid strain is obtained by adding EPELAXL and EPPLAXL for element 9 (end J).

VM135: Bending of a Beam on an Elastic Foundation

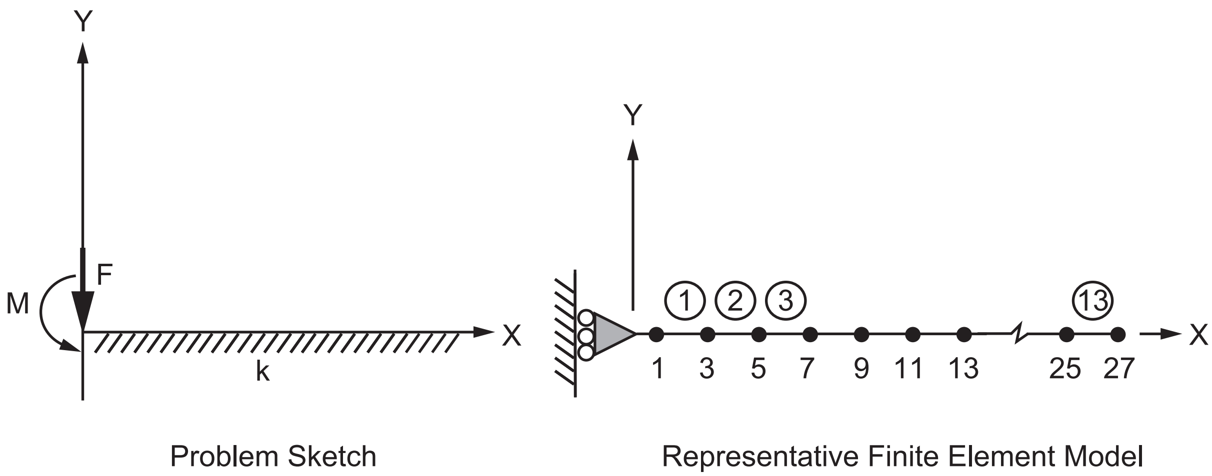
Overview

Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pg. 12, article 2.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 3 node Beam Element (BEAM189) 2-D Structural surface Effect (SURF153)
Input Listing:	vm135.dat

Test Case

A long (semi-infinite) rectangular beam on an elastic foundation is bent by a force F and a moment M applied at the end as shown. Determine the lateral end deflection of the beam δ_{end}.

Figure 135.1: Beam Problem Sketch



Material Properties	Geometric Properties	Loading
k = 1515.15 lb/in^3 E = 30 x 10^6 psi	h = 5 in b = 4.224 in	F = 1000 lb M = 10,000 in-lb

Analysis Assumptions and Modeling Notes

The beam length is arbitrarily selected to be 286 in. Note that SURF153 only functions in the X-Y plane

Results Comparison

	Target	Mechanical APDL	Ratio
Deflection$_{end}$, in	-0.03762	-0.03767[1]	1.001

1. UY at Node 1.

VM136: Large Deflection of a Buckled Bar (the Elastica)

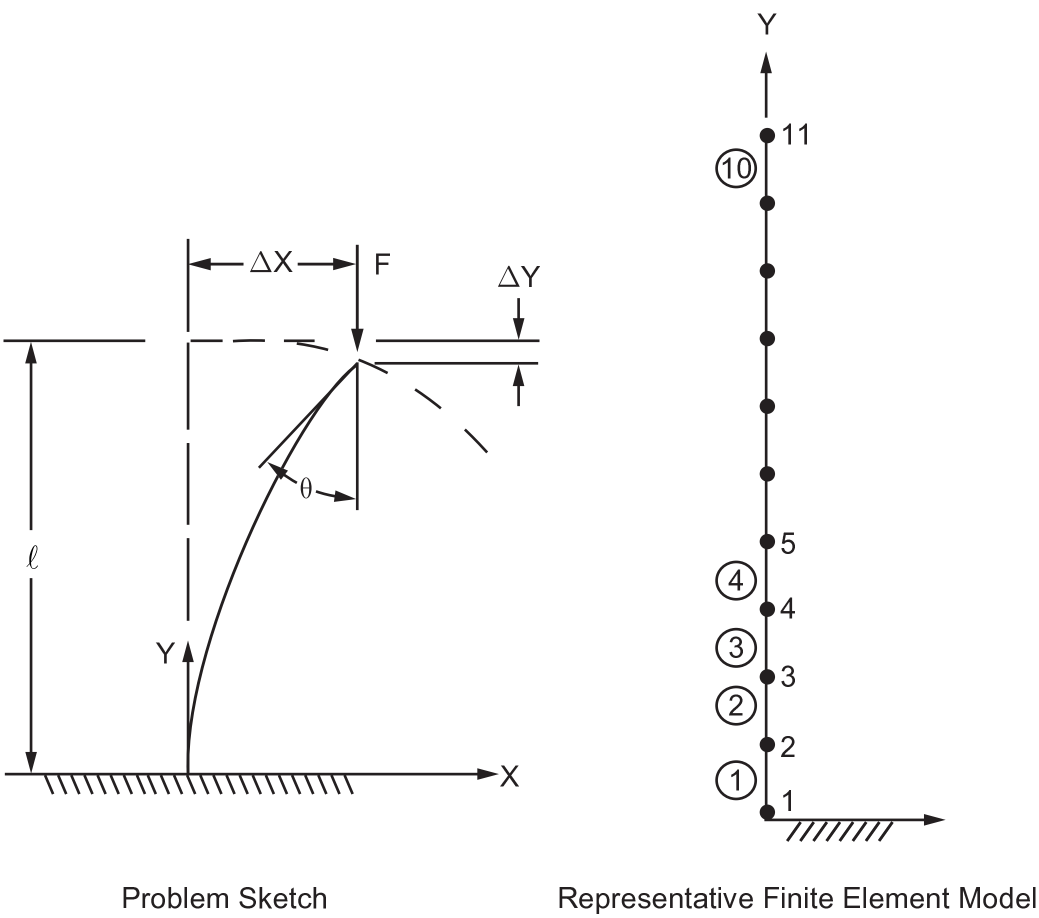
Overview

Reference:	S. Timoshenko, J. M. Gere, *Theory of Elastic Stability*, 2nd Edition, McGraw-Hill Book Co. Inc., New York, NY, 1961, pg. 78, article 2.7.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0) with Large Deflection
Element Type(s):	3-D 2 Node Beam (BEAM188)
Input Listing:	vm136.dat

Test Case

A slender square cross-sectional bar of length l, and area A, fixed at the base and free at the upper end, is loaded with a value larger than the critical buckling load. Determine the displacement (ΔX, ΔY, Θ) of the free end and display the deformed shape of the bar at various loadings.

Figure 136.1: Buckled Bar Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi	ℓ = 100 in width (w) = 0.5 height (h) = 0.5	F/F_{cr} = 1.015; 1.063; 1.152; 1.293; 1.518 and 1.884

Analysis Assumptions and Modeling Notes

The critical force, $F_{cr} = \pi^2 EI/4 \ell^2$ = 38.553 lb, is used for calculation of the applied load F.

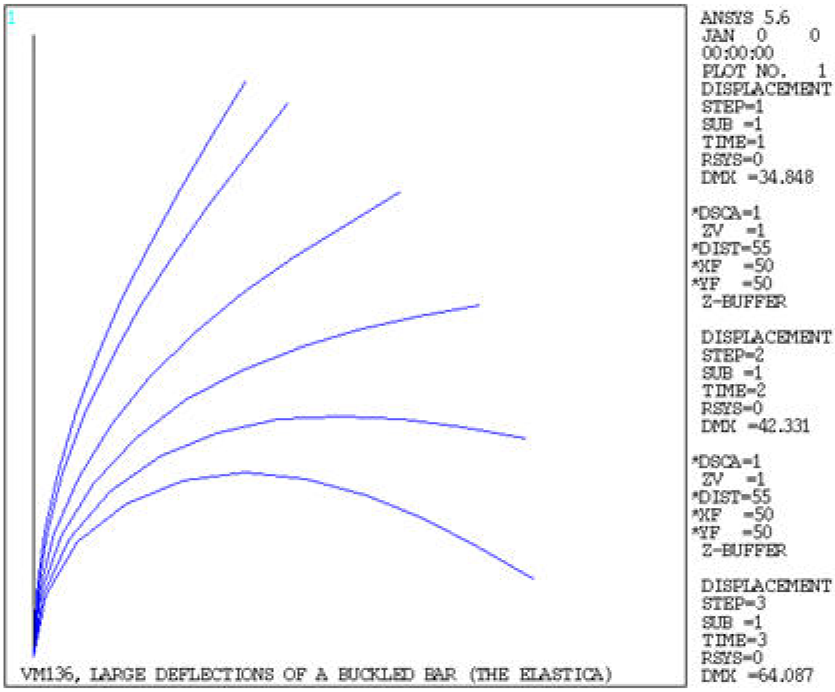
A small perturbing force is introduced in the first load step to produce lateral, rather than pure compressive, motion. The number of equilibrium iterations for convergence increases significantly as the loading approaches the critical load (i.e. for solutions with Θ near zero). The six displacement solutions are overlaid by displaying with the **/NOERASE** option set.

Results Comparison

		Target	Mechanical APDL	Ratio
F = 44.413 lb Load Step 3	Angle, deg[1]	-60.0	-60.1	1.001
	DeflectionX, in	59.3	59.4	1.001
	DeflectionY, in	-25.9	-25.9	1.002
F = 49.849 lb Load Step 4	Angle, deg[1]	-80.0	-79.9	0.999
	DeflectionX, in	71.9	71.9	1.000
	DeflectionY, in	-44.0	-44.0	0.999
F = 58.523 lb Load Step 5	Angle, deg[1]	-100.0	-100.0	1.000
	DeflectionX, in	79.2	79.1	0.999
	DeflectionY, in	-65.1	-65.1	1.000
F = 72.634 lb Load Step 6	Angle, deg[1]	-120.0	-120.0	1.000
	DeflectionX, in	80.3	80.3	1.000
	DeflectionY, in	-87.7	-87.6	0.999

1. Angle (Θ) = ROTZ * (180/π), where ROTZ is the node rotation in radians.

Figure 136.2: Deformed Shapes at Various Loads



VM137: Large Deflection of a Circular Membrane

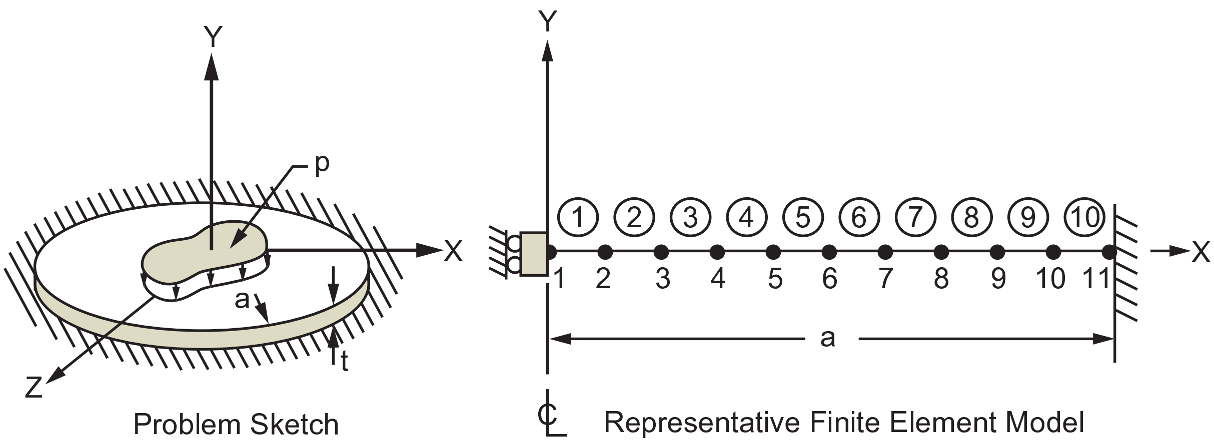
Overview

Reference:	S. Timoshenko, S. Woinowsky-Knieger, *Theory of Plates and Shells*, McGraw-Hill Book Co., Inc., New York, NY, 1959, pg. 404, eq. 236.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0) with Large Deflection and Stress Stiffening
Element Type(s):	2-Node Finite Strain Axisymmetric Shell (SHELL208)
Input Listing:	vm137.dat

Test Case

A circular membrane (of radius a and thickness t), clamped around its outer rim, is loaded with a uniform pressure p. Determine the deflection δ at the center, the radial stress σ_o at the center, and the radial stress σ_a at the rim.

Figure 137.1: Circular Membrane Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\alpha = 1 \times 10^{-5}$ in/in-°F $\upsilon = 0.25$	a = 10 in t = 0.0001 in	p = 0.1 psi

Analysis Assumptions and Modeling Notes

Since there is no significant bending stiffness, the membrane is cooled by -50°F (arbitrary) in the first load step to induce a thermal prestress for stability. The pressure load is applied in the second load step. The cooling load is removed in the third load step. Moment convergence is removed by specifying force convergence, since the moments are not significant to the solution, thereby speeding convergence.

Results Comparison

Load Step 3	Target	Mechanical APDL	Ratio
Deflection, in (UY @ Node 1)	-0.459	-0.464	1.010
$Stress_o$, psi	61,010	61,421.243[1]	1.007
$Stress_a$, psi	47,310	47,490.041[2]	1.004

1. Near center at x = 0.5 in (SM stress at MID for element 1)
2. Near rim at x = 9.5 in (SM stress at MID for element 10)

VM138: Large Deflection Bending of a Circular Plate

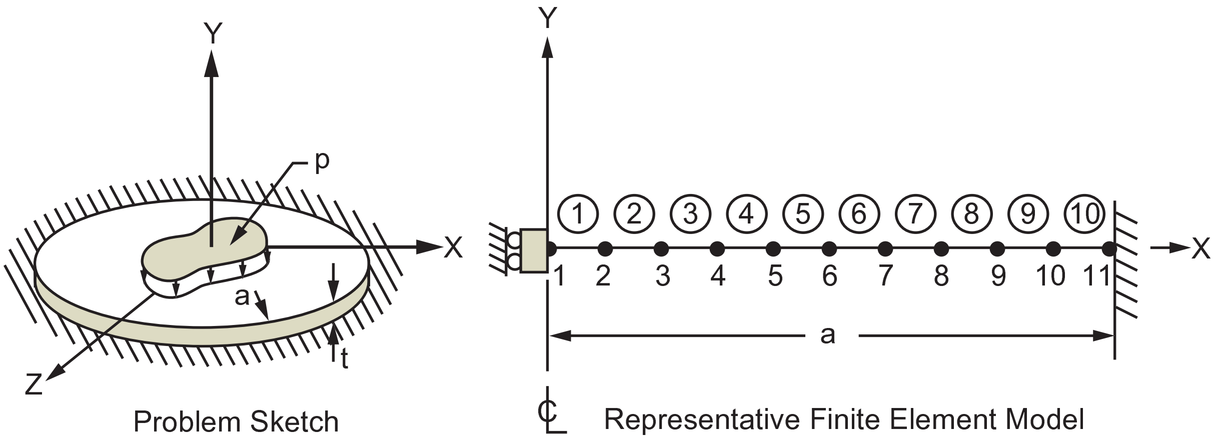
Overview

Reference:	S. Timoshenko, S. Woinowsky-Knieger, *Theory of Plates and Shells*, McGraw-Hill Book Co., Inc., New York, NY, 1959, pg. 401, eq. 232.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0) with Large Deflection and Stress Stiffening
Element Type(s):	2-Node Finite Strain Axisymmetric Shell (SHELL208)
Input Listing:	vm138.dat

Test Case

A circular plate (radius a and thickness t) built-in around its outer rim is loaded with a uniform pressure p. Determine the deflection δ at the center of the plate.

Figure 138.1: Circular Plate Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 2 \times 10^{11}$ N/m^2 $\upsilon = 0.3$	a = 0.25 m t = 0.0025 m	p = 6585.175 N/m^2

Results Comparison

	Target	Mechanical APDL	Ratio
Deflection, m	-0.00125	-0.00124[1]	0.991

1. UY @ Node 1

VM139: Bending of a Long Uniformly Loaded Rectangular Plate

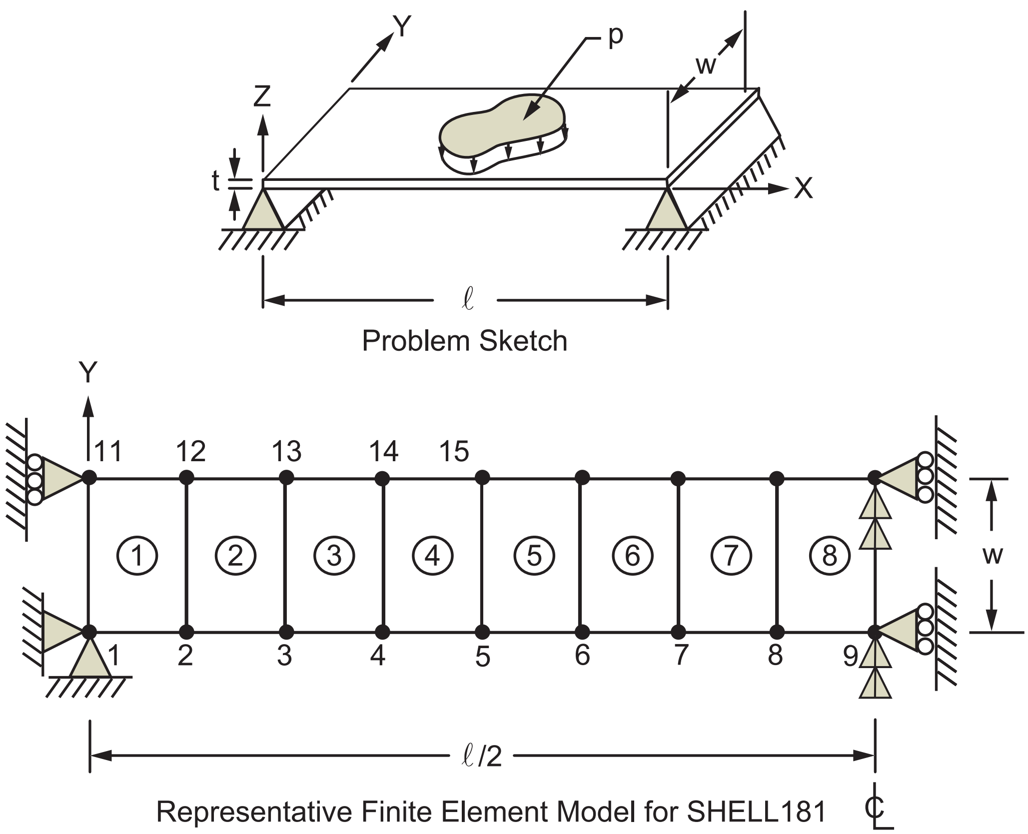
Overview

Reference:	S. Timoshenko, *Strength of Material, Part II, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1956, pg. 80, article 14.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0) with Large Deflection and Stress Stiffening
Element Type(s):	4-Node Structural Shell (SHELL181) 3-D Structural Solid Shell Elements (SOLSH190)
Input Listing:	vm139.dat

Test Case

A rectangular plate whose length is large compared to its width is subjected to a uniform pressure p as shown. The shorter edges are simply-supported. Determine the direct stress σ_x (MID) at the middle of the plate and the maximum combined stress (direct plus bending) σ_x (BOT) at the bottom of the plate.

Figure 139.1: Rectangular Plate Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.3$	ℓ = 45 in w = 9 in t = 0.375 in	$p = 10$ lb/in^2

Analysis Assumptions and Modeling Notes

Since the plate ends are immovable along the X-axis, a small lateral displacement caused by the pressure load induces membrane stresses. The geometric and loading symmetry is used to model only half of the plate with appropriate symmetry boundary conditions at the midspan.

Two analysis solutions are performed. The first solution is performed without large deflection results in a static solution with no coupling between in-plane and transverse deflections. The second solution is performed with large deflection results in a converged solution with the coupling effects. POST1 is used to report nodal stresses along the plate middle and bottom. Note that these stresses are based on the original geometry, and include the element rotations due to the large deflection option.

The two solutions above are repeated using 3-D Solid Shell Elements (SOLSH190). Two layers of SOLSH190 elements are used across the thickness, and appropriate symmetry boundary conditions are applied at mid-thickness. The solid model adopts an approximate method for simulating shell simple support, resulting in differences in the stress Y component within a small boundary region.

Results Comparison

		Target	Mechanical APDL	Ratio
SHELL181				
Small Deflection Solution	$Stress_x$ (MID), psi	0.0	0.0	-
	$Stress_x$ (BOT), psi	108,000.	107,073.[1]	0.991
Large Deflection Solution	$Stress_x$ (MID), psi	11,240.	10,955.[1]	0.975
	$Stress_x$ (BOT), psi	25,280.	24,152.[1]	0.955
SOLSH190				
Small Deflection Solution	$Stress_x$ (MID), psi	0.0	0.0	-
	$Stress_x$ (BOT), psi	108,000.	107,971[1]	1.000
Large Deflection Solution	$Stress_x$ (MID), psi	11,240	11,193 [1]	0.996
	$Stress_x$ (BOT), psi	25,280	24,605 [1]	0.973

1. POST1 maximum nodal stresses.

VM140: Stretching, Twisting and Bending of a Long Shaft

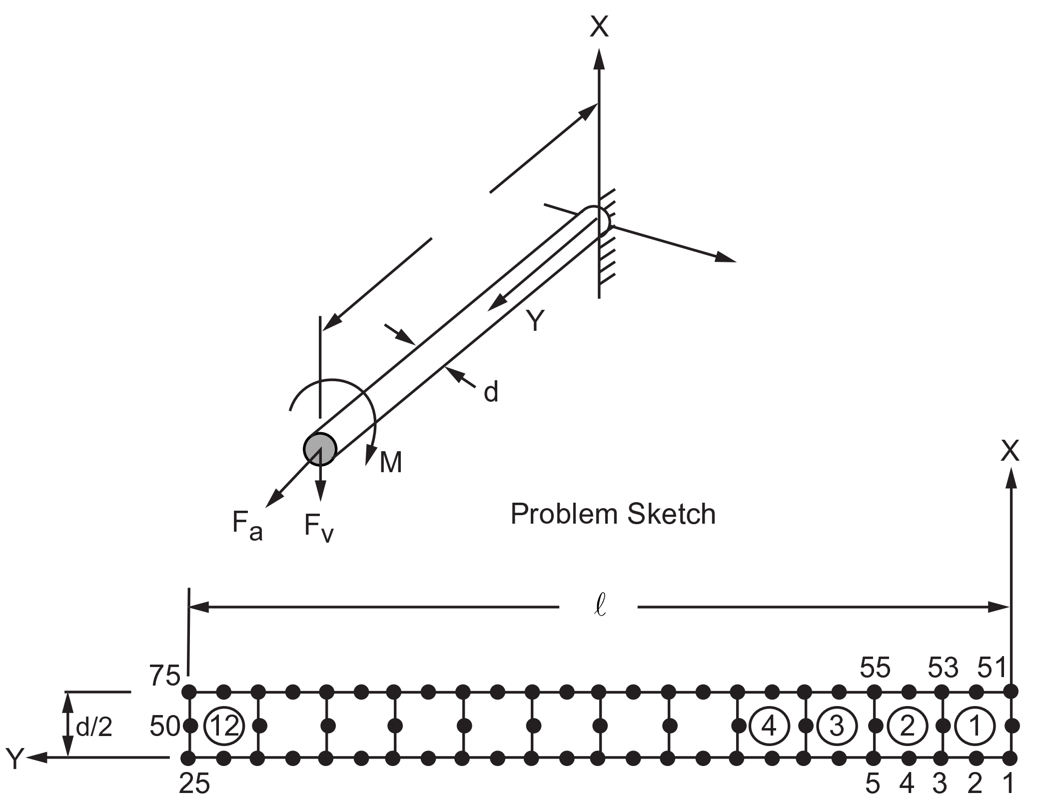
Overview

Reference:	S. Timoshenko, *Strength of Material, Part I, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 296, article 65.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Axisymmetric-Harmonic 8-Node Structural Solid Elements (PLANE83)
Input Listing:	vm140.dat

Test Case

A long solid circular shaft of length ℓ and diameter d is built-in at one end and loaded at the other end by a twisting moment, an axial force, and a vertical force as shown. Determine the maximum shear stress τ at the wall due to the moment. Determine the maximum normal stress σ_y at the wall and at one inch from the wall due to the forces. Also determine the maximum combined stress σ_1 at the wall due to both the moment and the forces.

Figure 140.1: Shaft Problem Sketch



Representative Finite Element Model (not to scale)

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.0$	ℓ = 24 in d = 1 in	F_v = -25 lb M = -200 in-lb

Material Properties	Geometric Properties	Loading
		F_a = 100 lb

Analysis Assumptions and Modeling Notes

The loads are applied at only one node (node 75) for convenience since the cross section of interest (at the wall) is far from the load. Nodal forces are applied on full circumference basis and are calculated for symmetric mode 1 as follows:

FZ =	-2M/d	= 400
FX =	2_{Fv}	= -50 (see Figure 5.4: Bending and Shear Loading (ISYM = 1) in the *Element Reference*)
FY =	F_a	= 100

Poisson's ratio is taken as zero to avoid the stress concentration at the built-in end due to the axial force. The nonaxisymmetric loading capability of this element type (PLANE83) is used to model the bending effect. POST1 is used to report maximum stresses at the wall.

Results Comparison

Maximum Stresses	Target	Mechanical APDL	Ratio
TORSION shear stress, psi	1018.6	1018.6[1]	1.000
AXIAL + BENDING $Stress_y$, psi (at y = 0)	6238.9	6239.9[1]	1.000
COMBINED $Stress_1$, psi	6401.0	6402.1[1]	1.000

1. POST1 nodal stresses at node 51

VM141: Diametral Compression of a Disk

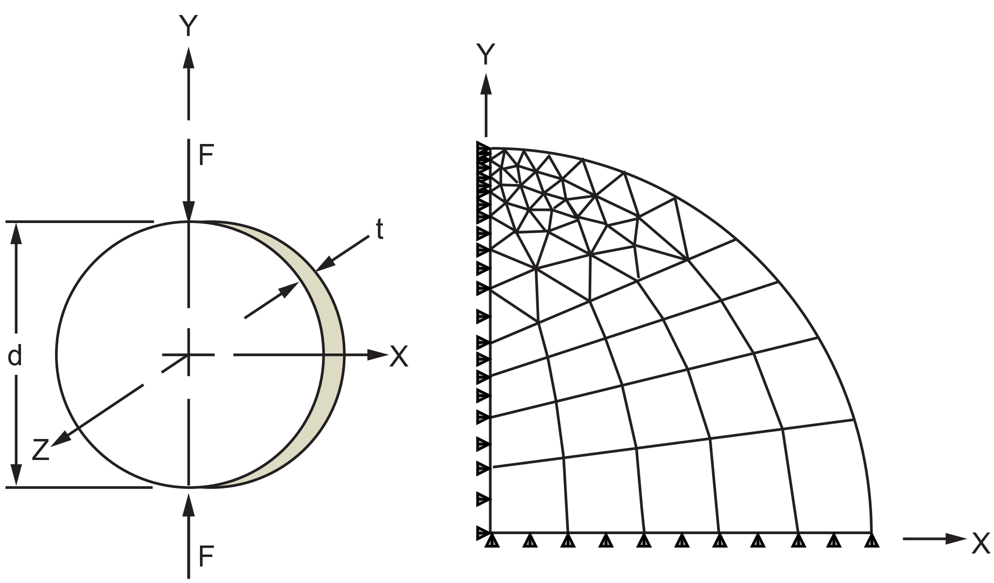
Overview

Reference:	S. Timoshenko, J. N. Goodier, *Theory of Elasticity*, 2nd Edition, McGraw-Hill Book Co., Inc., New York, NY, 1951, pg. 107, article 37.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0) Substructure Analysis (**ANTYPE** = 7)
Element Type(s):	2-D 8-Node Structural Solid Plane Stress Elements (PLANE82) 2-D 8-Node Structural Solid Elements (PLANE183) Superelement (or Substructure) (MATRIX50) 4-Node Finite Strain Shell Elements (SHELL181) 8-Node Finite Strain Shell Elements (SHELL281)
Input Listing:	vm141.dat

Test Case

Two equal and opposite forces act along the vertical diameter of a disk as shown. Determine the compressive stress at the center of the disk and on the major horizontal diameter at 0.1 in. from the center.

Figure 141.1: Disk Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
E = 30 x 10^6 psi υ = 0.3	d = 2 in t = 0.2 in	F = 2000 lb

Analysis Assumptions and Modeling Notes

The problem is solved first using plane stress elements (PLANE82 and PLANE183), then using shell elements (SHELL281) with the substructure analysis and expansion pass. In the second case, the model is created as a superelement only to illustrate the procedure for substructure capability. Third and fourth solution is done using finite strain shell elements SHELL181 and SHELL281.

A one-fourth symmetry model is used. Three element types and the corresponding element type modifications are used only for various printout control purposes. One half of the load is applied because of symmetry. POST1 is used to extract results from the solution phase. Since the midside nodal stresses are not available in POST1, path operations are performed to get the compressive stress at 0.1 in. from the center of the disk.

Results Comparison

		Target	Mechanical APDL	Ratio
PLANE82 and PLANE183	$Stress_y$, psi (at x = 0.0, y = 0.0)	-9549.	-9649.	1.010
	$Stress_y$, psi (at x = 0.1, y = 0.0)	-9298.	-9139.	0.983
SHELL281-Substructure	$Stress_y$, psi (at x = 0.0, y = 0.0)	-9549.	-9646.	1.010
	$Stress_y$, psi (at x = 0.1, y = 0.0)	-9298.	-9130.	0.982
SHELL181	$Stress_y$, psi (at x = 0.0, y = 0.0)	-9549	-9593.	1.005
	$Stress_y$, psi (at x = 0.1, y = 0.0)	-9298.	-9293.	0.999
SHELL281	$Stress_y$, psi (at x = 0.0, y = 0.0)	-9549.	-9646.	1.010
	$Stress_y$, psi (at x = 0.1, y = 0.0)	-9298.	-9130.	0.982

VM142: Stress Concentration At a Hole in a Plate

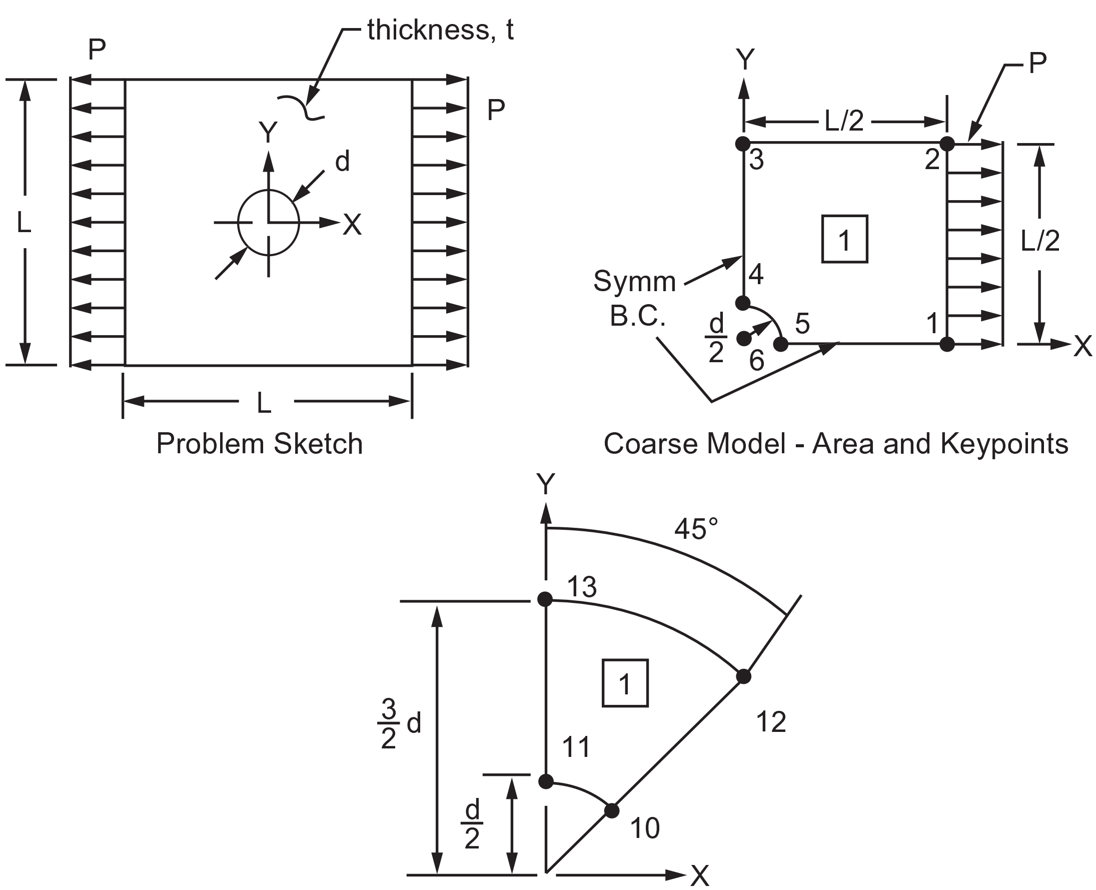
Overview

Reference:	R. J. Roark, *Formulas for Stress and Strain*, 4th Edition, McGraw-Hill Book Co., Inc., New York, NY, 1965, pg. 384.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0), Submodeling
Element Type(s):	2-D 4-Node Structural Solid Elements (PLANE182) 2-D 8-Node Structural Solid Elements (PLANE183)
Input Listing:	vm142.dat

Test Case

Determine the maximum stress at a circular hole cut into a square plate loaded with uniform tension P.

Figure 142.1: Plate Problem Sketch



Refined Keypoint and Area Model Around Hole (Submodel)

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.3$	L = 12 in d = 1 in t = 1 in	P = 1000 psi

Analysis Assumptions and Modeling Notes

Due to symmetry, only a quarter sector of the plate is modeled. Mesh generation is used for node and element creation. The area around the hole is remodeled with a fine mesh and boundary conditions are interpolated from the first model by use of the cut-boundary interpolation capability (**CBDOF**) in POST1.

Results Comparison

		Target	Mechanical APDL	Ratio
Coarse Model	$stress_x$ max PLANE183	3018	2721	0.902
Submodel	$stress_x$ max PLANE182	3018	2975	0.986

Max σ_x based on estimated bounds due to discretization error for the coarse model and submodel are 2855. and 3076. respectively.

The coarse PLANE183 model is offered for comparison with the submodel. Coarse PLANE183 results may vary across platforms.

Figure 142.2: Stress Concentration in Coarse Model

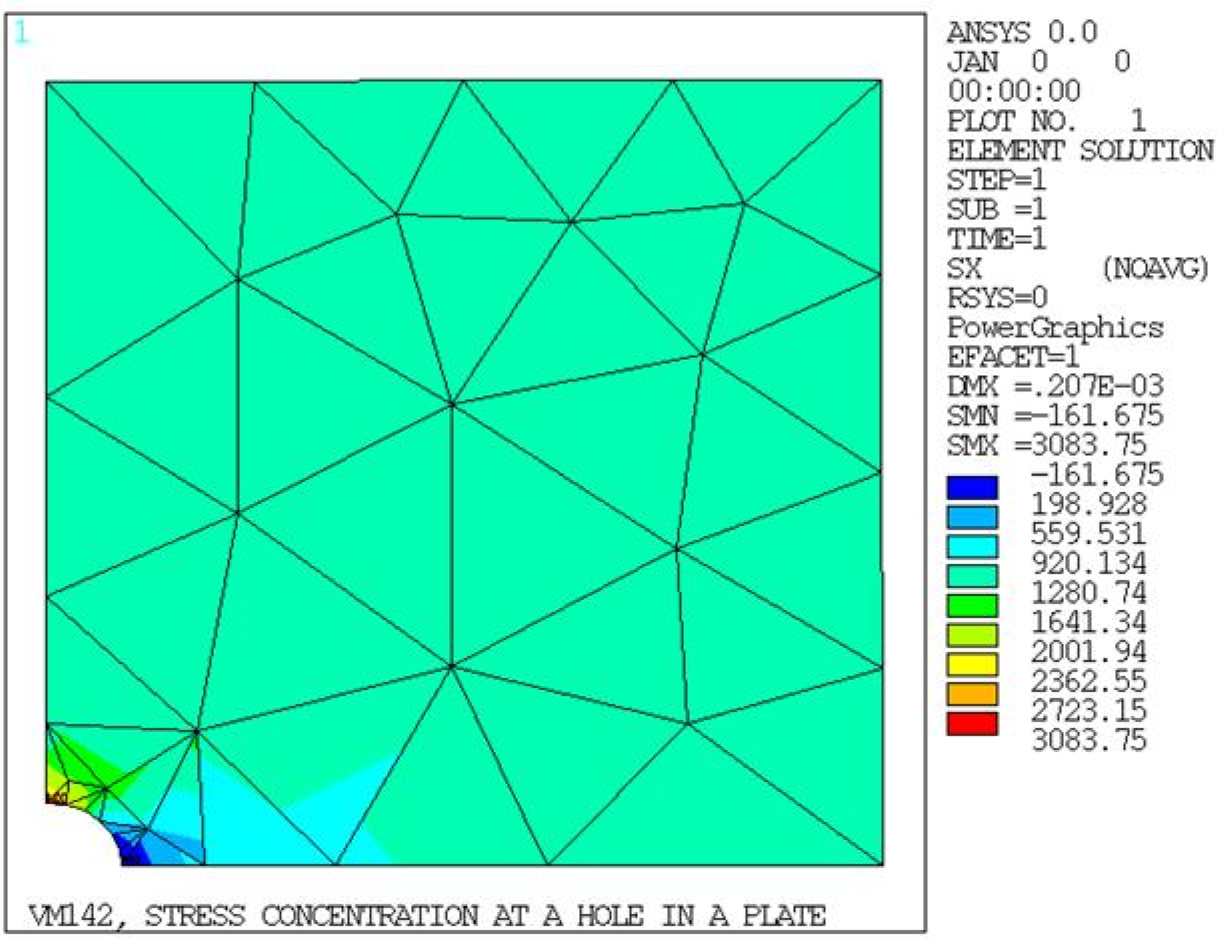
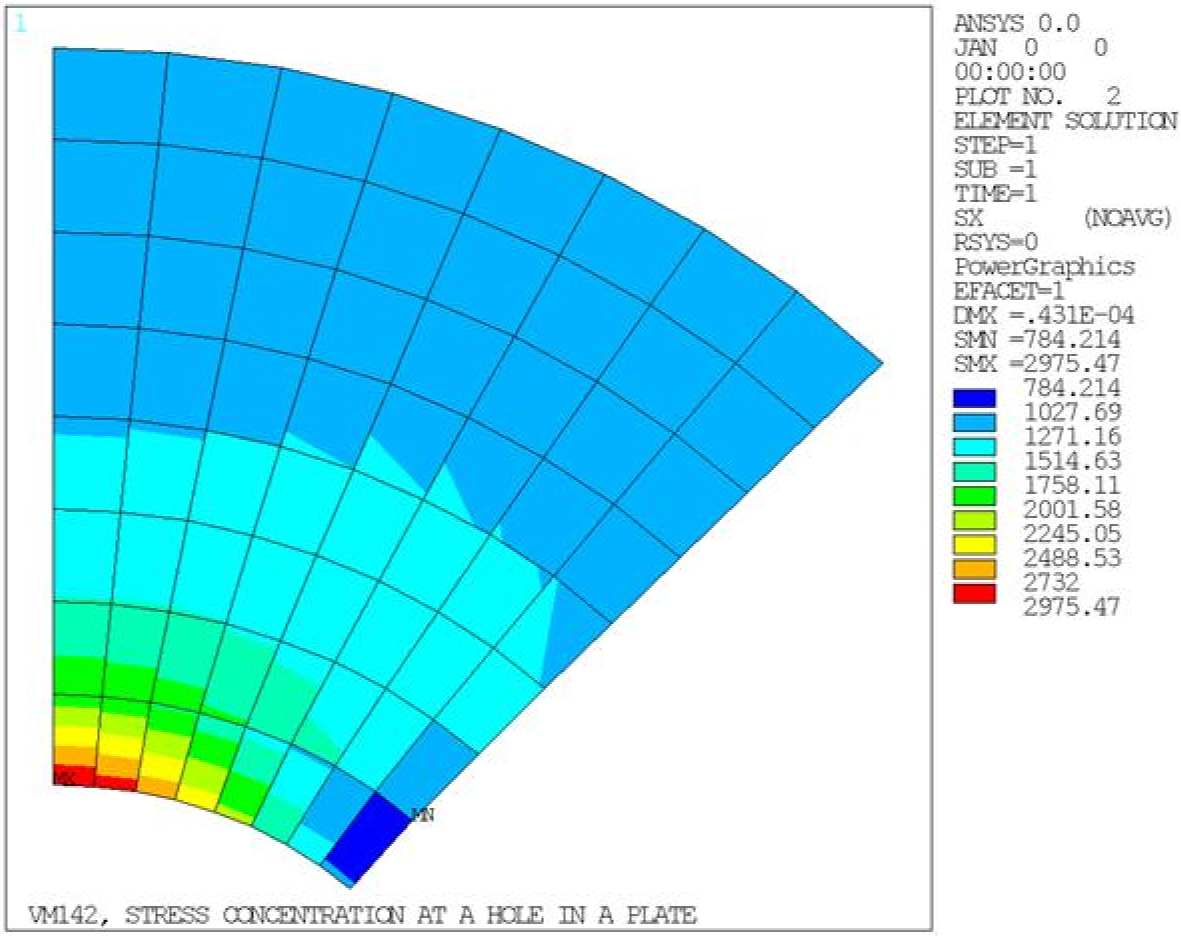


Figure 142.3: Stress Concentration in Fine Model



VM143: Fracture Mechanics Stress for a Crack in a Plate

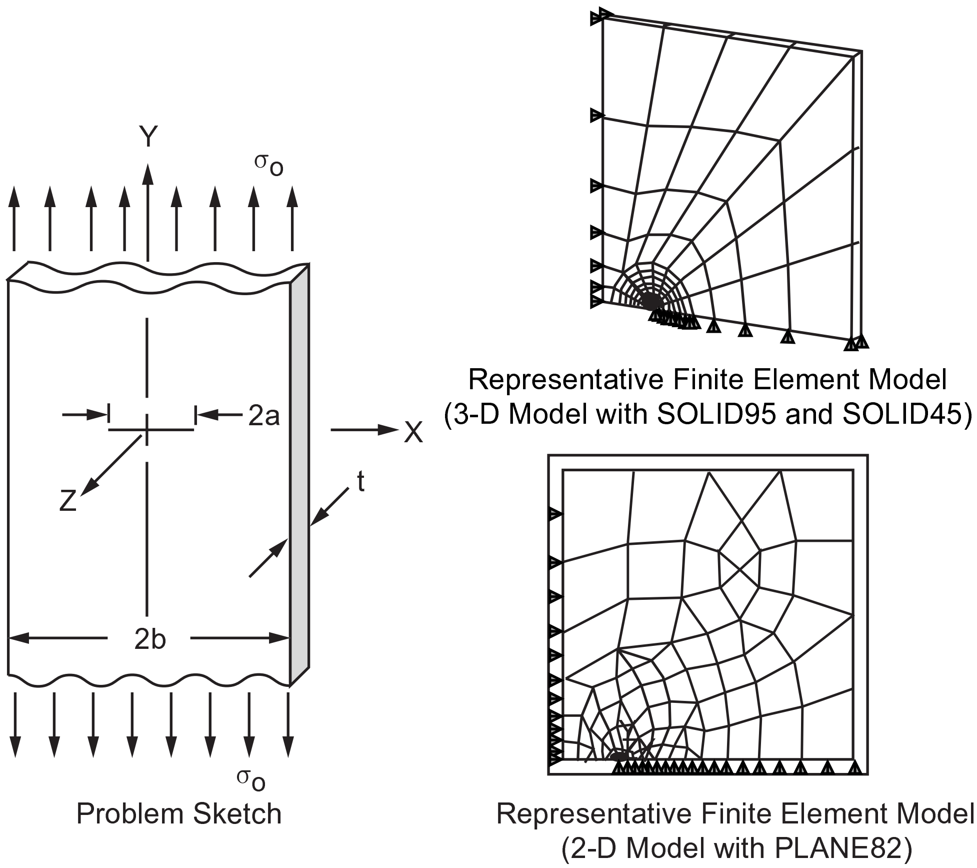
Overview

Reference:	W. F. Brown, Jr., J. E. Srawley, "Plane Strain Crack Toughness Testing of High Strength Metallic Materials", *ASTM STP-410*, 1966.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 20-Node Structural Solid Elements (SOLID95) 3-D Structural Solid Elements (SOLID45) 2-D 8-Node Structural Solid Elements (PLANE183) 3-D 20-Node Structural Solid Elements (SOLID186) 3-D Structural Solid Elements (SOLID185)
Input Listing:	vm143.dat

Test Case

A long plate with a center crack is subjected to an end tensile stress σ_o as shown in the problem sketch. Determine the fracture mechanics stress intensity factor KI.

Figure 143.1: Finite Width Plate Problem Sketch



Material Properties	Geometric Properties	Loading
E = 30 x 10^6 psi	a = 1 in b = 5 in	σ_o = 0.5641895 psi

Material Properties	Geometric Properties	Loading
$\upsilon = 0.3$	h = 5 in t = 0.25 in	

Analysis Assumptions and Modeling Notes

The problem is solved using 3-D solid elements (SOLID95, SOLID45, SOLID185, and SOLID186) and using 2-D plane strain elements (PLANE183). A one-quarter model is used because of symmetry. The macro FRACT is used to create the SOLID95 crack tip elements from the SOLID45 model and SOLID186 crack tip elements from the SOLID185 model using a weighted midside node position (quarter point location).

In the 3-D analysis, the plane strain condition is achieved by constraining UZ degrees of freedom of all the nodes (displacements in the Z-direction). Only the back plane of nodes are shown numbered in the enlargements of the 3-D model. The simpler 2-D model using PLANE183 elements are created by automatic mesh generation. The **KSCON** command is used to create 2-D crack tip elements with nodal singularity.

POST1 is used to get fracture mechanics stress intensity factor (KI) by displacement extrapolation (**KCALC** command), and J-Integral methods. A user file `JIN1` is created in the input. It consists of path operations necessary to compute the J-Integral. In general usage, the user file would be available in the local directory rather than being created in the input.

Results Comparison

KI	Target	Mechanical APDL	Ratio
Using SOLID95 and SOLID45 (3-D Analysis)			
By Displacement Extrapolation[1]	1.0249	1.0620	1.036
By J-Integral[2]	1.0249	1.0458	1.020
Using PLANE183 (2-D Analysis)			
By Displacement Extrapolation[1]	1.0249	1.0587	1.033
By J-Integral[2]	1.0249	1.0561	1.030
Using SOLID186 and SOLID185 (3-D Analysis)			
By Displacement Extrapolation1]	1.0249	1.0595	1.034
By J-Integral2]	1.0249	1.0493	1.024

1. As parameter KI1 by **KCALC** command

2. As parameter KI2

VM144: Bending of a Composite Beam

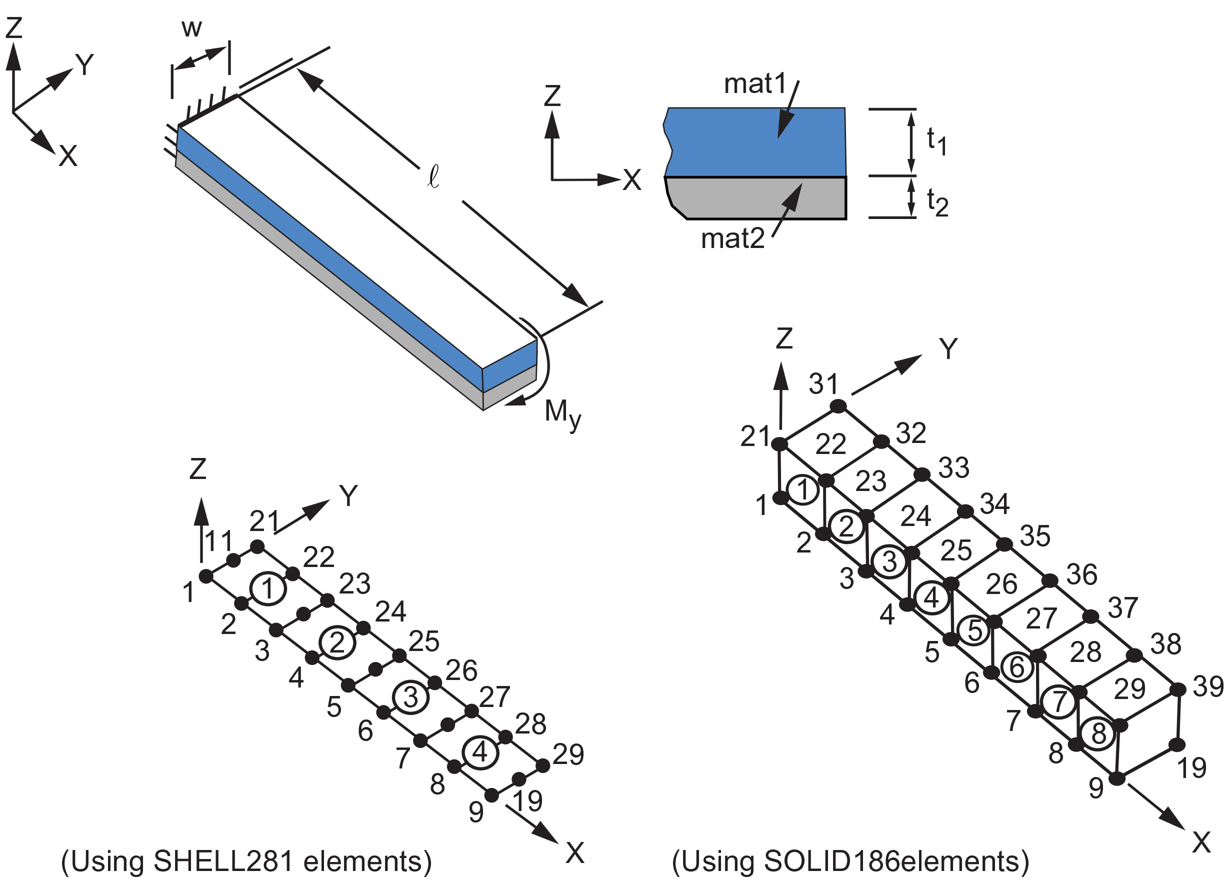
Overview

Reference:	R. J. Roark, W. C. Young, *Formulas for Stress and Strain*, McGraw-Hill Book Co., Inc., New York, NY, 1975, pg. 112-114, article 7.2.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Structural Solid Elements (SOLID185) 3-D 20-Node Layered Structural Solid Elements (SOLID186) 3-D 8-Node Layered Solid Shell Elements (SOLSH190) 8-Node Finite Strain Shell Elements (SHELL281)
Input Listing:	vm144.dat

Test Case

A beam of length ℓ and width w, made up of two layers of different materials, is subjected to a uniform rise in temperature from T_{ref} to T_o and a bending moment M_y at the free-end. Determine the free-end displacement δ (in the Z-direction) and the X- direction stresses at the top and bottom surfaces of the layered beam. E_i and α_i correspond to the Young's modulus and thermal coefficient of expansion for layer i, respectively.

Figure 144.1: Composite Beam Problem Sketch



Material Properties	Geometric Properties	Loading
MAT1: E_1 = 1.2 x 10^6 psi α_1 = 1.8 x 10^{-4} in/in/°F MAT2: E_2 = 0.4 x 10^6 psi α_2 = 0.6 x 10^{-4} in/in/°F	ℓ = 8 in w = 0.5 in t_1 = 0.2 in t_2 = 0.1 in	T_o = 100°F T_{ref} = 0°F M_y = 10.0 in-lb

Analysis Assumptions and Modeling Notes

The beam is idealized to match the theoretical assumptions by taking $\nu = \alpha_y = \alpha_z = 0$. Nodal coupling of the ROTY degree of freedom is used for the SHELL281 model to apply the uniform edge moment. Opposing nodal forces are applied at the top and bottom edges of the free end for the SOLSH190 model to apply the end moment. The magnitude of these applied nodal forces is calculated as: FX = $M_y/(2 * (t_1+t_2))$ = 10/0.6 = (100/6). POST1 is used to obtain the nodal stresses and displacements.

For the fourth model (SHELL281), two sets of four overlapping elements (a total of eight SHELL281 elements) are used. Each set represents a single layer. The set of four elements representing the lower layer has its nodal plane located on the "top" face whereas the set of elements corresponding to the top layer has its nodal plane located on the "bottom" face. The combination of overlapping elements thus defines a two-layered beam with its nodal plane at the interface between the layers (offset from the middle plane).

The second model uses eight SOLID186 elements (each with 2 layers), similar to the fourth SHELL281 model. Tapered pressure is applied on the end face to apply moment.

The third model uses eight SOLSH190 elements (each with 2 layers).

Results Comparison

		Target	Mechanical APDL	Ratio
SOLID185 model	Displacement, in	0.832	0.832[1]	1.000
	$Stress_x$TOP , psi	2258	2257.57	1.000
	$Stress_x$BOT , psi	1731	1730.56	1.000
SOLID186 model	Disp	.832	.832	1.00
	PRS TP	2258	2257.57	1.00
	RRS BTM	1731	1730.57	1.00
SOLSH190 model	Disp	.832	.832	1.00
	PRS TP	2258	2257.57	1.00
	RRS BTM	1731	1730.57	1.00
SHELL281 model	Disp	.832	.832	1.00
	PRS TP	2258	2257.567	1.00
	RRS BTM	1731	1730.564	1.00

1. UZ at Nodes 9, 19, 29

2. Corresponding shell TOP stresses for selected elements representing the top layer
3. Corresponding shell BOT stresses for selected elements representing the bottom layer

VM145: Stretching of an Orthotropic Solid

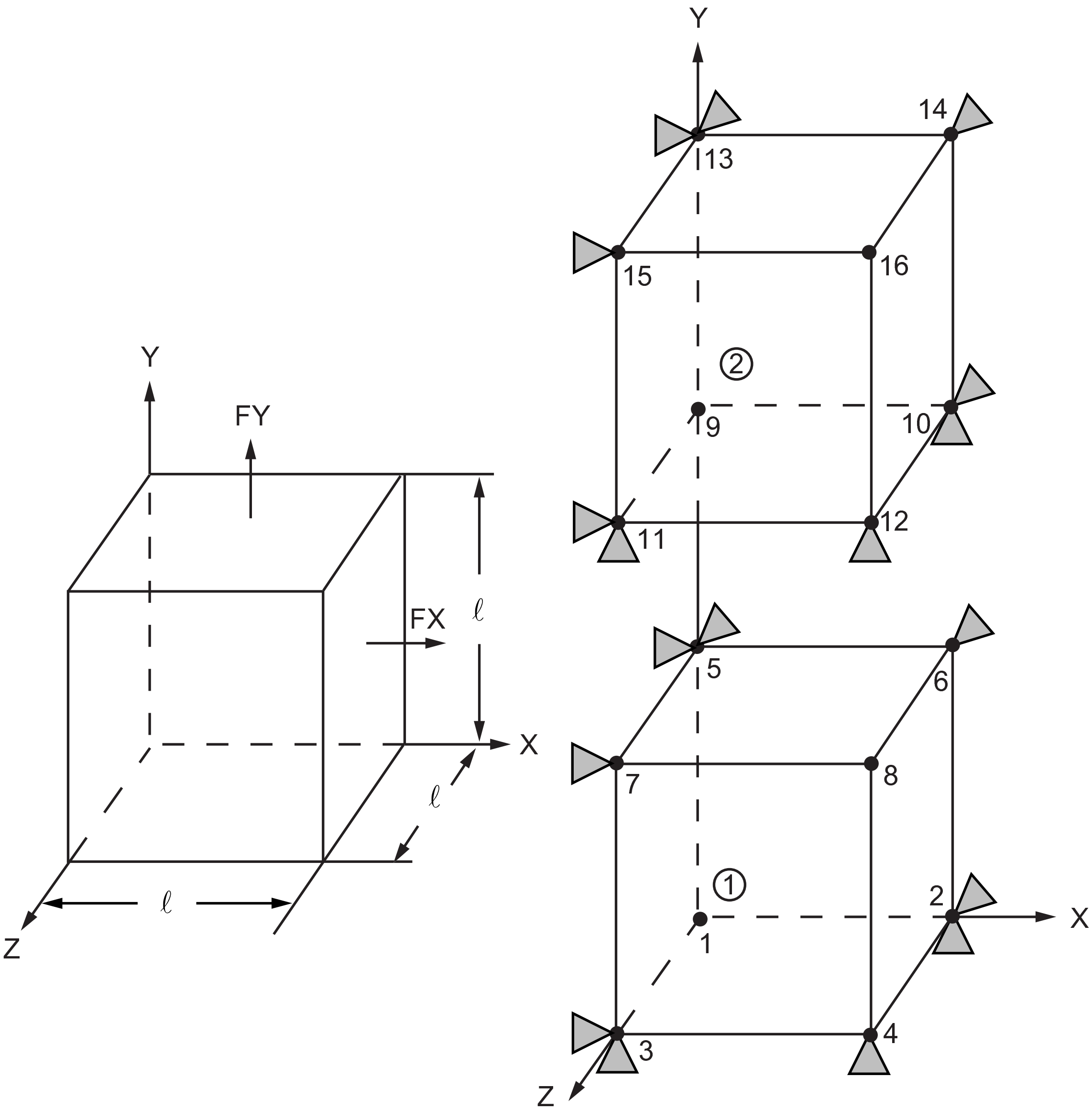
Overview

Reference:	S. H. Crandall, N. C. Dahl, *An Introduction to the Mechanics of Solids*, McGraw-Hill Book Co., Inc., New York, NY, 1959, pg. 225. SOLID185 - 3-D 8-Node Structural Solid in the *Mechanical APDL Theory Reference*
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 8-Node Structural Solid or Layered Solid (SOLID185)
Input Listing:	vm145.dat

Test Case

A unit cube of side ℓ, having orthotropic material properties, is subjected to forces FX and FY as shown. Three orthogonal faces are supported and the opposite three faces are free. Determine the translational displacements (ΔX, ΔY, and ΔZ) of the free faces.

Figure 145.1: Orthotropic Solid Problem Sketch



Material Properties	Geometric Properties	Loading
$E_x = 10 \times 10^6$ psi $E_y = 20 \times 10^6$ psi $E_z = 40 \times 10^6$ psi $\upsilon_{xy} = 0.1$ $\upsilon_{yz} = 0.2$ $\upsilon_{xz} = 0.3$ $G_{xy} = G_{xz} = G_{yz} =$ 10×10^6 psi	ℓ = 1.0 in	FX = 100 lb FY = 200 lb

Analysis Assumptions and Modeling Notes

Two independent one-element models are used. Element 1 uses the material property data input in the nonlinear material table (material 1) in a matrix form that is to be inverted by the program. Element 2 uses directly labeled material property input.

The matrix input is defined as shown in Equation 2.4 of the *Mechanical APDL Theory Reference* with matrix term numbers 1, 2, 3, 7, 8, 12, 16, 19 and 21. Set *TBOPT* = 1 on the **TB** command to input the stiffness matrix in flexibility form. The same terms are input with the **TBDATA** command as described in the *Element Reference*.

Results Comparison

	Target	Mechanical APDL [1]	Ratio
UX, in	0.9×10^{-5}	0.9×10^{-5}	1.000
UY, in	0.95×10^{-5}	0.95×10^{-5}	1.000
UZ, in	-0.175×10^{-5}	-0.175×10^{-5}	1.000

1. for Nodes 8 and 16

VM146: Bending of a Reinforced Concrete Beam

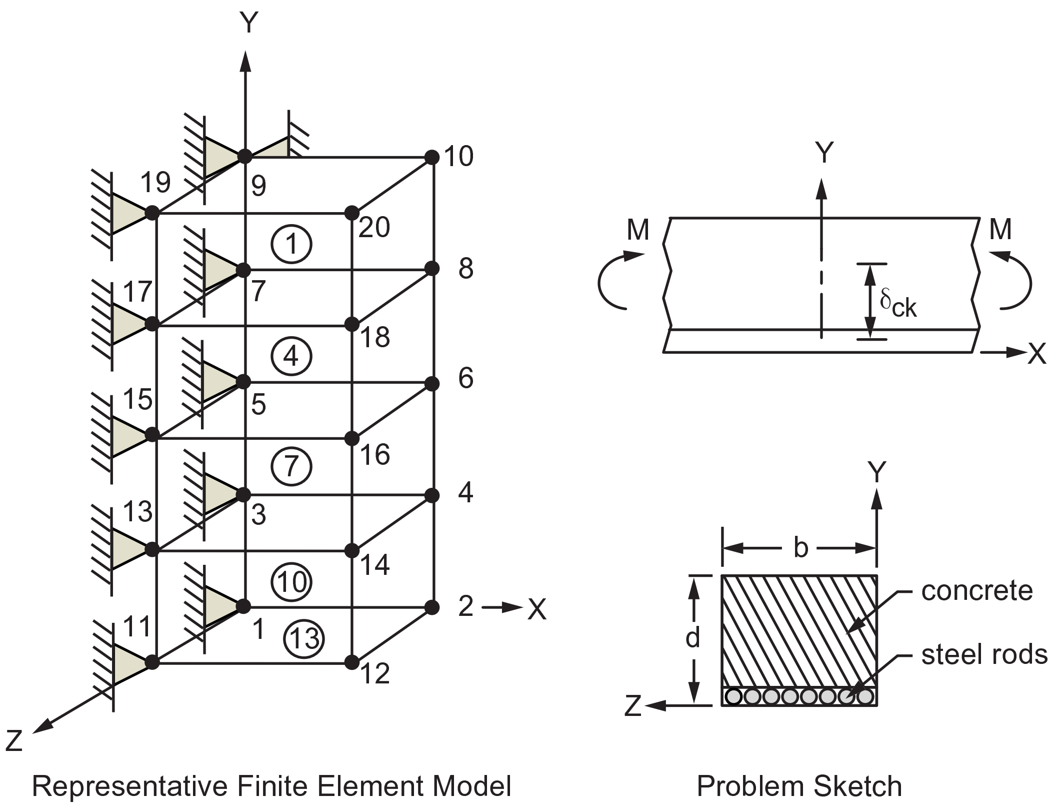
Overview

Reference:	S. Timoshenko, *Strength of Material, Part I, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 221, article 48.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Reinforced Concrete Solid Elements (SOLID65) 3-D Spar (or Truss) Elements (LINK180) 3-D 2-Node Pipe Elements (PIPE288)
Input Listing:	vm146.dat

Test Case

A concrete beam reinforced with steel rods (of cross-sectional area A) is subjected to a pure bending load M. Determine the depth of the crack δ_{ck} from the bottom surface, the maximum tensile stress σ_t in the steel, and the maximum compressive stress σ_c in the concrete, assuming the cracking tensile strength of concrete σ_{ct} to be zero.

Figure 146.1: Reinforced Concrete Beam Problem Sketch



Material Properties	Geometric Properties	Loading
Concrete (material 1) $E = 2 \times 10^6$ psi	b = 5 in d = 6 in $A = 0.30$ in^2	M = 600 in-lb

Material Properties	Geometric Properties	Loading
σ_{ct} = 0.0 psi υ = 0.0 **Steel (material 2)** E = 30 x 10^6 psi υ = 0.3		

Analysis Assumptions and Modeling Notes

The bottom concrete element is lined with two spar elements to match the assumption given in the reference of discrete (rather than smeared) reinforcement. A zero Poisson's ratio and an infinite crushing strength are also assumed for the concrete to match the reference assumptions. An element width (in the X-direction) of 1.5 in. is arbitrarily selected. Constraint equations are used along the beam depth to conveniently apply the load and match the reference assumption that cross-sections remain plane. Dummy PIPE288 pipe elements are used to "line" the constraint equation region to provide the necessary rotational degrees of freedom at the nodes. Up to five substeps are specified with automatic load stepping to allow convergence of the crack nonlinearity.

Results Comparison

	Target	Mechanical APDL	Ratio
$Depth_{ck}$, in	3.49	Between 3.32 - 4.18[1]	-
$Stress_t$, psi	387.28	387.25[2]	1.000
$Stress_c$, psi	-18.54	-18.49[3]	0.997

1. Five sets of integration points (each set consisting of 4 points parallel to the X-Z plane) below 3.49 in. crack open, including one set at 3.32 in. from the bottom. Three sets of integration points above 3.32 in. remain closed, including one set at 4.18 in. from the bottom. Note that the integration points are printed only if the element has cracked. A more exact comparison with theory could be obtained with more elements along the depth of the beam (and thus a closer spacing of integration points).

2. $Stress_t$ = SAXL in the spars (elements 13 and 14).

3. $Stress_c$ = SX in element 1 at nodes 9, 10, 19, or 20.

VM147: Gray-Body Radiation within a Frustum of a Cone

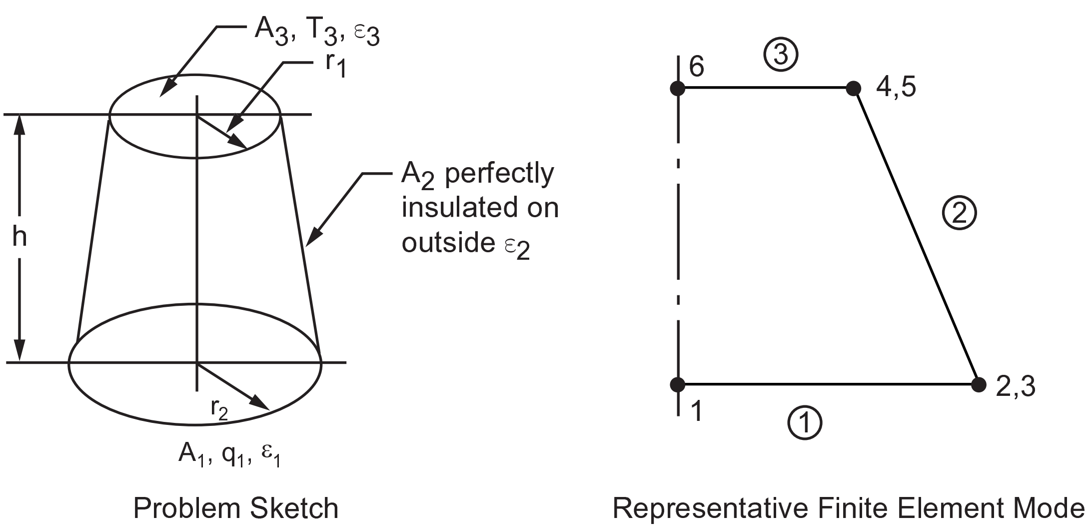
Overview

Reference:	R. Siegel, J. R. Howell, *Thermal Radiation Heat Transfer*, 2nd Edition, Hemisphere Publishing Corporation, 1981, pg. 277, prob. 9.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0) AUX12 (Radiation View Factor Utility)
Element Type(s):	3-D Conduction Bar Elements (LINK33) 2-D Thermal Surface Effect Elements (SURF151) Superelement (or Substructure) Elements (MATRIX50)
Input Listing:	vm147.dat

Test Case

A frustum of a cone has its base heated (q_1) as shown. The top is held at temperature T_3, while the side is perfectly insulated. All the surfaces are diffuse-gray (with emissivities ε_1, ε_2, ε_3, respectively). Determine the temperature T_1, achieved by surface 1 as a result of radiation exchange within the enclosure.

Figure 147.1: Gray-Body Radiation Problem Sketch



Material Properties	Geometric Properties	Loading
ε_1 = .06 ε_2 = 0.8 ε_3 = 0.5	r_i = 0.050 m r_2 = 0.075 m h = 0.075 m	T_3 = 550 K q_1 = 6000 W/m^2

Analysis Assumptions and Modeling Notes

An axisymmetric model is used for the cone. The radiating surfaces are modeled using three LINK33 elements. The non-hidden method (**VTYPE**) is used since there are no blocking or obscuring surfaces within the enclosure (i.e. all radiating surfaces fully "see" each other). The radiation matrix is written using 50 circumferential divisions (**GEOM**). Since all the radiating surfaces form an enclosure, no space node is specified. Heat flux on the bottom surface is applied using SURF151 (surface effect element). The value of Stefan-Boltzmann constant is specified in consistent units as 5.6696E-8 W/m^2-K.

Results Comparison

Non-hidden method	Target	Mechanical APDL	Ratio
T_1 , K	904	907	1.003

VM148: Bending of a Parabolic Beam

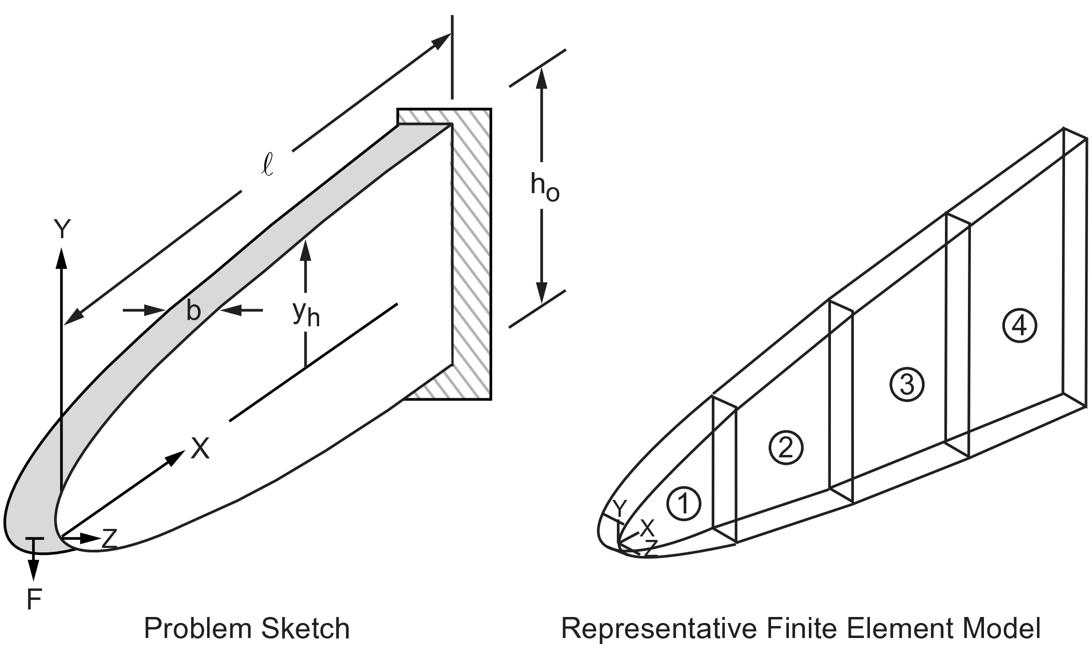
Overview

Reference:	S. Timoshenko, *Strength of Material, Part I, Elementary Theory and Problems*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 210, article 46.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 20-Node Structural Solid Elements (SOLID95) 3-D 20-Node Structural Solid Elements (SOLID186)
Input Listing:	vm148.dat

Test Case

A beam having a parabolic depth-to-length variation is subjected to an end load as shown. The other end is supported at a wall. Determine the deflection δ at the tip of the beam.

Figure 148.1: Parabolic Beam Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $G = 1.5 \times 10^8$ psi $\upsilon = 0.0$	ℓ = 4 in h_o = 2 in b = 0.2 in	F = -1000 lb

Analysis Assumptions and Modeling Notes

The problem is solved first using 3-D solid (SOLID95) and then using 3-D solid SOLID186 elements.

A large shear modulus G is assumed (1.5×10^8) and the Poisson's ratio is taken as zero to match the theoretical assumptions. The six nodes at the top and bottom edges near the tip of element 1 are defined closer to the tip so that the two mid-edge nodes (11 and 71) are not improperly located. Other nodes along the parabolic edge are generated with parametric input, at uniform spacing along the axis, using the equation:

$$Y_h = (h_o / 2)^* Y_h = (h_o / 2)^* \sqrt{x / \ell}$$

Results Comparison

	Target	Mechanical APDL	Ratio
SOLID95			
Deflection, in	-0.01067	-0.01062[1]	0.995
SOLID186			
Deflection, in	-0.01067	-0.01076	1.009

1. UY at node 11 or 71.

VM149: Residual Vector in Mode-Superposition Harmonic Analysis

Overview

Reference:	J.M.Dickens, J.M. Nakagawa, M.J. Wittbrodt, " A Critique of Mode Acceleration and Modal Truncation Augmentation Methods for Modal Response Analysis". *Computers & Structures*, Vol.62, pp.985-998, 1997.
Analysis Type(s):	Modal Analysis (**ANTYPE** =2) Harmonic Analysis (**ANTYPE** =3)
Element Type(s):	Spring-Damper (COMBIN14) Structural Mass (MASS21)
Input Listing:	vm149.dat

Test Case

A mode-superposition harmonic analysis is performed on a spring-mass model for two cases:

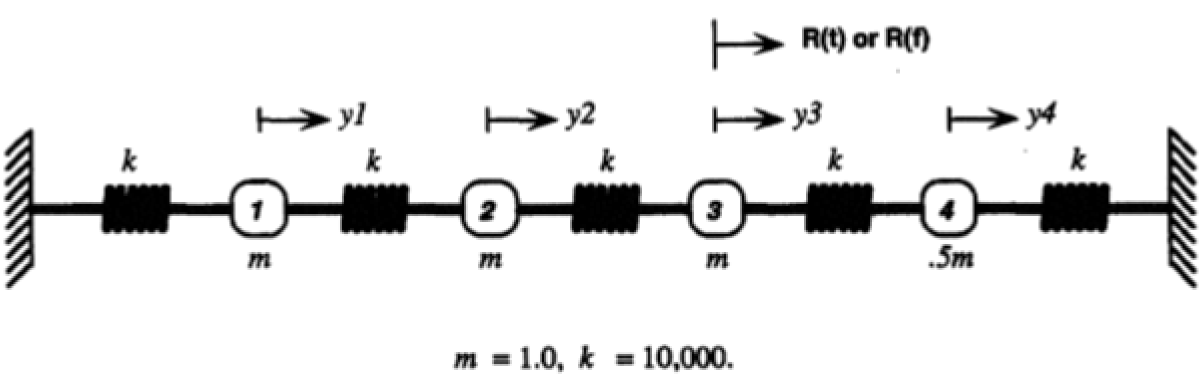
Case 1: Extracting all available modes
Case 2: Extracting one mode and residual vector (**RESVEC**)

The following values are computed for both cases and compared against the target values shown in the reference:

- Peak displacement amplitude along X direction at node 4
- First and second peak force amplitude for the spring element
- Frequency corresponding to first peak displacement and first peak force amplitudes

Because the target values are taken from figures, they are reported to an appropriate accuracy in the results comparison section. The modal truncation (MT) method shown in the reference corresponds to the residual vector method (Case 2).

Figure 149.1: Spring-Mass Model



Material Properties	Geometric Properties	Loading
Spring Stiffness (K) = 1000 N/m Mass1 = 1.0 Kg Mass 2 = 0.5 Kg Damping ratio = 2%	Total Length = 5m	Force along X direction at node 4 = 1N Excitation frequency: 3 – 70 Hz

Analysis Assumptions and Modeling Notes

The spring-mass model is represented using 2-D COMBIN14 and 2-D MASS21 elements without rotary inertia. The X and Y axis of the spring model are inverted from the reference to model it along global X axis. The model is fixed at both the ends, and displacement along the Y direction is constrained on all nodes. In order to obtain four distinct modes, the mass at node 5 is set to half the value of the other three masses defined at nodes 2, 3, and 4. A modal analysis is performed first using the Block Lanczos eigensolver. A mode-superposition harmonic analysis is then performed with an excitation frequency range of 3-70 Hz and a force load along the X direction at node 4. A constant damping ratio of 0.02 (2%) is defined using the **DMPRAT** command. Calculations are done in **/POST26** to determine the displacement and force amplitudes. Results are retrieved using the ***GET** command.

Results Comparison

	Target	Mechanical APDL	Ratio
Extracting all available modes			
UX_MAX (m)	0.00250	0.00226	1.106
F_MAX (N)	10.00000	10.04035	0.996
Frequency @ UX_MAX (Hz)	10.10000	10.10200	1.000
Frequency @ F_MAX (Hz)	10.10000	10.10200	1.000
F_MAX2 (N)	4.50000	4.28867	1.049
Extracting one mode and Residual Vector			
Residual Mode	21.8650	21.86523	1.000
UX_MAX (m)	0.00250	0.00226	1.106
F_MAX (N)	10.00000	10.05002	0.995
Frequency @ UX_MAX (Hz)	10.10000	10.10200	1.000
Frequency @ F_MAX (Hz)	10.10000	10.10200	1.000
F_MAX2(N)	4.50000	4.72924	0.952

Figure 149.2: Displacement Amplitude and Spring Force Amplitude Versus Frequency for Case 1

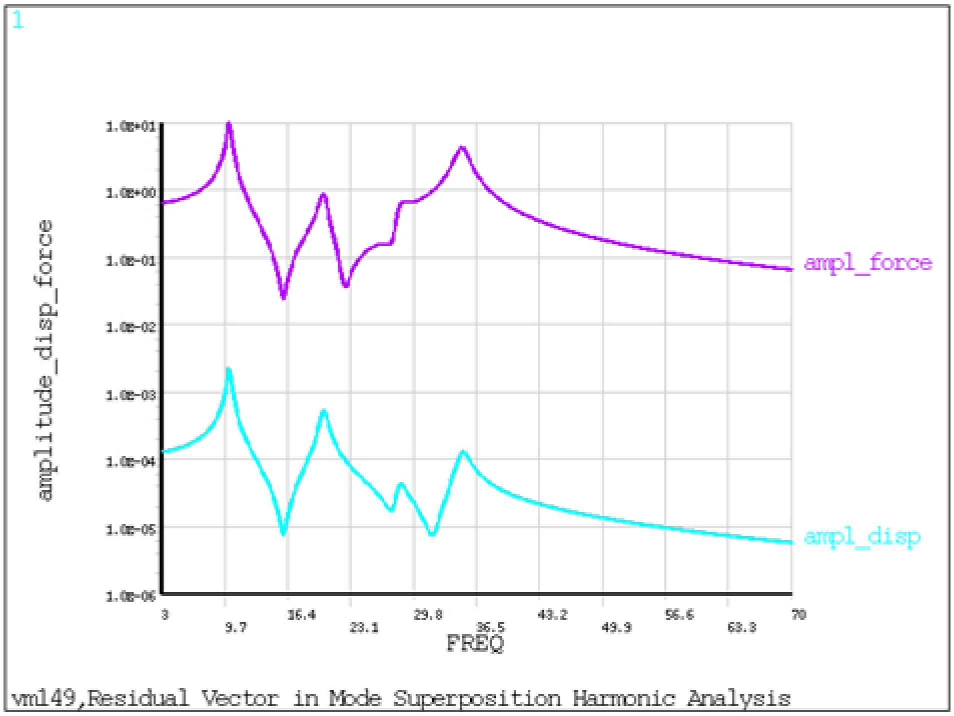
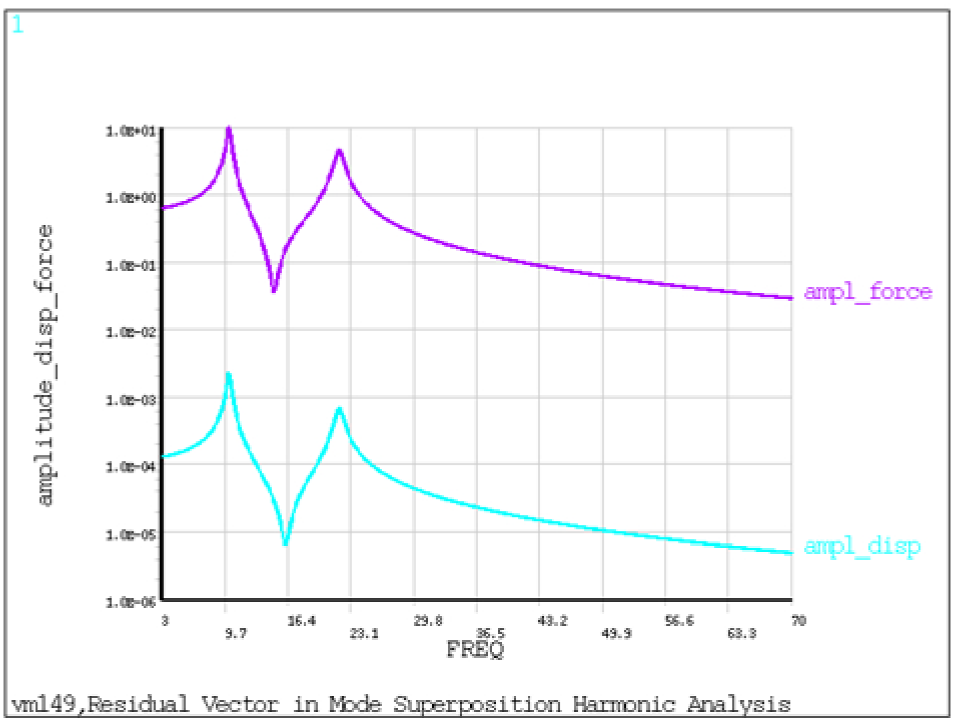


Figure 149.3: Displacement Amplitude and Spring Force Amplitude Versus Frequency for Case 2



VM150: Moisture Diffusion in a Plate Under Constant Surface Concentration

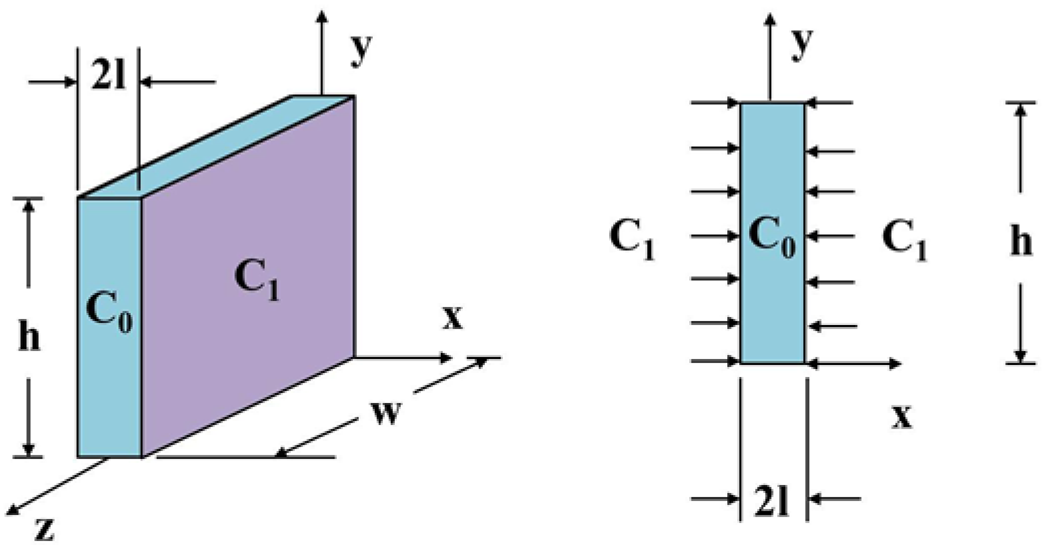
Overview

Reference:	Crank, J. *The Mathematics of Diffusion*. 2nd Printing, Bristol: Oxford University Press, 1975 pp. 47-48.
Analysis Type(s):	Transient Analysis (**ANTYPE** = 4)
Element Type(s):	3-D 20-Node Diffusion Solid Elements (SOLID239)
Input Listing:	vm150.dat

Test Case

A plane sheet of thickness 2l at an initial concentration C_0 is subjected to an applied concentration of C_1 at its surface ($x = \pm l$). A time transient analysis (**ANTYPE** = 4) is performed with a run time of t=5760000s to determine the moisture concentration in the plane sheet at location x=l/2 and at time=t/2. Also the total moisture weight gain is determined at time=t/2.

Figure 150.1: Fluid Tank Problem Sketch



Material Properties	Geometric Properties	Loading
Diffusivity coefficient D = 1e-12 m^2/s	l = 2e-3 m w = 50e-3 m h = 50e-3 m	C_0 = 0.01 kg/m^3 C_1 = 0.2 kg/m^3

Analysis Assumptions and Modeling Notes

The initial concentration C_0 is applied using the **IC** command, and the concentration C_1 is applied using the **D** command. The transient analysis is run with stepped loading (KBC=1).

To calculate the moisture weight gain, the concentration of each element is multiplied by the element's volume. These individual element weight gains are then summed to give the total weight gain.

The target concentration solution was obtained using Eq. 4.17 given in the reference. The equation was truncated to five terms for target result calculation:

$$C = C_1 - \frac{4(C_1 - C_0)}{\pi} \sum_{n=0}^{\infty} \frac{(-1)^n \exp\{\frac{-D(2n+1)^2 \pi^2 t}{4l^2}\} \cos\{\frac{(2n+1)\pi x}{2l}\}}{2n+1}$$

Where:

x = X-location in plate. The value l/2 was used.

The target moisture weight gain solution was obtained using Eq. 4.18 given in the reference. The equation was truncated to five terms for target result calculation:

$$M_t = M_\infty - \frac{8M_\infty}{\pi^2} \sum_{n=0}^{\infty} \frac{\exp\{\frac{-D(2n+1)^2 \pi^2 t}{4l^2}\}}{(2n+1)^2}$$

Where:

M_∞ = the total moisture weight gain at saturation. This was assumed to be:

$$\frac{C_1}{2l*h*w}$$

Results Comparison

	Target	Mechanical APDL	Ratio
Concentration, kg/m^3 (x = l/2, t = 2880000 s)	0.17105	0.17000	0.994
Moisture Weight Gain, kg (t = 2880000 s)	0.17257e-5	0.17397e-5	1.008

Figure 150.2: Concentration in Plate over Time

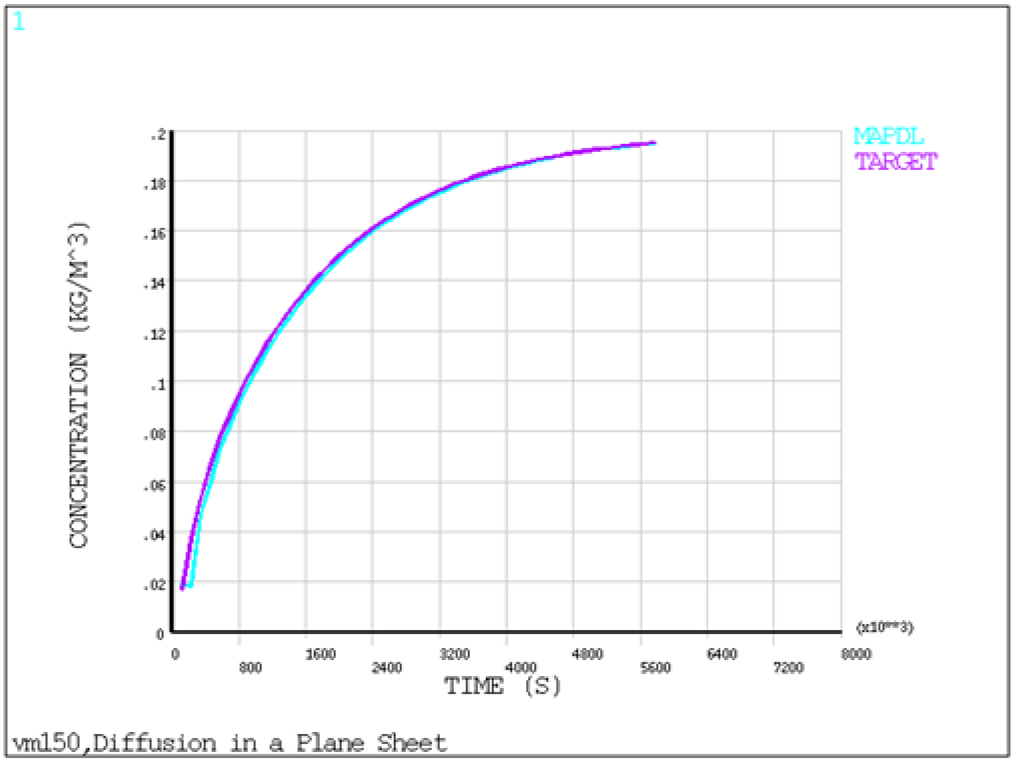
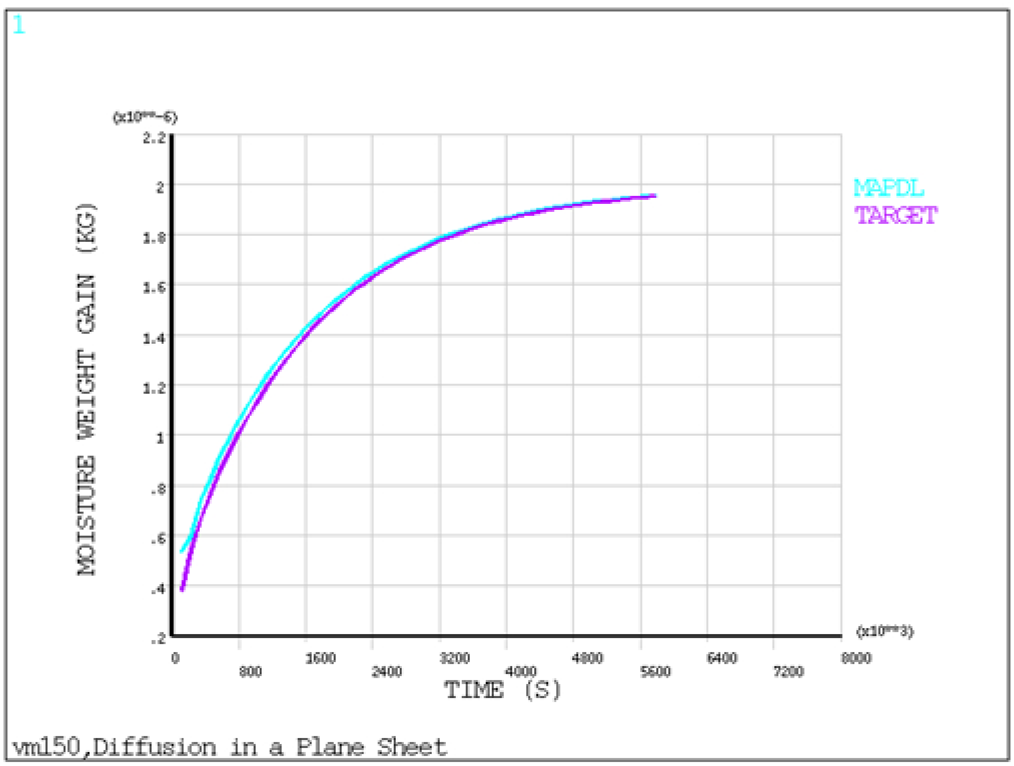


Figure 150.3: Moisture Weight Gain over Time



VM151: Nonaxisymmetric Vibration of a Circular Plate

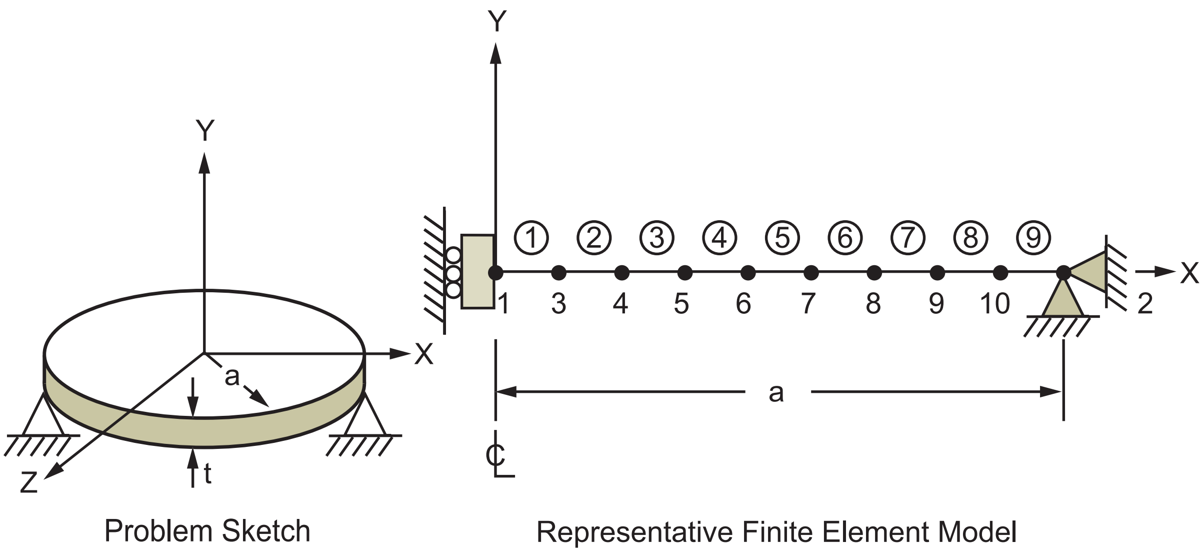
Overview

Reference:	R. J. Blevins, *Formulas for Natural Frequency and Mode Shape*, Van Nostrand Reinhold Co., New York, NY, 1979, pg. 240, no. 2.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	Axisymmetric-Harmonic Structural Shell Elements (SHELL61)
Input Listing:	vm151.dat

Test Case

A circular plate with a simply supported edge is allowed to vibrate freely. Determine the natural frequencies $f_{i,j}$ for the first mode of vibration (j = 1 = no. of nodal circles, including the boundary) for the first three harmonics (i = 0,1,2 = no. of harmonic indices).

Figure 151.1: Circular Plate Problem Sketch



Material Properties	Geometric Properties
$E = 30 \times 10^6$ psi $\upsilon = 0.3$ $\rho = 0.00073$ lb-sec^2/in^4	a = 3 in t = 0.05 in

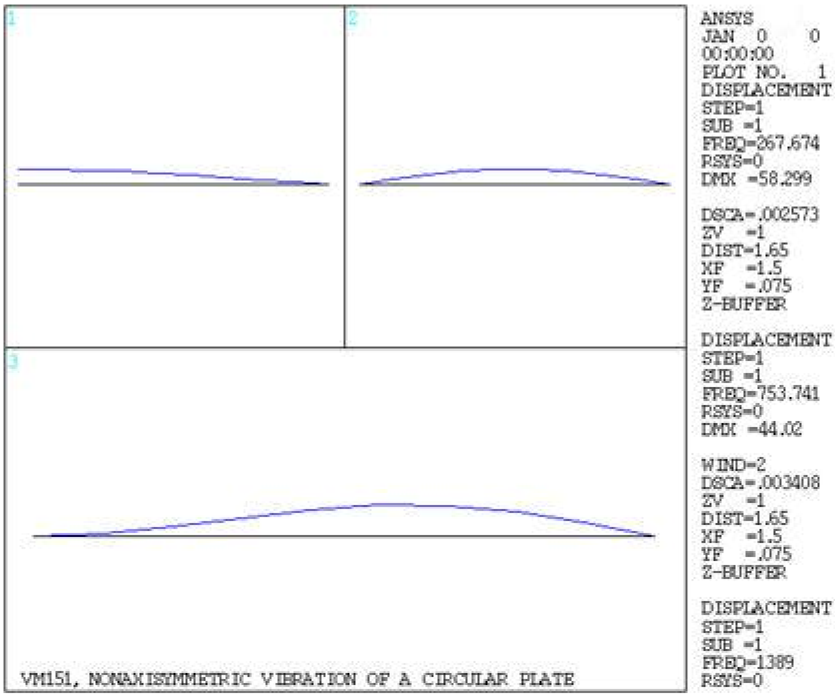
Analysis Assumptions and Modeling Notes

Poisson's ratio defaults to 0.3 and is not defined with the input data. A total of 9 elements is selected for meshing. Modal analysis is solved using Block-Lanczos eigensolver.

Results Comparison

	Target	Mechanical APDL	Ratio
$f_{o,1}$, Hz	269.96	267.67	0.992
$f_{1,1}$, Hz	756.13	753.74	0.997
$f_{2,1}$, Hz	1391.3	1388.89	0.998

Figure 151.2: Mode Shape Displays



Window 1 - $f_{0,1}$; Window 2 - $f_{1,1}$; Window 3 - $f_{2,1}$

VM152: 2-D Nonaxisymmetric Vibration of a Stretched Membrane

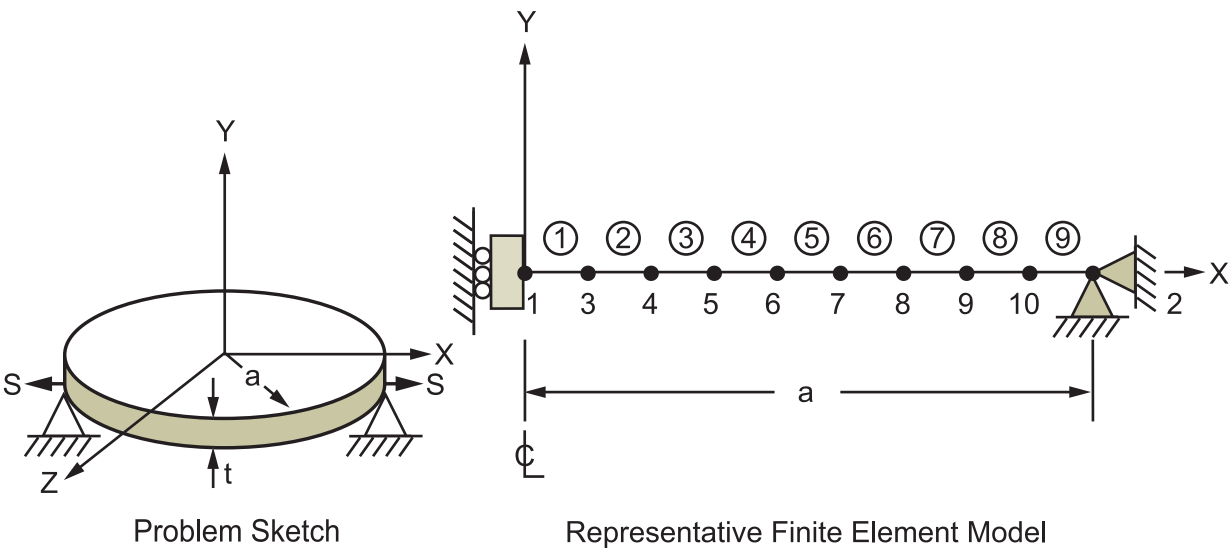
Overview

Reference:	S. Timoshenko, D. H. Young, *Vibration Problems in Engineering*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pp. 438-439, article 69.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2) Static Analysis, Prestress (**ANTYPE** = 0)
Element Type(s):	Axisymmetric-Harmonic Structural Shell Elements (SHELL61)
Input Listing:	vm152.dat

Test Case

A circular membrane under a uniform tension S is allowed to vibrate freely. The edge of the membrane is simply supported. Determine the natural frequencies $f_{i,j}$ for the first mode of vibration (j = 1 = no. of nodal circles, including the boundary) for the first three harmonic (i = 0,1,2 = no. of harmonic indices). Also determine the next highest axisymmetric frequency $f_{0,2}$. See VM153 for a 3-D solution of this problem.

Figure 152.1: Circular Membrane Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.0$ $\rho = 0.00073$ lb-sec^2/in^4 $\alpha = 1 \times 10^{-5}$ in/in-°F	a = 3 in t = 0.00005 in	S = 0.1 lb/in of boundary $\Delta T = -6.6666$°F

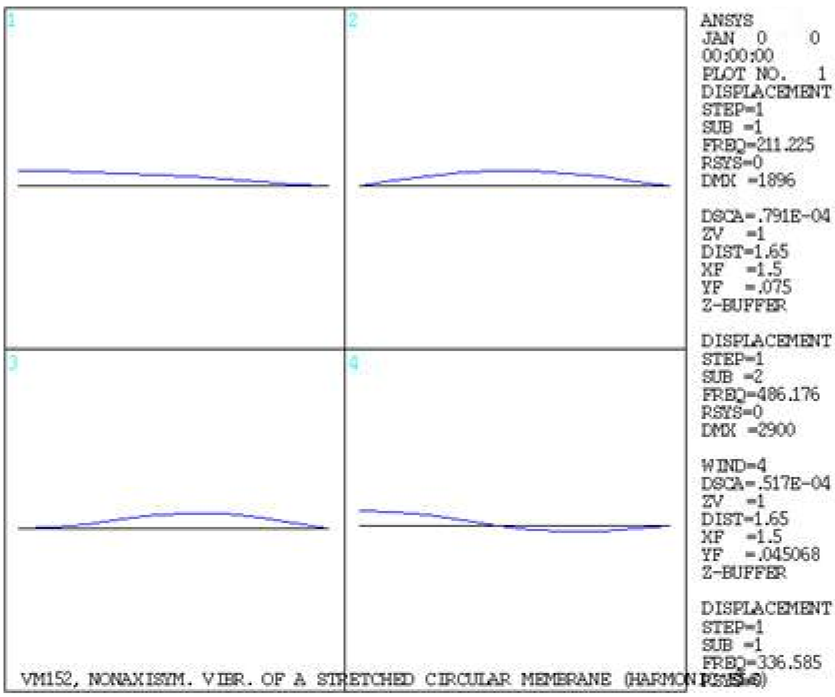
Analysis Assumptions and Modeling Notes

A total of 9 elements is selected for meshing. The prestress is induced by cooling the membrane. The necessary temperature difference, ΔT, is calculated from $S = -E \alpha t(\Delta T)$. Modal analysis is solved using Block-Lanczos eigensolver.

Results Comparison

	Target	Mechanical APDL	Ratio
$f_{o,1}$, Hz (L.S. 1, ITER 1)	211.1	211.2	1.000
$f_{1,1}$, Hz (L.S. 2, ITER 1)	336.5	336.5	1.000
$f_{2,1}$, Hz (L.S. 3, ITER 1)	450.9	451.0	1.000
$f_{0,2}$, Hz (L.S. 1, ITER 2)	484.7	484.7	1.000

Figure 152.2: Mode Shape Displays



Window 1 - $f_{0,1}$; Window 2 - $f_{1,1}$; Window 3 - $f_{2,1}$; Window 4 - $f_{0,2}$;

VM153: 3-D Nonaxisymmetric Vibration of a Stretched Membrane

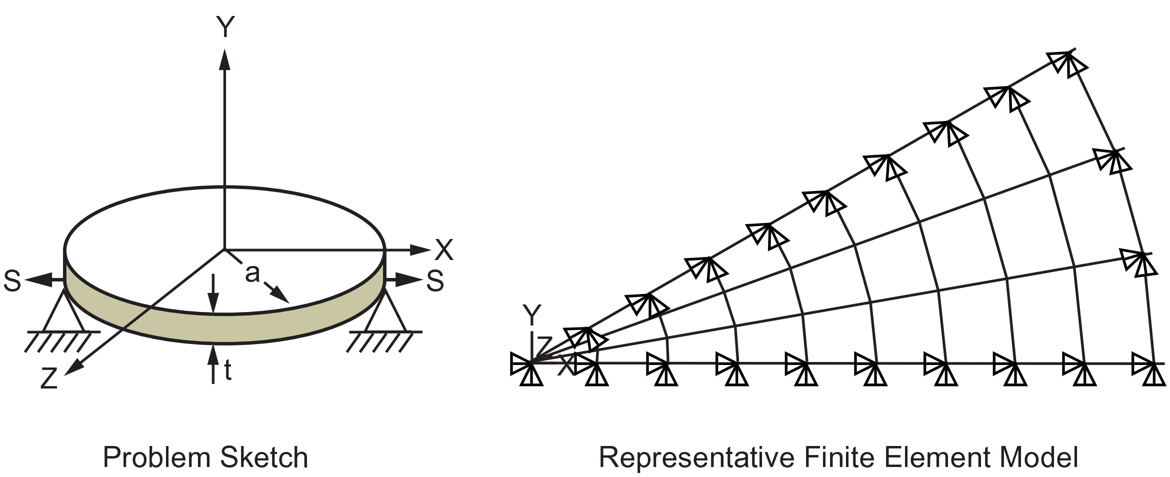
Overview

Reference:	S. Timoshenko, D. H. Young, *Vibration Problems in Engineering*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 439, article 69.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2) Prestress Static Analysis (**ANTYPE** = 0) Substructure Cyclic Symmetry Matrix (Macro)
Element Type(s):	Membrane Shell Elements (SHELL41) 4-Node Finite Strain Shell Elements (SHELL181)
Input Listing:	vm153.dat

Test Case

A circular membrane under a uniform tension S is allowed to vibrate freely. The edge of the membrane is simply supported. Determine the natural frequencies $f_{i,j}$ for the first two modes of vibration (j = 1, 2 = no. of nodal circles, including the boundary) for the first two harmonics (i = 0, 1 = no. of harmonic indices). See VM152 for a 2-D solution of this problem.

Figure 153.1: Circular Membrane Problem Sketch



Material Properties	Geometric Properties	Loading
E = 30 x 10^6 psi υ = 0.0 ρ = 0.00073 lb-sec^2/in^4 α = 1 x 10^{-5} in/in-°F	a = 3 in t = 0.00005 in	S = 0.1 lb/in of boundary ΔT = -6.6666°F

Analysis Assumptions and Modeling Notes

A 30° sector is used with cyclic symmetry to model the membrane. The prestress is induced by uniform cooling. The temperature difference, ΔT, is calculated from S = E αt (ΔT). The low angle edge of the sector is defined as a component for cyclic symmetry analyses. Block Lanczos is used in the modal analysis to extract the first four frequencies.

The model is first solved using membrane shell elements (SHELL41) and then using finite strain shell elements (SHELL181) using the membrane option (KEYOPT(1) = 1).

Results Comparison

	Target	**Mechanical APDL**	**Ratio**
SHELL41			
$f_{o,1}$, Hz	211.1	212.1	1.005
$f_{o,2}$, Hz	484.7	491.7	1.014
$f_{1,1}$, Hz	336.5	338.9	1.007
$f_{1,2}$, Hz	616.1	629.0	1.021
SHELL181			
$f_{o,1}$, Hz	211.1	211.3	1.001
$f_{o,2}$, Hz	484.7	486.5	1.004
$f_{1,1}$, Hz	336.5	338.1	1.005
$f_{1,2}$, Hz	616.1	626.6	1.017

VM154: Vibration of a Fluid Coupling

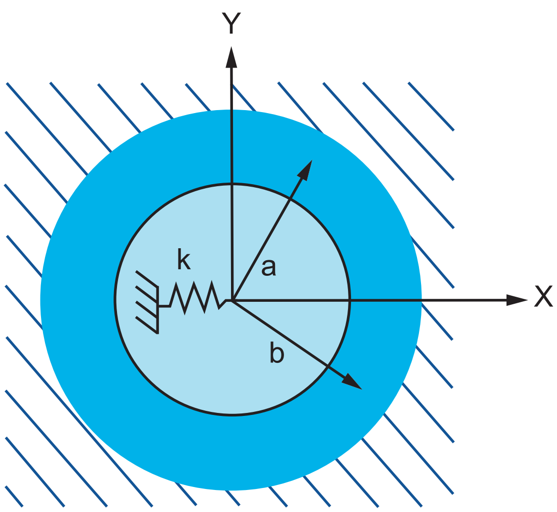
Overview

Reference:	R. J. Fritz, "The Effect of Liquids on the Dynamic Motions of Immersed Solids", *ASME, J. of Engr. for Industry*, Vol. 94, Feb. 1972, pp. 167-173.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	Dynamic Fluid Coupling Element (FLUID38) Spring-Damper Elements (COMBIN14)
Input Listing:	vm154.dat

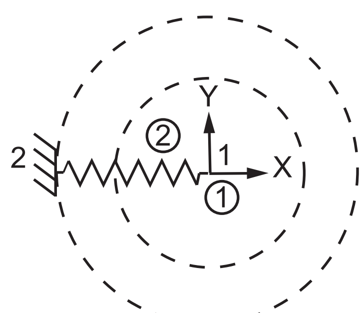
Test Case

A long cylinder is immersed in a circular hole as shown. The cylinder is separated from the containment surface by a frictionless, incompressible liquid annulus. A spring restraint is attached to the cylinder from ground. Determine the natural frequency f of the system based upon the hydrodynamic mass of the liquid annulus.

Figure 154.1: Fluid Coupling Problem Sketch



Problem Sketch



Representative Finite Element Model
(using FLUID38)

Material Properties	Geometric Properties
ρ = 0.0000934 lb-sec^2/in^4 k = 10 lb/in β = 30 x 10^4 psi	a = 7 in b = 8 in

Analysis Assumptions and Modeling Notes

The problem is solved using the fluid coupling element (FLUID38).

The total length of the assembly is assumed to be long in comparison to its radius. The solution is based on radial motion of a unit length of the assembly. The cylinder is assumed to be massless so that all mass effects are from liquid annulus. The nodes are defined as coincident, but they are shown apart for clarity. An effective harmonic spring constant, k=10 lb/in is used for each spring element to produce equivalent spring force.

Results Comparison

	Target	Mechanical APDL	Ratio
f, Hz (FLUID38)	1.5293	1.5293	1.000

VM155: Chaboche Rate-Dependent Plastic Material under Cyclic Loading

Overview

Reference:	R.C. Lin, J. Betten, W. Brocks, "Modeling of finite strain viscoplasticity based on the logarithmic corotational description." *Archive of Applied Mechanics*. Vol. 75, pp. 693-708, 2006
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Structural Solid Elements (PLANE182)
Input Listing:	vm155.dat

Test Case

A thin plate is modeled with chaboche rate-dependent plastic material model. Uniaxial cyclic displacement loading is applied in vertical direction (Figure 155.1: Uniaxial Loading Problem Sketch (p. 403)). The loading history is composed of 23 cycles (Figure 155.2: Loading history (p. 404)), in which the first 22 cycles have an identical displacement path. In the last load cycle the displacement is made constant at time gaps 910 to 940 seconds and at time gaps 960 to 990 seconds. The stress history is computed and compared against the reference solution.

Figure 155.1: Uniaxial Loading Problem Sketch

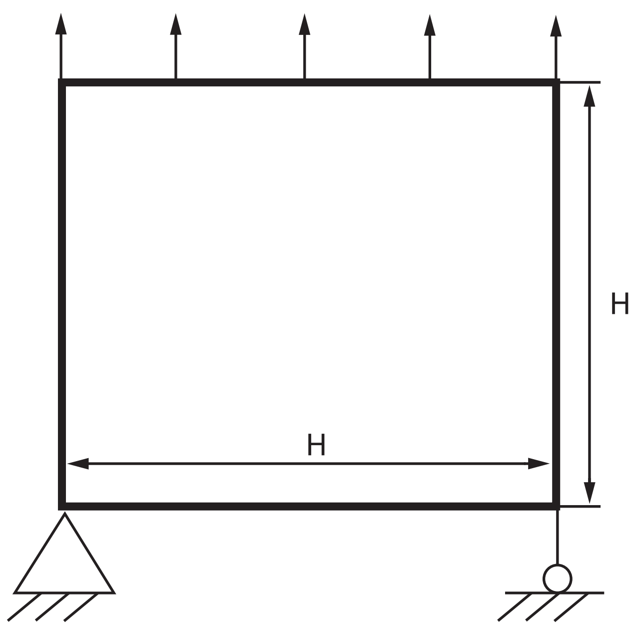
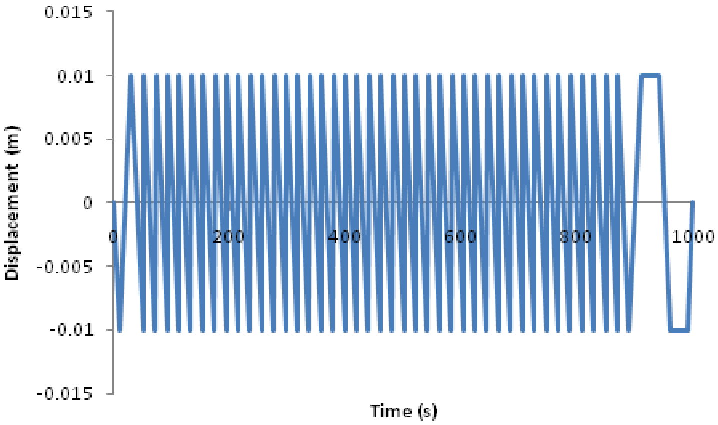


Figure 155.2: Loading history



Material Properties	Geometric Properties	Loading
E = 149,650 MPa μ = 0.33 Chaboche model: Yield stress k = 153MPa C_1 = 62511MPa y_1 = 201 Rate dependent model: k_0 = 153MPa r_0 = 0 r_∞ = -153MPa b = 317 m = 1/7.7 K = 1150MPa $s^{1/m}$	H=1m	Cyclic uniaxial displacement load

Analysis Assumptions and Modeling Notes

The problem is solved using 2-D PLANE182 elements with plain stress element behavior. The chaboche rate-dependent plasticity is defined by **TB**, CHAB and **TB**, RATE, respectively. A static analysis is performed with uniaxial displacement loading. The element stresses along the X direction are computed in POST1.

Results Comparison

Time	Target	Mechanical APDL	Ratio
910s	0.6810E+09	0.6984E+09	0.975
940s	0.5010E+09	0.4996E+09	1.003
960s	-0.6920E+09	-0.7097E+09	0.975
990s	-0.5020E+09	-0.5070E+09	0.990
1000s	0.4660E+09	0.4787E+09	0.973

VM156: Natural Frequency of a Nonlinear Spring-Mass System

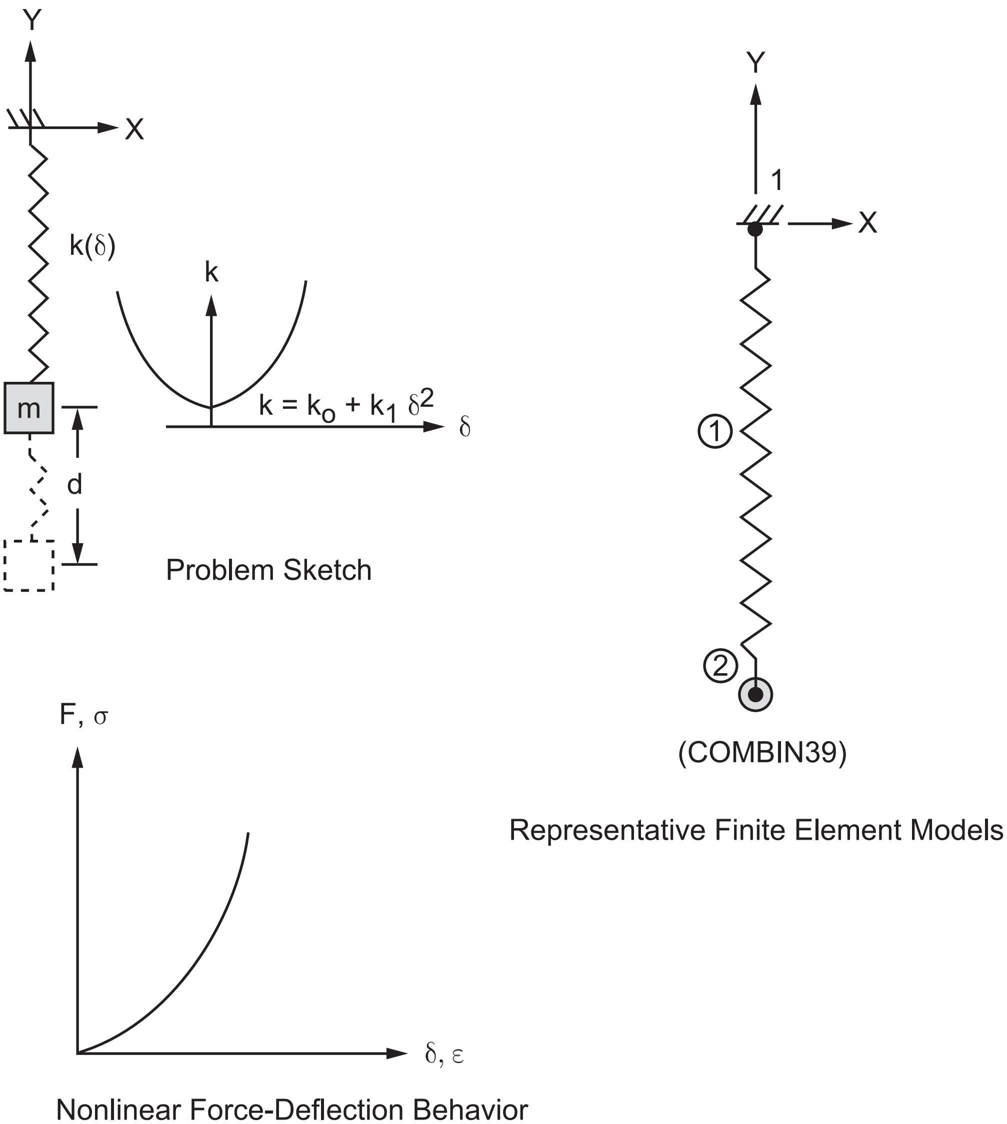
Overview

Reference:	S. Timoshenko, D. H. Young, *Vibration Problems in Engineering*, 3rd Edition, D. Van Nostrand Co., Inc., New York, NY, 1955, pg. 141.
Analysis Type(s):	Full Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	Nonlinear Spring Elements (COMBIN39) Structural Mass Elements (MASS21)
Input Listing:	vm156.dat

Test Case

A mass is supported from a spring having the nonlinear characteristics shown. The mass is displaced an amount δ from its equilibrium position and released (with no initial velocity). Find the corresponding period of vibration τ.

Figure 156.1: Nonlinear Spring-Mass System Problem Sketch



Material Properties	Geometric Properties	Loading
$m = 1/386.4 = 0.002588$ lb-sec^2/in $k_o = 2$ lb/in $k_1 = 4$ lb/in^3 see force-deflection curve in Figure 156.1: Nonlinear Spring-Mass System Problem Sketch (p. 406)	$A = 0.01$ in^2 ℓ = 100 in	$\delta = -1$ in

Analysis Assumptions and Modeling Notes

The problem is solved using the nonlinear spring element (COMBIN39).

For the nonlinear spring element (COMBIN39), the nonlinear spring constant is converted to eleven discrete force-deflection points by $F = k\delta$ for $\delta = 0.0$ to 1.0 in in steps of 0.1 in.

The **IC** command is used to impose the initial displacement and velocity configuration. The first load step is defined over a very small time step (.0002 sec) to allow the initial step change in acceleration to be attained. The integration time step for the second load step is based on 1/30 of the period to produce a fine resolution for the theoretical comparison. A final time of 0.18 sec is arbitrarily selected.

The nodes for the nonlinear spring element (COMBIN39) are defined as coincident but are shown apart in the model for clarity.

POST26 is used to extract results from the solution phase. The period is determined by the time when the mass is closest to the original released position after it passes through the spring's equilibrium position.

Results Comparison

		Target	Mechanical APDL	Ratio
COMBIN39	Vibration, sec	0.1447	0.1440	0.995

VM157: 3-D Acoustic Modal Analysis with Temperature Change

Overview

Reference:	C.L. Oberg, N.W. Ryan, A.D. Baer. "*A Study of T-Burner Behavior*". *AIAA Journal*. Vol. 6, No. 6. 1131-1137.
Analysis Type(s):	Modal Analysis (**ANTYPE** = 2)
Element Type(s):	3-D 8-Node Acoustic Fluid (FLUID30)
Input Listing:	vm157.dat

Test Case

A cylindrical region (single-ended T-burner) is filled with propellant. The temperature distribution in the propellant is discontinuous, where 31% of the length is occupied by "cool" gas and the rest is the "hot" gas. Determine the ratio of the amplitudes of pressure at the two ends of the T-burner.

Material Properties	Geometric Properties	Loading
Cool Gas: ρ_c=1.1e-7 lbf s^2 / in^4 c_c=13200 in/s^2 Hot Gas: ρ_h=2.2e-8 lbf s^2 / in^4 c_h=29516 in/s^2 Reference Pressure = 14.7 psi	R = 1.5 inches L = 9 inches	T_c = 440.33 F T_h = 4040.33 F

Analysis Assumptions and Modeling Notes

The T-burner is represented as a cylindrical volume. The cool gas occupies 31% of the length at 440.3° F, while the hot gas of 4040.3° F is in the remainder. The first non-zero mode is of interest, and the mode is essentially 1-D in nature. Using the ideal gas relationship, the ratio of the temperatures can be used to determine the ratio of the speed of sound and density:

$$c_h = c_c\sqrt{\frac{T_h}{T_c}}$$

$$Á_h = Á_c \frac{T_c}{T_h}$$

The temperature is applied in the cool and hot regions with a discontinuity at 31% of the length. Based on the reference, the relative amplitude at the hot end should be 0.45.

Results Comparison

	Target	Mechanical APDL	Ratio
Ratio of Hot/Cold Amplitude	0.450	0.447	1.007

VM158: Motion of a Bobbing Buoy

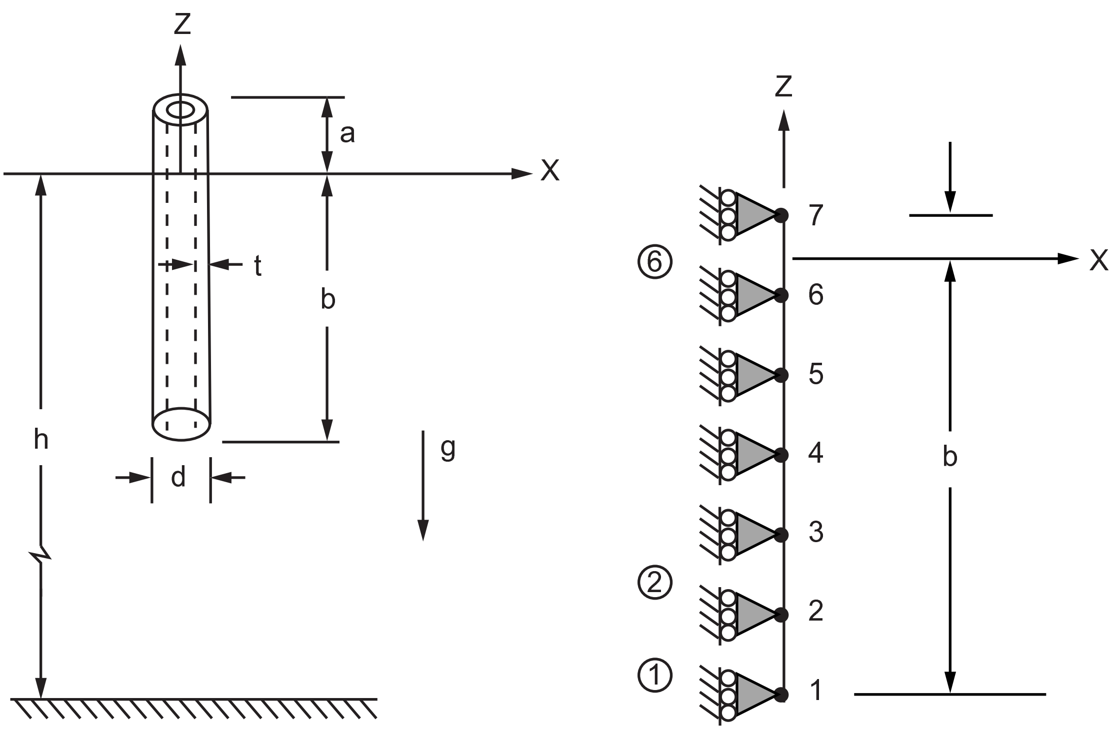
Overview

Reference:	K. Brenkert, Jr., *Elementary Theoretical Fluid Mechanics*, John Wiley and Sons, Inc., New York, NY, 1960, pg. 37, article 14.
Analysis Type(s):	Full Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	Immersed Pipe or Cable Elements (PIPE288)
Input Listing:	vm158.dat

Test Case

A cylindrical buoy is initially held at the position shown (above its equilibrium position) and then released (with no initial velocity). Determine the equilibrium position δ of the top of the buoy relative to the water surface.

Figure 158.1: Buoy Problem Sketch



Problem Sketch   Representative Finite Element Model

Material Properties	Geometric Properties	Loading
ρ = 8000 kg/m^3 ρ_w = 1000 kg/m^3	a = 1 m b = 9 m d = 1 m t = .03 m h = 30 m tangential drag coefficient = 0.3	g = 9.807 m/sec^2

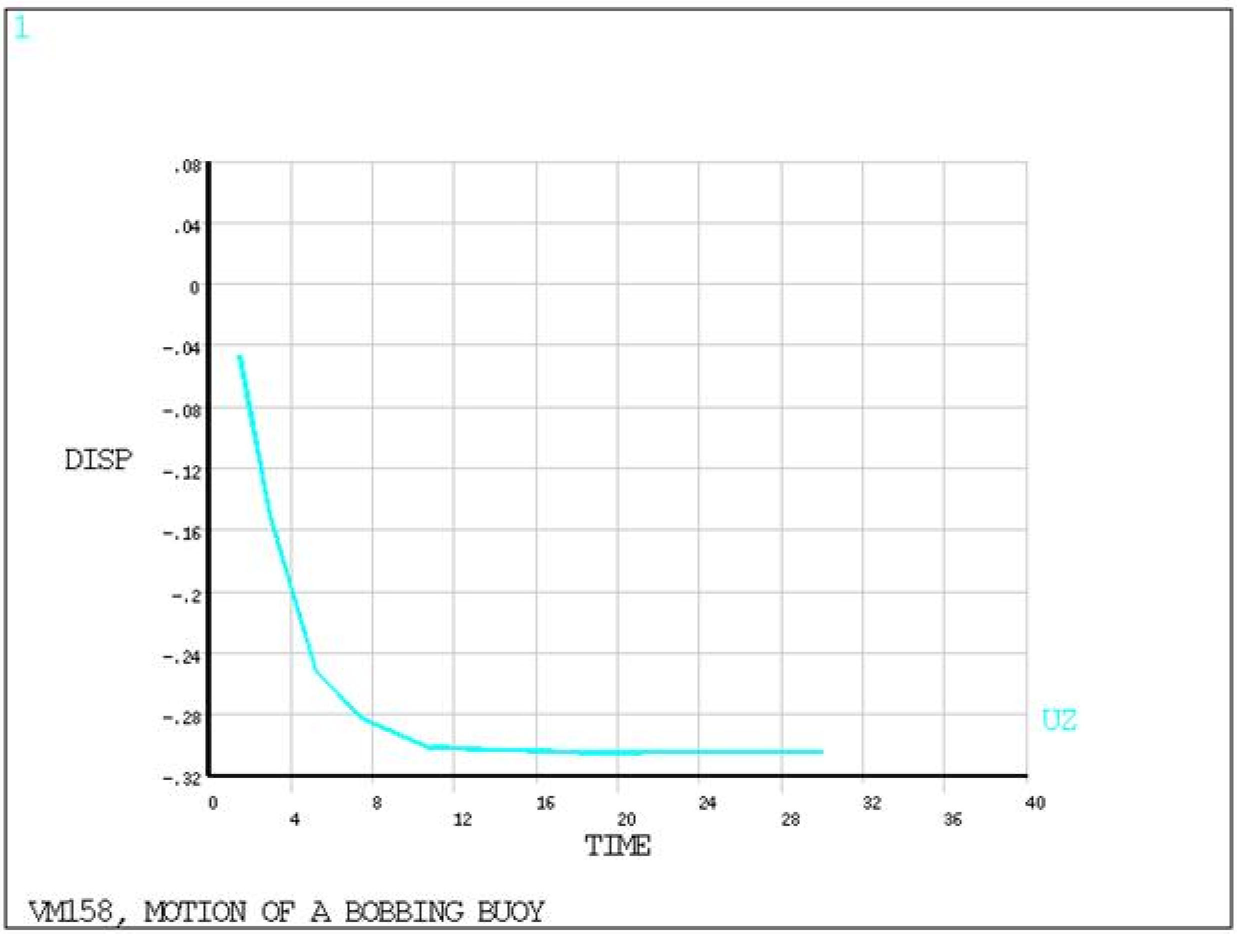
Analysis Assumptions and Modeling Notes

The static solution to this problem is best obtained by the "slow dynamics" technique with damping, since the buoy is initially subjected to free fall. An arbitrary time to steady state of 30 sec and 1.5 seconds per time step is selected for the slow dynamics. The mass damping value α determines the bouncing (if any) before the final steady state solution. An approximate α value is determined from F/MV where the force F = CV and damping C = αM. The force F is the out-of-balance force (buoyancy force $(1/4 \rho_w g \pi d^2 b)$ minus the buoy weight) for the initial position pushing the buoy into the water, M is the mass of the buoy, and V is an estimated average velocity (0.1 m/sec). Based upon these approximations, $\alpha \approx 3 \text{ sec}^{-1}$.

Results Comparison

	Target	Mechanical APDL	Ratio
Deflection , m	-.312	-.312	1.000

Figure 158.2: Displacement vs. Time Display



VM159: Temperature-controlled Heater

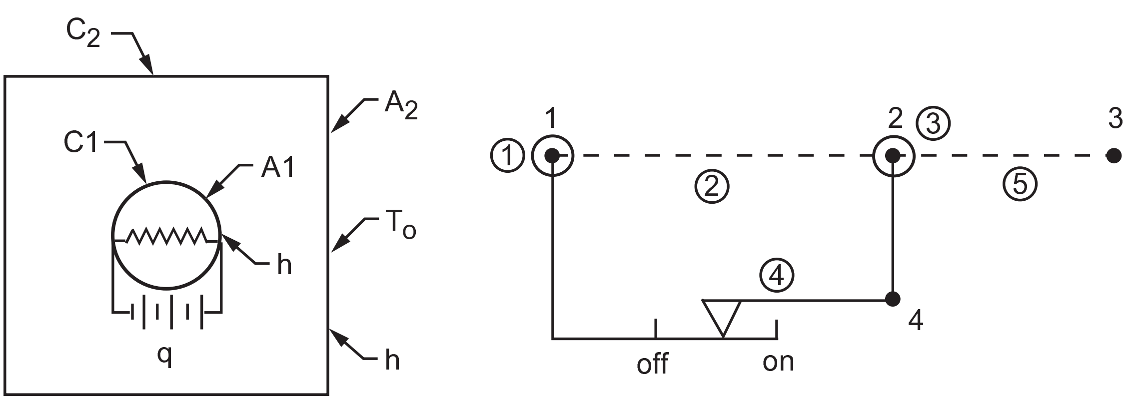
Overview

Reference:	Self-checking (Response Follows Input Request)
Analysis Type(s):	Transient Thermal Analysis (**ANTYPE** = 4)
Element Type(s):	Control Elements (COMBIN37) Convection Link Elements (LINK34) Thermal Mass Elements (MASS71)
Input Listing:	vm159.dat

Test Case

An assembly consisting of a heater with capacitance C_1 and surface area A_1 is surrounded by a box having capacitance C_2 and surface area A_2. The box is initially at a uniform temperature T_o. The heater, which supplies heat at a rate q, is turned on and remains on until the surrounding box temperature reaches a value T_{off}. The heater then switches off until the box temperature lowers to T_{on} and then switches on again. Determine the temperature response of the box and the heater status vs. time.

Figure 159.1: Temperature-controlled Heater Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$C_1 = 2.7046 \times 10^{-4}$ Btu/°F $C_2 = 2.7046 \times 10^{-3}$ Btu/°F h = 4 Btu/hr-ft^2-°F	$A_1 = 8.1812 \times 10^{-3}$ ft $A_2 = 4.1666 \times 10^{-2}$ ft	q = 10 Btu/hr T_{on} = 100°F T_{off} = 125°F T_o = 70°F

Analysis Assumptions and Modeling Notes

The conductivity resistance is assumed to be small compared with the thermal capacitance for both the heater and the box. A time of 12 min (0.2 hr) is arbitrarily selected to allow several cycles of response.

The integration time step is chosen to be 0.001 and automatic time stepping is used to reduce the number of substeps. The nodes are arbitrarily located at the origin.

Results Comparison

	Target	Mechanical APDL	Ratio
First "off" temp,°F	125	Between 124.842 - 125.003	-
First "on" temp,°F	100	Between 100.854 - 99.564	-

Figure 159.2: Box Temperature vs. Time

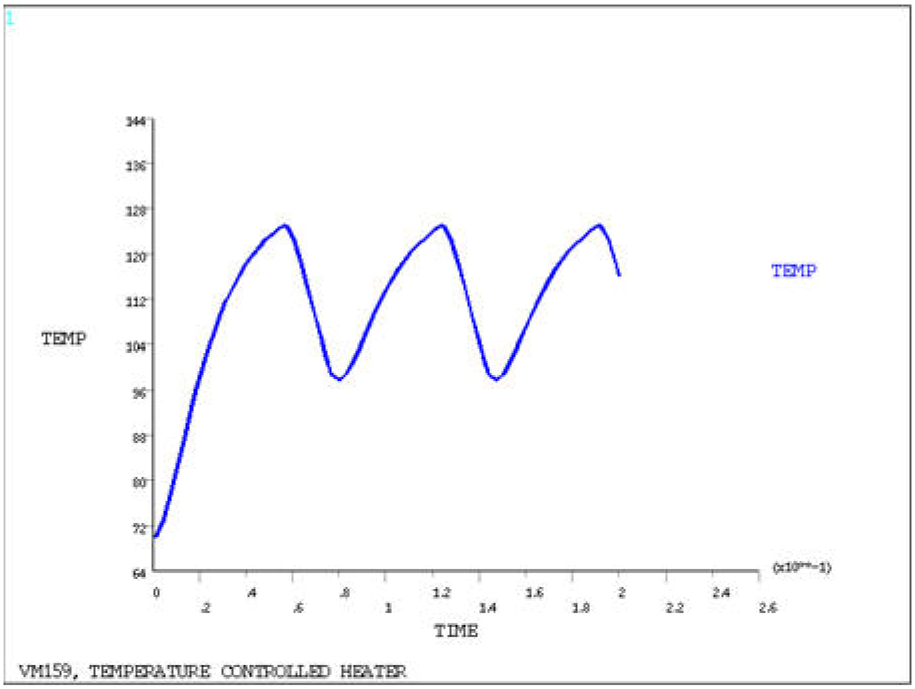
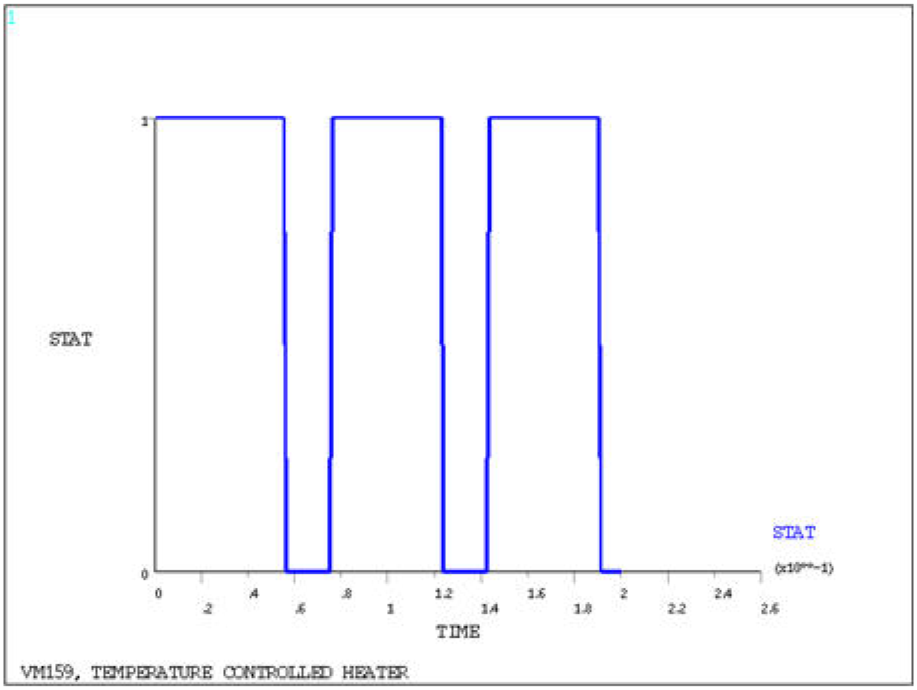


Figure 159.3: Control Status vs. Time



VM160: Solid Cylinder with Harmonic Temperature Load

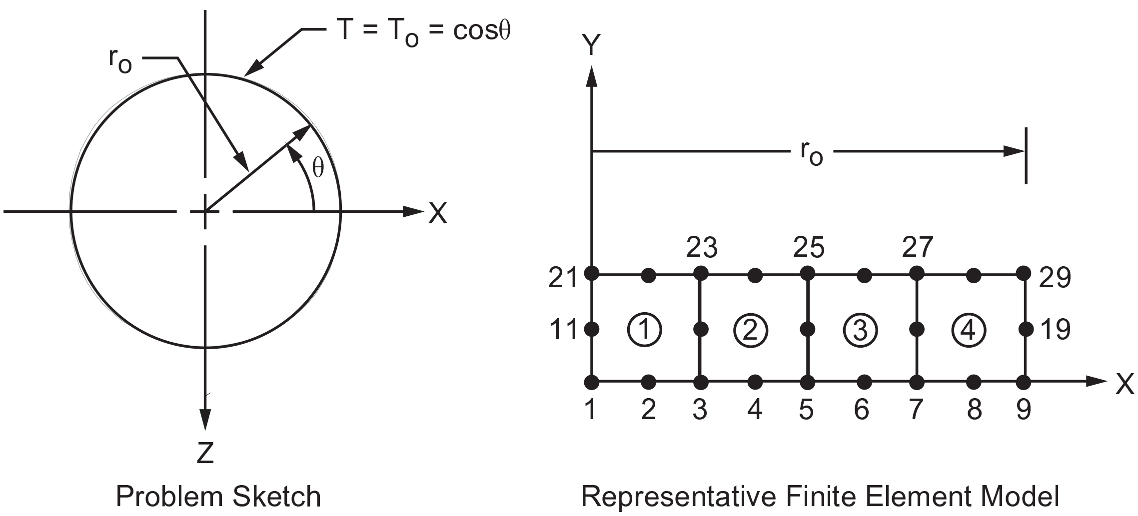
Overview

Reference:	F. B. Hildebrand, *Advanced Calculus for Applications*, 2nd Edition, Prentice-Hall, Inc., Englewood, NJ, 1976, pg. 447, equations 38-44.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	Axisymmetric-Harmonic 8-Node Thermal Solid Elements (PLANE78)
Input Listing:	vm160.dat

Test Case

A long solid cylinder has a harmonically-varying temperature load along its circumference represented by a cosine function with positive peaks at Θ = 0° and 180° and negative peaks at Θ = 90° and 270°. Determine the temperature distribution along the radius at Θ = 0 and Θ = 90°.

Figure 160.1: Solid Cylinder Problem Sketch



Material Properties	Geometric Properties	Loading
k = 1 Btu/hr-ft-°F	r_o = 20 ft	T_o = 80°F

Analysis Assumptions and Modeling Notes

The axial length of the model is arbitrarily chosen to be 5 ft. The temperature loading is applied as a symmetric harmonic function (Mode 2) around the periphery of the cylinder. To obtain the theoretical solution, equations 43 and 44 in F. B. Hildebrand, *Advanced Calculus for Applications* are used. Applying the temperature boundary condition and the requirement that T(r, Θ) should be finite and single-valued leads to the solution: $T(r, \Theta) = T_o * (r/r_o)^2 * \cos(2\Theta)$.

Results Comparison

		Target	Mechanical APDL	Ratio
Mode = 2 Angle = 0°	T, °F (Node 1)	0.0	0.0	1.00
	T, °F (Node 3)	5.0	5.0	1.00
	T, °F (Node 5)	20.0	20.0	1.00
	T, °F (Node 7)	45.0	45.0	1.00
Mode = 2 Angle = 90°	T, °F (Node 1)	0.0	0.0	1.00
	T, °F (Node 3)	-5.0	-5.0	1.00
	T, °F (Node 5)	-20.0	-20.0	1.00
	T, °F (Node 7)	-45.0	-45.0	1.00

VM161: Heat Flow From an Insulated Pipe

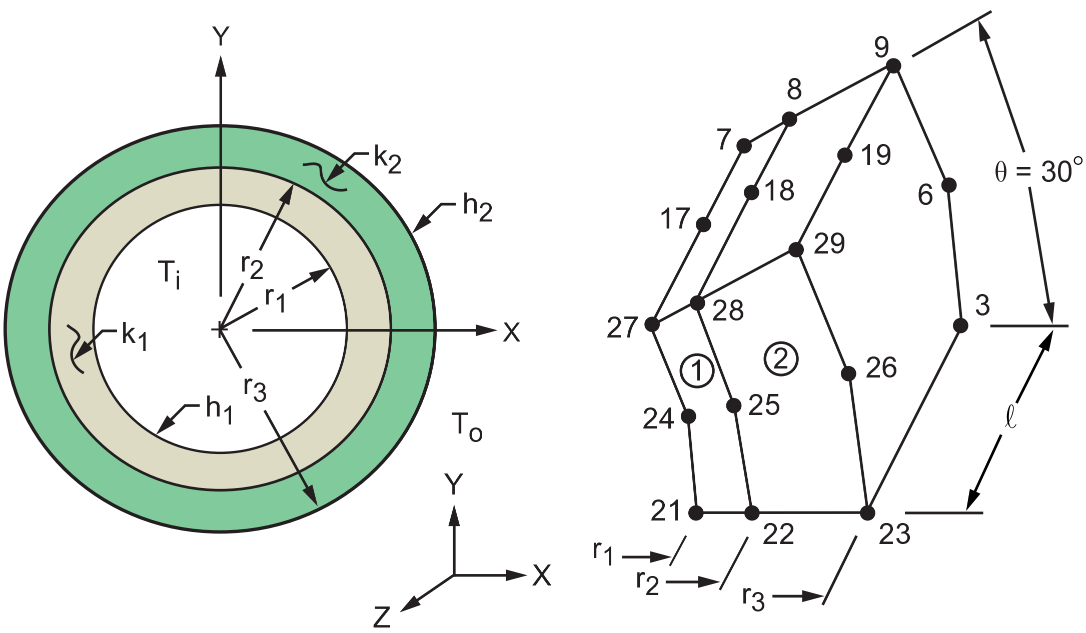
Overview

Reference:	F. Kreith, *Principles of Heat Transfer*, 2nd Printing, International Textbook Co., Scranton, PA, 1959, pg. 36, ex. 2-7.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 20-Node Thermal Solid Elements (SOLID90)
Input Listing:	vm161.dat

Test Case

A pipe, covered with a layer of insulation, transports a fluid at a temperature T_i. For a given ambient air temperature T_o, determine the heat loss q across the outer surface per lineal foot of pipe.

Figure 161.1: Insulated Pipe Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
k_1 = 25 Btu/hr-ft-°F k_2 = 0.11 Btu/hr-ft-°F h_1 = 40 Btu/hr-ft^2-°F h_2 = 4 Btu/hr-ft^2-°F	r_1 = 1.535 in = 0.1279166 ft r_2 = 1.75 in = 0.1458333 ft r_3 = 2.25 in = 0.1875 ft ℓ = 1 ft	T_i = 300°F T_o = 80°F

Analysis Assumptions and Modeling Notes

An arbitrary 30° sector, of unit length ℓ, is used for the axisymmetric model.

Results Comparison

	Target	Mechanical APDL	Ratio
q, Btu/hr	362.0	362.0	1.000

Calculated from the surface heat flow rate of 30.17 x 360°/30°.

VM162: Cooling of a Circular Fin of Rectangular Profile

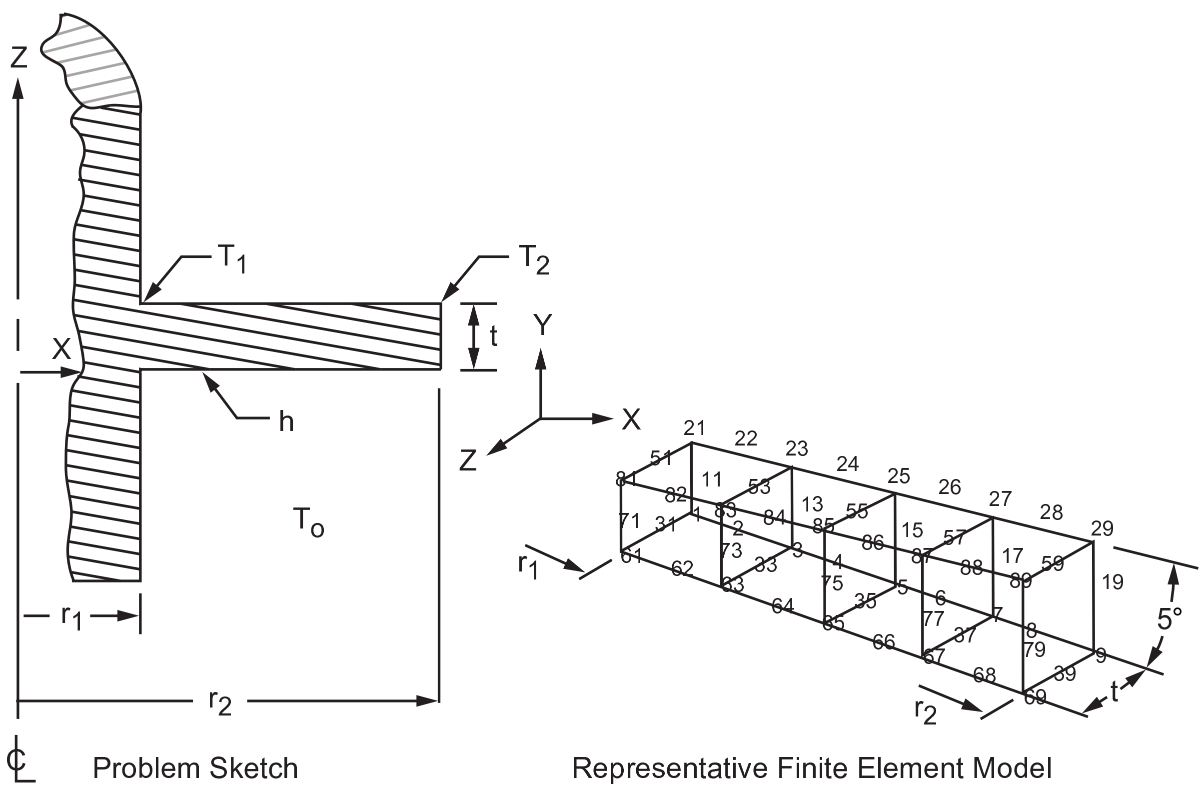
Overview

Reference:	P. J. Schneider, *Conduction Heat Transfer*, 2nd Printing, Addison-Wesley Publishing Co., Inc., Reading, MA, 1957, pg. 82, article 4-10.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 20-Node Thermal Solid Elements (SOLID90)
Input Listing:	vm162.dat

Test Case

A circular cooling fin of rectangular profile is attached to a cylindrical surface having a temperature T_1. Determine the temperature T_2 at the tip of the fin if the fin is surrounded by cooling air at temperature T_o having a convective film coefficient h.

Figure 162.1: Circular Fin Problem Sketch



Material Properties	Geometric Properties	Loading
h = 100 Btu/hr-ft^2-°F k = 15 Btu/hr-ft-°F	r_1 = 0.5 in = 0.04167 ft r_2 = 0.75 in = 0.0625 ft t = 0.0625 in = 0.005208 ft	T_1 = 100°F T_o = 0°F

Analysis Assumptions and Modeling Notes

An arbitrary 5° sector is used to model the axisymmetric fin.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
T_2, °F	53.22	52.37	.984
q, Btu/hr	102.05	101.70[2]	.997

1. Based on interpolation with Bessel function tables.

2. Obtained from the reaction heat flow summation of 1.41246 x 360°/5°.

VM163: Groundwater Seepage (Permeability Analogy)

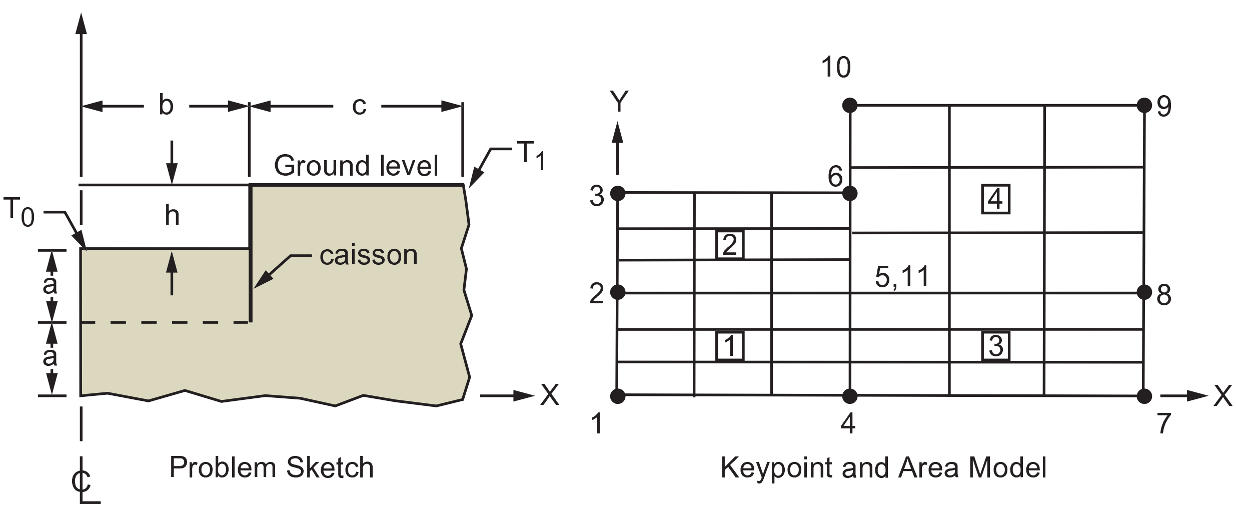
Overview

Reference:	D. R. J. Owen, E. Hinton, *A Simple Guide to Finite Elements*, Pineridge Press Ltd., Swansea, U. K., 1980, pg. 89, article 7.4.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0), with Analogous Seepage Variables
Element Type(s):	2-D Thermal Solid Elements (PLANE55)
Input Listing:	vm163.dat

Test Case

An opened top and bottom circular steel caisson separates a low level excavation from the surrounding ground. Determine the groundwater seepage flow rate q beneath the caisson for fully saturated soil. The pressure head is T_1 with respect to a datum T_o at the bottom of the caisson. Show the pressure contours and the flow path.

Figure 163.1: Groundwater Seepage Problem Sketch



Material Properties	Geometric Properties	Loading
k = permeability = 0.864 m/day	a = 3.5 m b = 8 m c = 10 m h = 3 m	T_o = 0 m (at Y = 7 m) T_1 = 3 m (at Y = 10 m)

Analysis Assumptions and Modeling Notes

The thermal analysis, which solves the Laplace equation, is used to solve this problem since the seepage flow is also governed by the Laplace equation. The following mental substitution of input and output variables (thermal : flow) are used:

- (temperature : flow potential (or pressure head))
- (heat flow rate : fluid flow rate)

- (thermal conductivity : permeability coefficient)

The bottom and side of the model are assumed to be far enough away from the caisson to be treated as impermeable.

Results Comparison

	Target	Mechanical APDL [1]	Ratio
q, m^3/day (per radian)	8.6	8.6	1.0

1. POST1 results for q are on a full circumference basis.

Figure 163.2: Pressure Contours

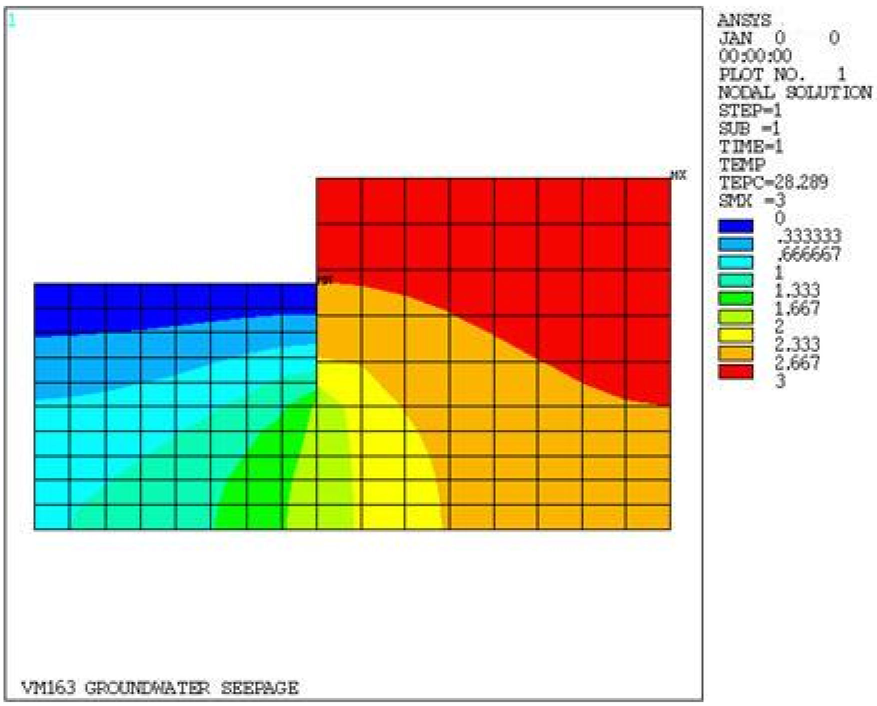
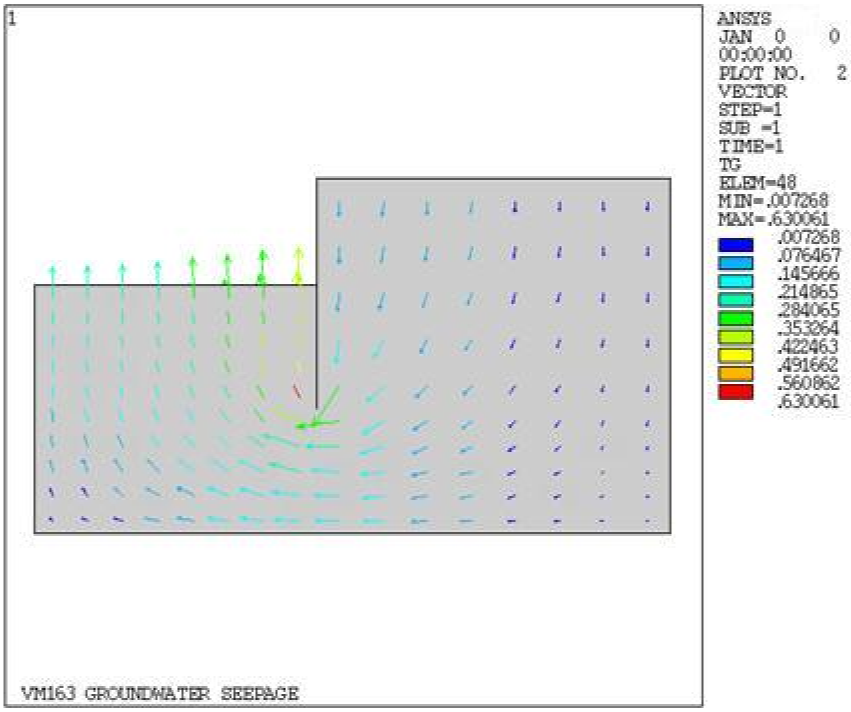


Figure 163.3: Flow Gradients



VM164: Drying of a Thick Wooden Slab (Diffusion Analogy)

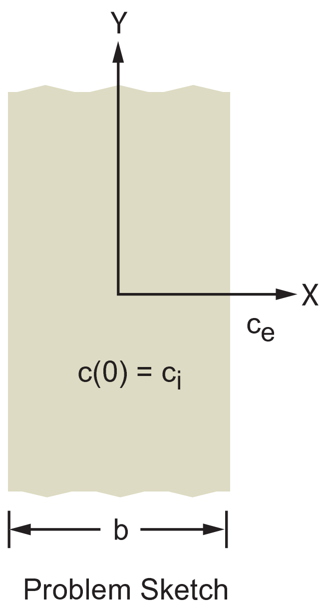
Overview

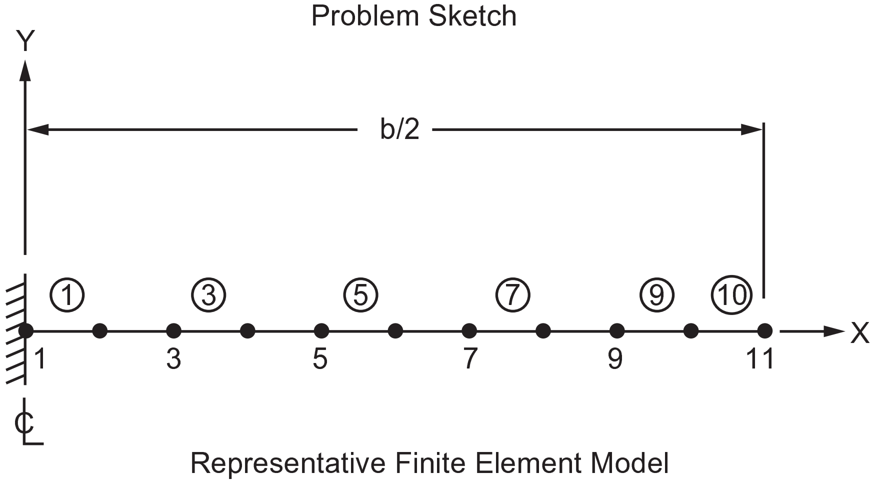
Reference:	W. M. Rohsenow, H. Y. Choi, *Heat, Mass and Momentum Transfer*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1963, pg. 392, article 15.4.
Analysis Type(s):	Transient Thermal Analysis (**ANTYPE** = 4) with Analogous Diffusion Variables
Element Type(s):	3-D Conduction Bar Elements (LINK33)
Input Listing:	vm164.dat

Test Case

A slab of wood of thickness b originally has a uniform moisture concentration c_i (relative to dry wood) when a drying period begins. The ambient moisture concentration of the drying air is c_e. Determine the moisture concentration c at the centerline of the slab after 127 hours.

Figure 164.1: Wooden Slab Problem Sketch





Material Properties	Geometric Properties	Loading
$D = 4 \times 10^{-5}$ ft^2/hr	b = 2 in = (2/12) ft	c_i = 30% c_e = 5%

Analysis Assumptions and Modeling Notes

The thermal analysis, which solves the Laplace equation, is used to solve this problem since the diffusion problem is also governed by the Laplace equation. The following analogy (thermal : diffusion) of input and output variables is used: (temperature : moisture concentration), (thermal conductivity : diffusion coefficient). The slab is assumed to have a large surface area compared with its thickness and a negligible surface resistance. The density and specific heat properties are arbitrarily set to 1.0 and the thermal conductivity is used for the diffusion coefficient input. The solution is obtained for an arbitrary cross-sectional area of 1 ft^2.

The initial integration time step of 0.434 hr. is determined from $\delta^2/4D$, where δ is a characteristic element length (0.008333 ft) and D is the diffusion coefficient. Automatic time stepping is used to reduce the number of iterations if possible.

Results Comparison

	Target[1]	Mechanical APDL	Ratio[1]
c, %	10.0	10.2	1.02

1. Based on graphical estimates.

VM165: Current-Carrying Ferromagnetic Conductor

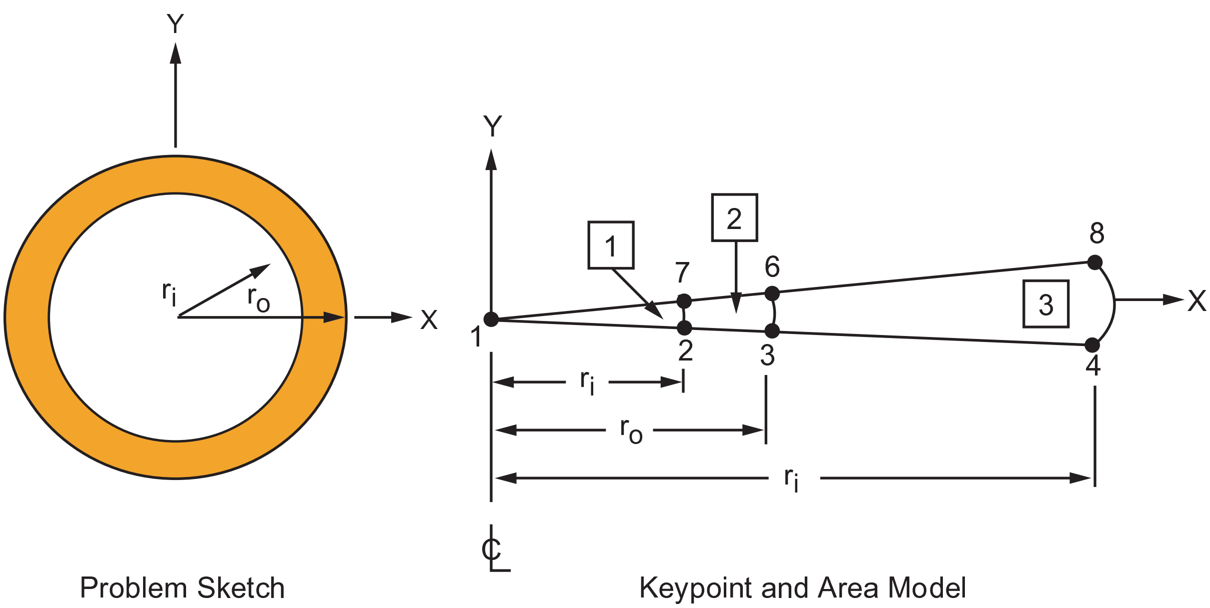
Overview

Reference:	W. B. Boast, *Principles of Electric and Magnetic Fields*, Harper & Brothers, New York, NY, 1948, pg. 225.
Analysis Type(s):	Nonlinear Static Magnetics Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Coupled-Field Solid Elements (PLANE13) 2-D 8-Node Electromagnetic Elements (PLANE233) 2-D Infinite Boundary Elements (INFIN9)
Input Listing:	vm165.dat

Test Case

A long cylindrical shell of cast steel carries a constant current I uniformly distributed within the conductor cross-section. Determine the tangential magnetic flux density B_θ at several locations within the conductor.

Figure 165.1: Current-Carrying Ferromagnetic Conductor Problem Sketch



Material Properties	Geometric Properties	Loading
B-H curve as shown in Table 165.1: B-H Data (p. 429)	r_i = 0.3 in r_o = 0.45 in r_1 = 0.75 in	I = 100 A

Table 165.1: B-H Data

B(T)[1]	0.21	0.55	0.80	0.95	1.0	1.1	1.15	1.25	1.40
H(A/m)[1]	150	300	460	640	720	890	1020	1280	1900

1. Graphical estimate from reference.

Analysis Assumptions and Modeling Notes

The conductor is assumed to be infinitely long, thus end effects are ignored allowing for a two-dimensional planar analysis. Since the field is symmetric around the circumference, only a 5° slice is chosen for modeling. The external air is modeled to a boundary at r_1= 0.75 in, where the infinite boundary element is placed.

Six elements are arbitrarily modeled through the conductor thickness, line segment divisions and spacing ratios for the inner and outer air regions are chosen to provide compatible element sizes with the steel elements. The solution procedure consists of ramping the boundary conditions over 5 iterations in the first load step and iterating to convergence in a second load step with a convergence criterion of 1 x 10.

The MKS system of units is used for the analysis. The conversion factor used in the **KPSCALE** command, from inches to meters is 0.0254. The current density is calculated as $J = I/A = I/\pi(r_o2 - r_i2) = 2.28019 \times 10^{-4}$ A/in^2 = 438559 A/m^2.

Results Comparison

	Target	Mechanical APDL	Ratio
PLANE13			
B_{angle}, T @ r r = .325 in	0.48	0.45	0.94
B_{angle}, T @ r = .375 in	1.03	1.02	0.99
B_{angle}, T @ r = .425 in	1.22	1.21	0.995
PLANE233			
Bangle, T @ r = .325 in	0.48	0.48	1.01
Bangle, T @ r = .375 in	1.03	1.03	0.996
Bangle, T @ r = .425 in	1.22	1.22	0.996

Figure 165.2: B-H Curve using PLANE13 elements

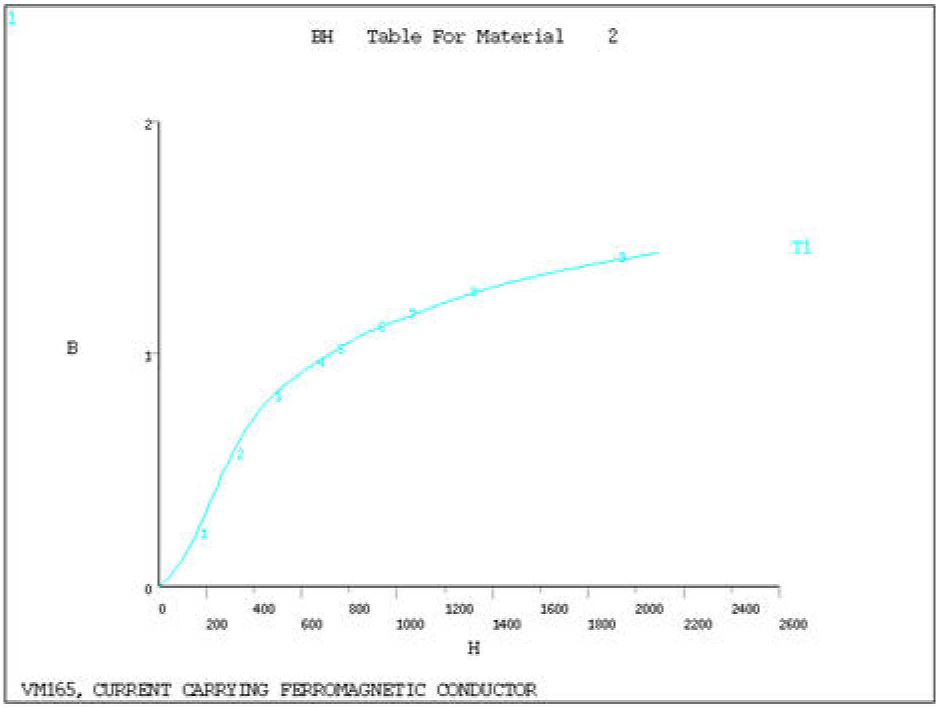


Figure 165.3: NU-B2 Curve using PLANE13 elements

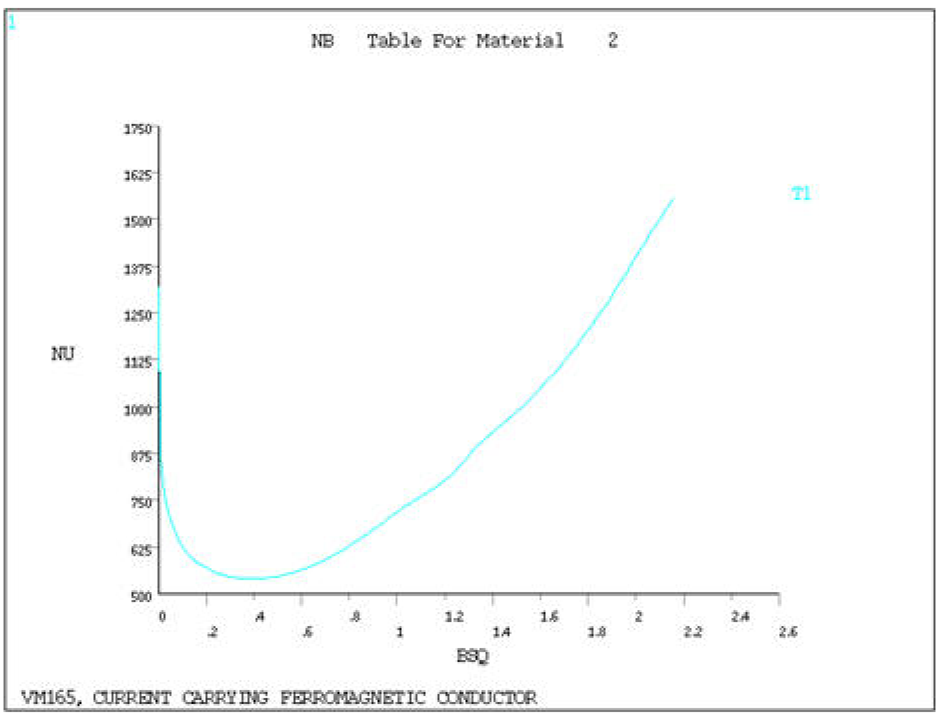


Figure 165.4: B-H Curve using PLANE233 elements

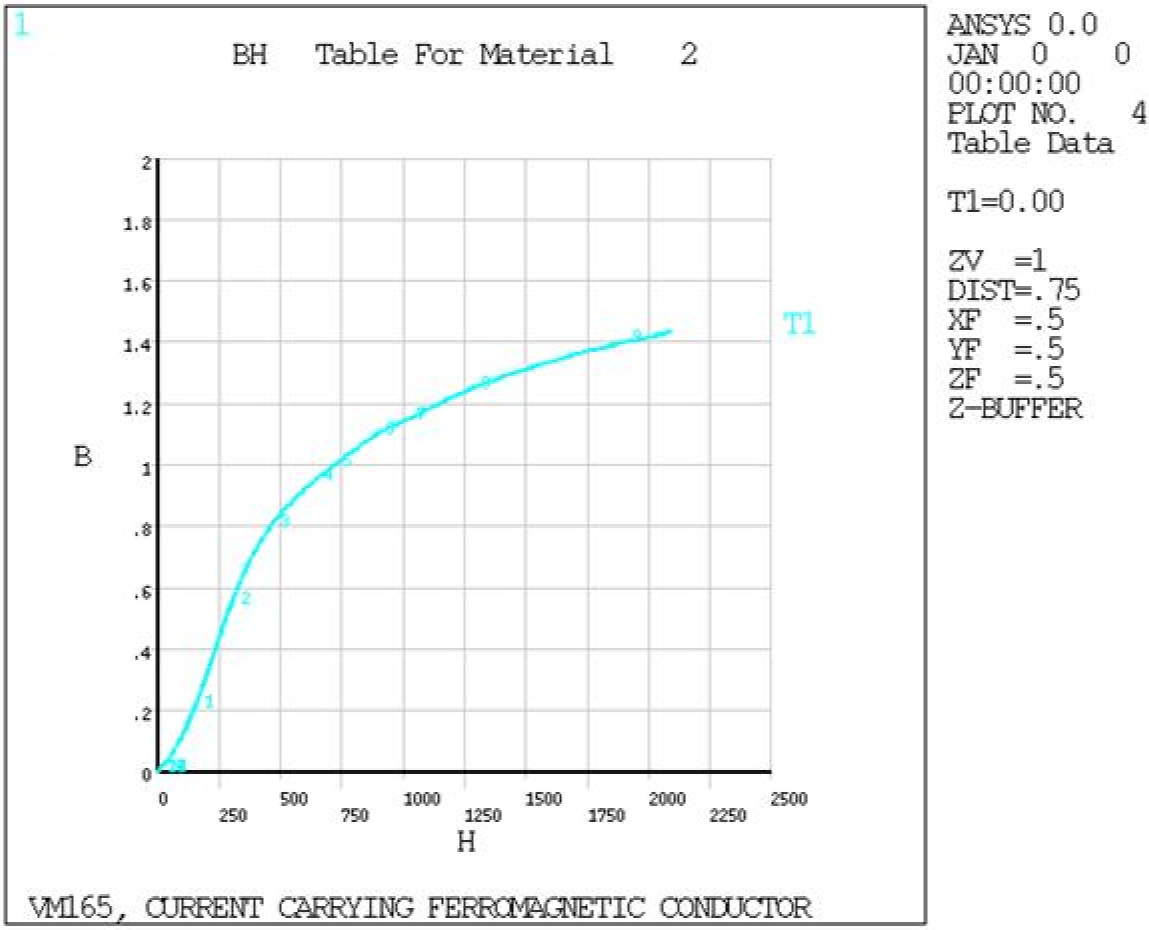
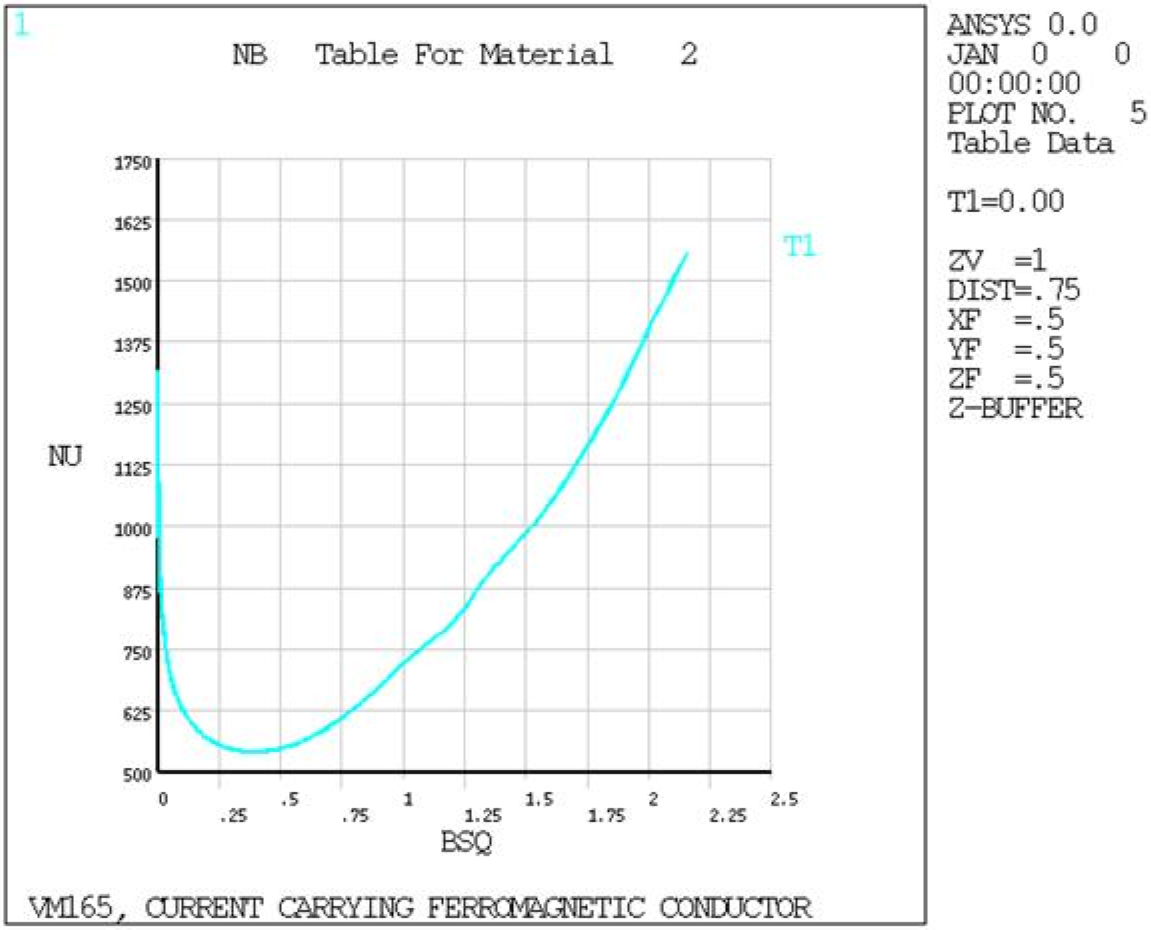


Figure 165.5: NU-B^2 Curve using PLANE233 elements



VM166: Long Cylinder in a Sinusoidal Magnetic Field

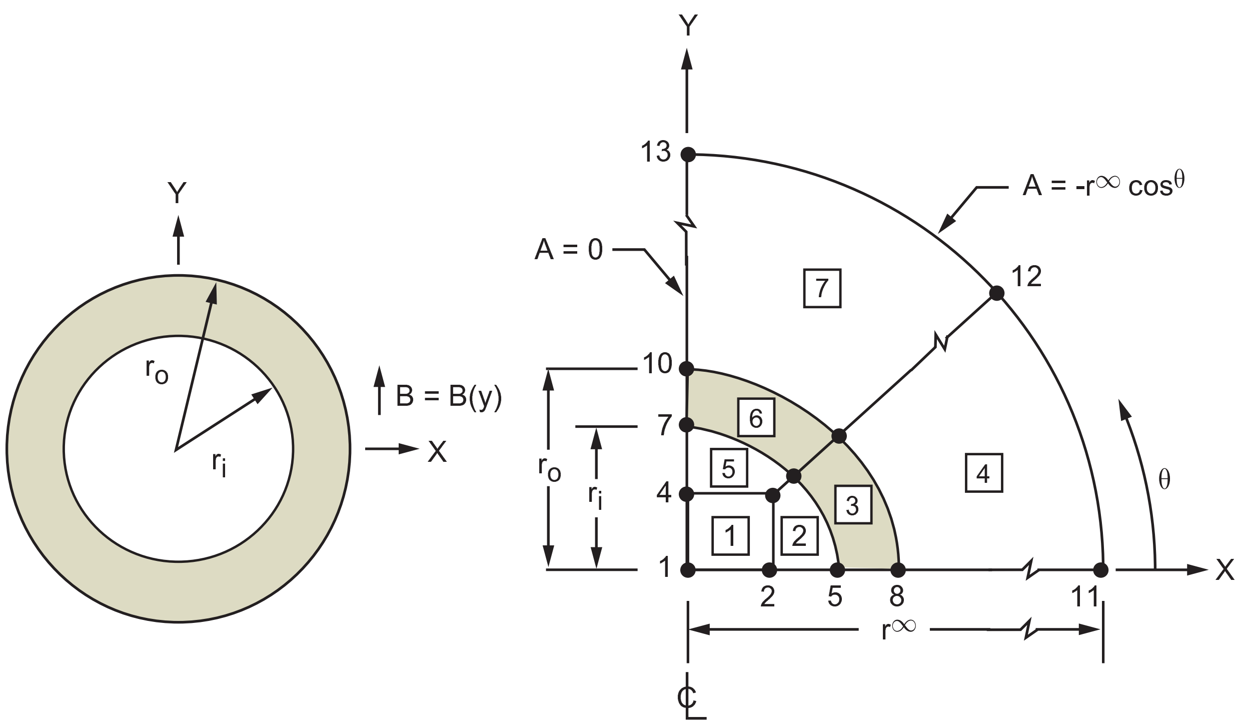
Overview

Reference:	C. R. I. Emson, "Electromagnetic Workshop", Report No. RAL-86-049, Rutherford Appleton Laboratory, Chitton, Didcot, Oxon, U.K., 1986, pg. 39.
Analysis Type(s):	Full Harmonic Analysis (**ANTYPE** = 3)
Element Type(s):	2-D Coupled-Field Solid Elements (PLANE13) 2-D 8-Node Electromagnetic Solid (PLANE233)
Input Listing:	vm166.dat

Test Case

A long hollow aluminum cylinder is placed in a uniform magnetic field. The magnetic field is perpendicular to the axis of the cylinder and varies sinusoidally with time. Determine the magnetic flux density at the center of the cylinder and the average power loss in the cylinder.

Figure 166.1: Long Cylinder Problem Sketch



Material Properties	Geometric Properties	Loading
σ = 2.5380711 x 10^7 S/m	r_i = 0.05715 m r_o = 0.06985 m r_∞ = 0.84 m	B = B(y) = B cos ωt, where B_o = 0.1T, ω = 60 Hz

Analysis Assumptions and Modeling Notes

The external radial boundary is set at r_∞ = 0.84 m. The applied external field is calculated as B(y) = -$\delta A / \delta x$, so at $\theta = 0$ and r = r_∞, A = -B_or = -.084. The vector potential A varies along r_∞ as $A_\theta = -B_o r \cos\theta$.

The cylinder is assumed to be infinitely long, thus end effects are ignored allowing for a two-dimensional planar analysis. The problem can be modeled in quarter symmetry with the flux-parallel (A = 0) boundary condition at x = 0, and the flux-normal (natural) boundary condition at y = 0. The average power loss in the cylinder is calculated from the real and imaginary power loss density (JHEAT) terms available in the database:

$$P_{avg} = \sum_{i=1}^{n} (JHEAT_i^{Re} + JHEAT_i^{Im}) V_i$$

when n is the number of elements in the aluminum cylinder, V_i is the element volume (per-unit-depth). A fine mesh is defined in the cylinder for accurate calculation of the power loss.

Results Comparison

	Target	Mechanical APDL	Ratio
PLANE13			
B_x (0,0), T	0 + $_j$0	0 + $_j$0	1.0
B_y (0,0), T	-0.0018 - $_j$0.0210	-0.0019 - $_j$0.02140	1.043, 1.018
Power Loss, W/m	2288	2341.3041	1.023
PLANE233			
B_x (0,0), T	0 + $_j$0	0 + $_j$0	1.0,1.0
B_y (0,0), T	-0.0018 - $_j$0.0210	-0.0018 - $_j$0.0212	0.992, 1.007
Power Loss, W/m	2288	2315.2128	1.012

VM167: Transient Eddy Currents in a Semi-Infinite Solid

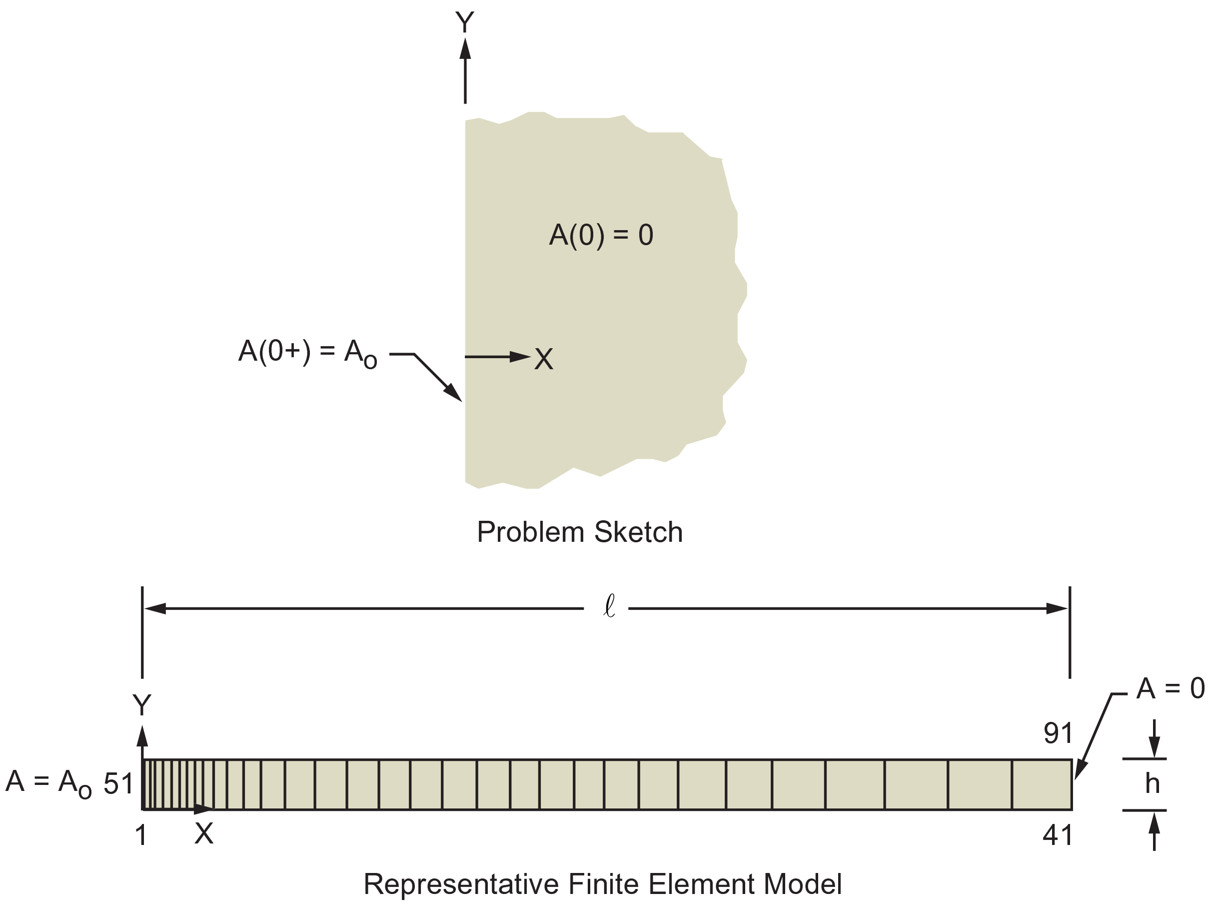
Overview

Reference:	J. P. Holman, *Heat Transfer*, 4th Edition, McGraw-Hill Book Co., Inc., New York, NY, 1976, pg. 104, eqn. 4-14 (analogous field solution).
Analysis Type(s):	Transient Magnetic Field Analysis (**ANTYPE** = 4)
Element Type(s):	2-D Coupled-Field Solid Elements (PLANE13) 2-D 8-Node Electromagnetic Solid (PLANE233)
Input Listing:	vm167.dat

Test Case

A semi-infinite solid is initially under no external magnetic field (vector potential A is zero throughout). The surface is suddenly subjected to a constant magnetic potential A_o. Determine the eddy current density, flux density and the vector potential field solution in the solid during the transient.

Figure 167.1: Semi-Infinite Solid Transient Eddy Currents Problem Sketch



Material Properties	Geometric Properties	Loading
$\mu = 4 \pi \times 10^{-7}$ H/m $\rho = 4 \times 10^{-7}$ ohm-m	ℓ = 20 m h = 0.4 m	A_o = 2.0 Wb/m

Analysis Assumptions and Modeling Notes

A $0.4 m^2$ area is arbitrarily selected for the elements. The model length (20 m) is arbitrarily selected such that no significant potential change occurs at the end points (nodes 41, 91) for the time period of interest. The node locations are defined with a higher density near the surface to accurately model the transient behavior.

The transient analysis makes use of automatic time step optimization over a time period of 0.24 sec. A maximum time step size ((.24/48) = .005 sec.) is based on $\approx \delta^2/4\alpha$, where δ is the conduction length within the first element (δ = .0775m) and α is the magnetic diffusivity ($\alpha = \rho / \mu$ = .31822 m^2/sec.). The minimum time step (.0002 sec) is selected as 1/25 of the maximum time step. The starting time step of 0.0002 sec. is arbitrarily selected. The problem is solved with two load steps to provide solution output at the desired time points. In the first load step, the step potential load is applied while setting initial boundary conditions of zero at all other potentials. The problem is first solved with PLANE13 elements and then using PLANE233 elements. The eddy current density output is not available with PLANE233.

Results Comparison

t = 0.15 sec	Target	Mechanical APDL	Ratio
PLANE13			
Vector Potential (Wb/m)			
@ x = 0.2517	0.831	0.831	1.000
@ x = 0.4574	0.282	0.278	0.984
@ x = 0.6914	0.050	0.044	0.884
Flux Density (T)			
@ x = 0.2517	3.707	3.687	0.995
@ x = 0.4574	1.749	1.794	1.026
@ x = 0.6914	0.422	0.454	1.076
Eddy Current Density (x107A/m2)			
@ x = 0.2517	-0.777	-0.780	1.004
@ x = 0.4574	-0.663	-0.677	1.021
@ x = 0.6914	-0.243	-0.245	1.008
PLANE233			
Vector Potential (Wb/m)			
@ x = 0.2517	0.831	0.831	1.000
@ x = 0.4574	0.282	0.278	0.984
@ x = 0.6914	0.050	0.044	0.884
Flux Density (T)			
@ x = 0.2517	3.707	3.687	0.995
@ x = 0.4574	1.749	1.794	1.026
@ x = 0.6914	0.422	0.454	1.076

Figure 167.2: Vector Potential vs. Time Plot using PLANE13 Elements

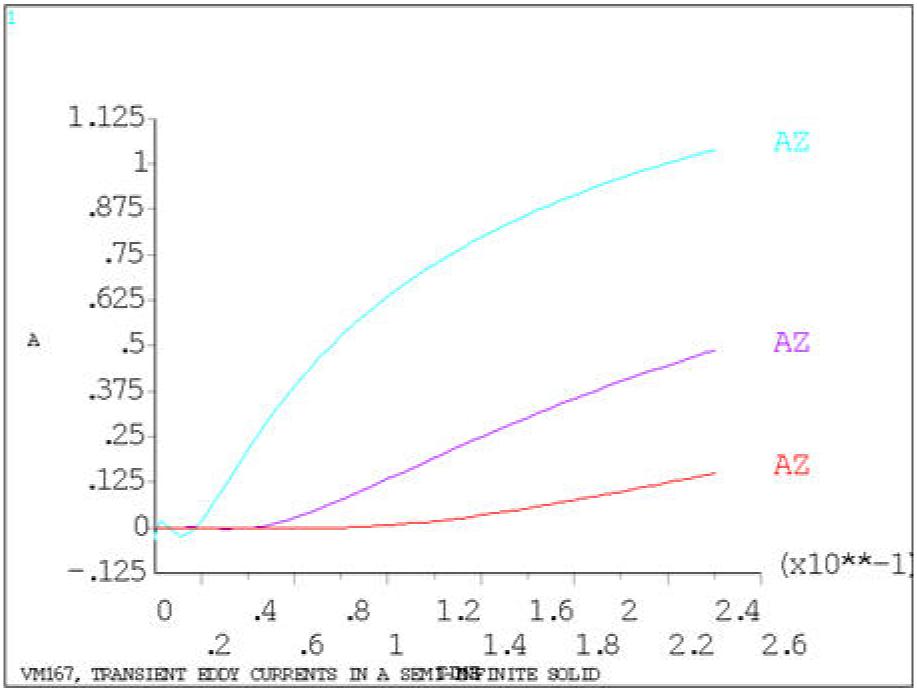


Figure 167.3: Eddy Current Density vs. Time Plot using PLANE13 Elements

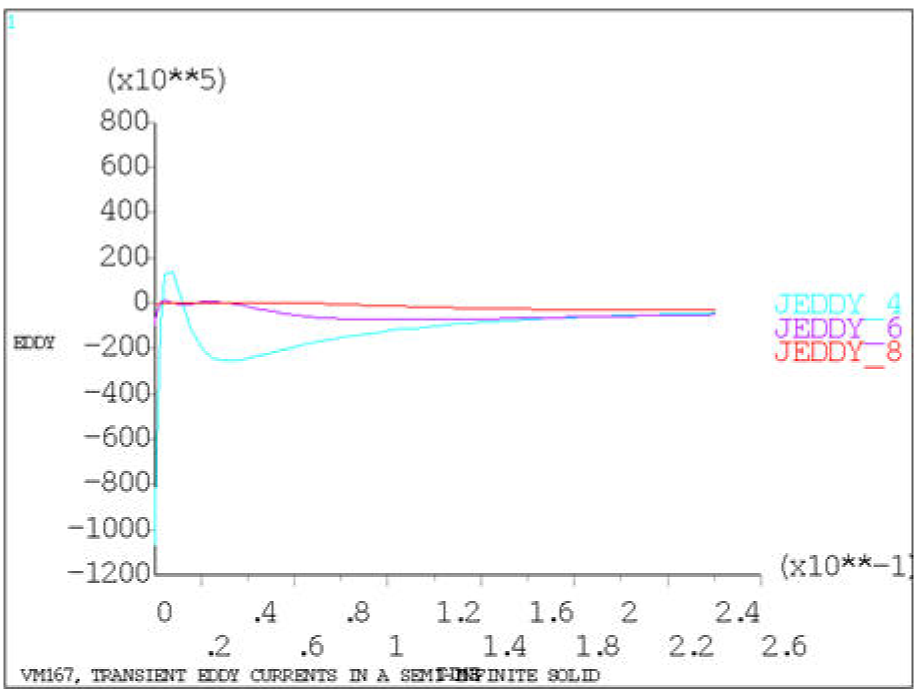
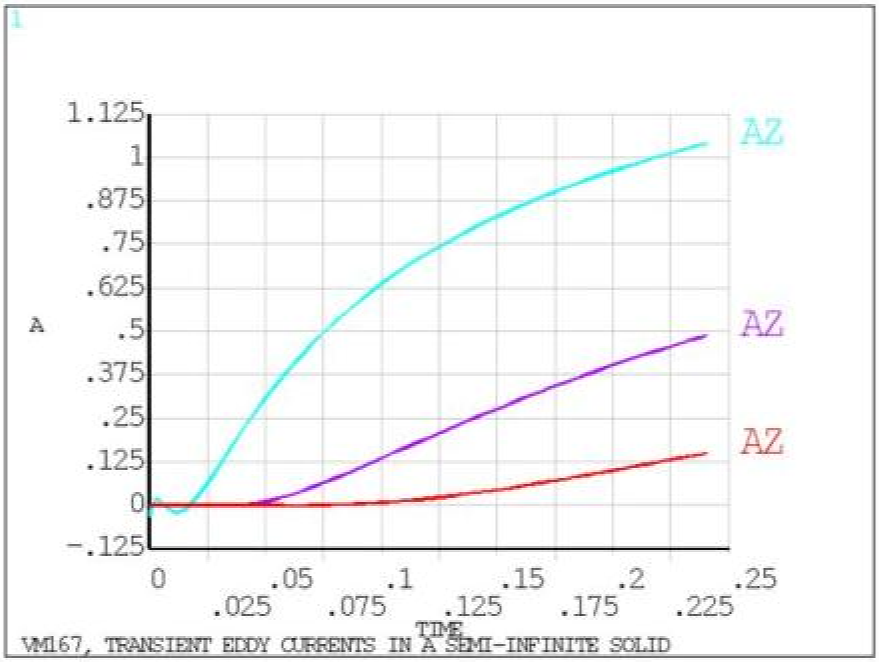


Figure 167.4: Vector Potential vs. Time Plot using PLANE233 Elements



VM168: Magnetic Field in a Nonferrous Solenoid

Overview

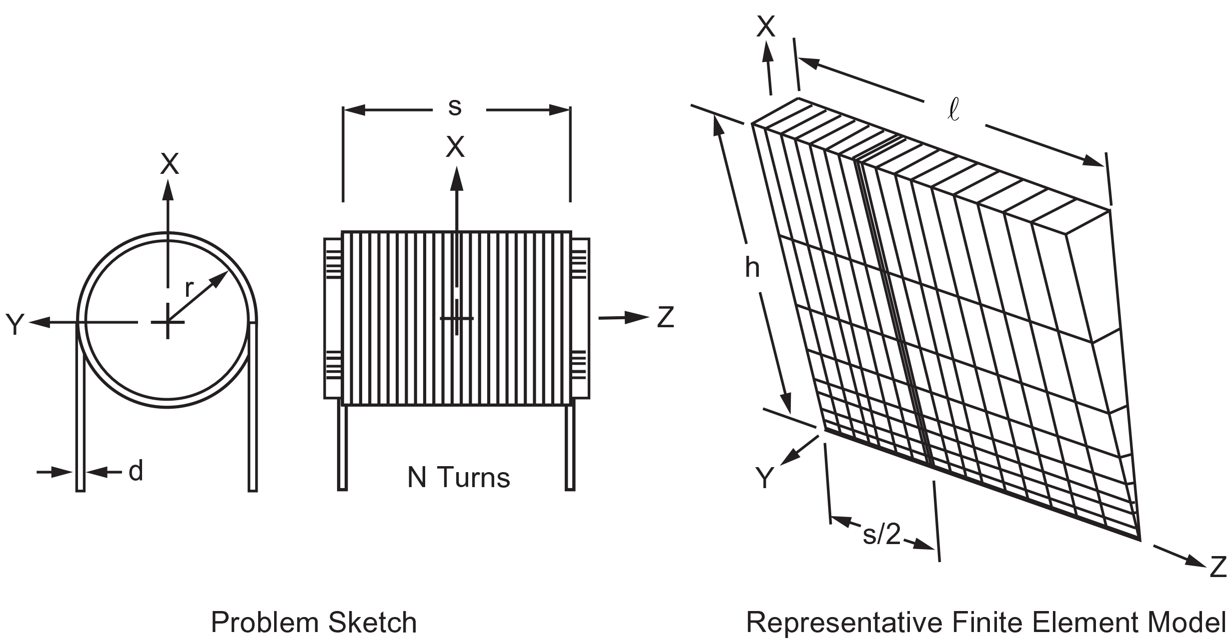
Reference:	W. B. Boast, *Principles of Electric and Magnetic Fields*, Harper & Brothers, New York, NY, 1948, pg. 243.
Analysis Type(s):	Static Magnetic Field Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Coupled-Field Solid Elements (SOLID5) Current Source Elements (SOURC36)
Input Listing:	vm168.dat

Test Case

A nonferrous solenoid is wound with one layer of No. 26 enameled wire and carries a current I. Determine the magnetic flux density on the centerline at

- the center of the coil
- the end of the coil
- at a point 5 inches from the end of the coil

Figure 168.1: Magnetic Field Problem Sketch



Geometric Properties	Loading
ℓ = 7.5 in s = 5 in r = 0.5 in h = 6 in d = 0.216	I = 0.5 A

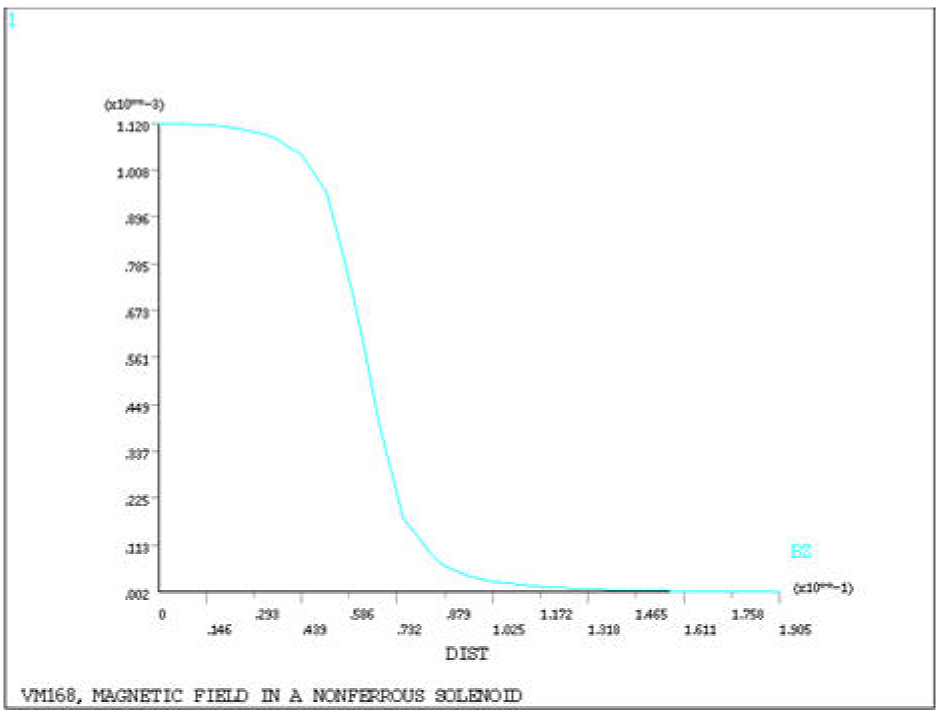
Analysis Assumptions and Modeling Notes

The number of turns is N = s/d = 5/.0216 = 231. Therefore, N x I = 115.5 Ampere-turns. Since no ferromagnetic materials are present, the field due to induced magnetization, H_m = 0, and thus no scalar potential is required. The total field can be determined from the numerical integration of the coil source field upon specification of the coil with the current source element (SOURC36). Since the field is symmetric, an arbitrary arc of 10° is chosen with an additional symmetry plane taken along the coil midspan. A sufficient number of integration points (50) are chosen along the Z-axis to adequately represent the coil. Only one point is specified through the coil thickness. The Reduced Scalar Potential (RSP) is selected since only a source field is to be calculated.

Results Comparison

	Target	Mechanical APDL	Ratio
B_z (x 10^6)T at z = 0	1120	1120.65	1.001
B_z (x 10^6)T at z = 7.5 in (.1905 m)	2.12	2.12	1.002

Figure 168.2: Axial Magnetic Field through Solenoid



VM169: Permanent Magnet Circuit With an Air Gap

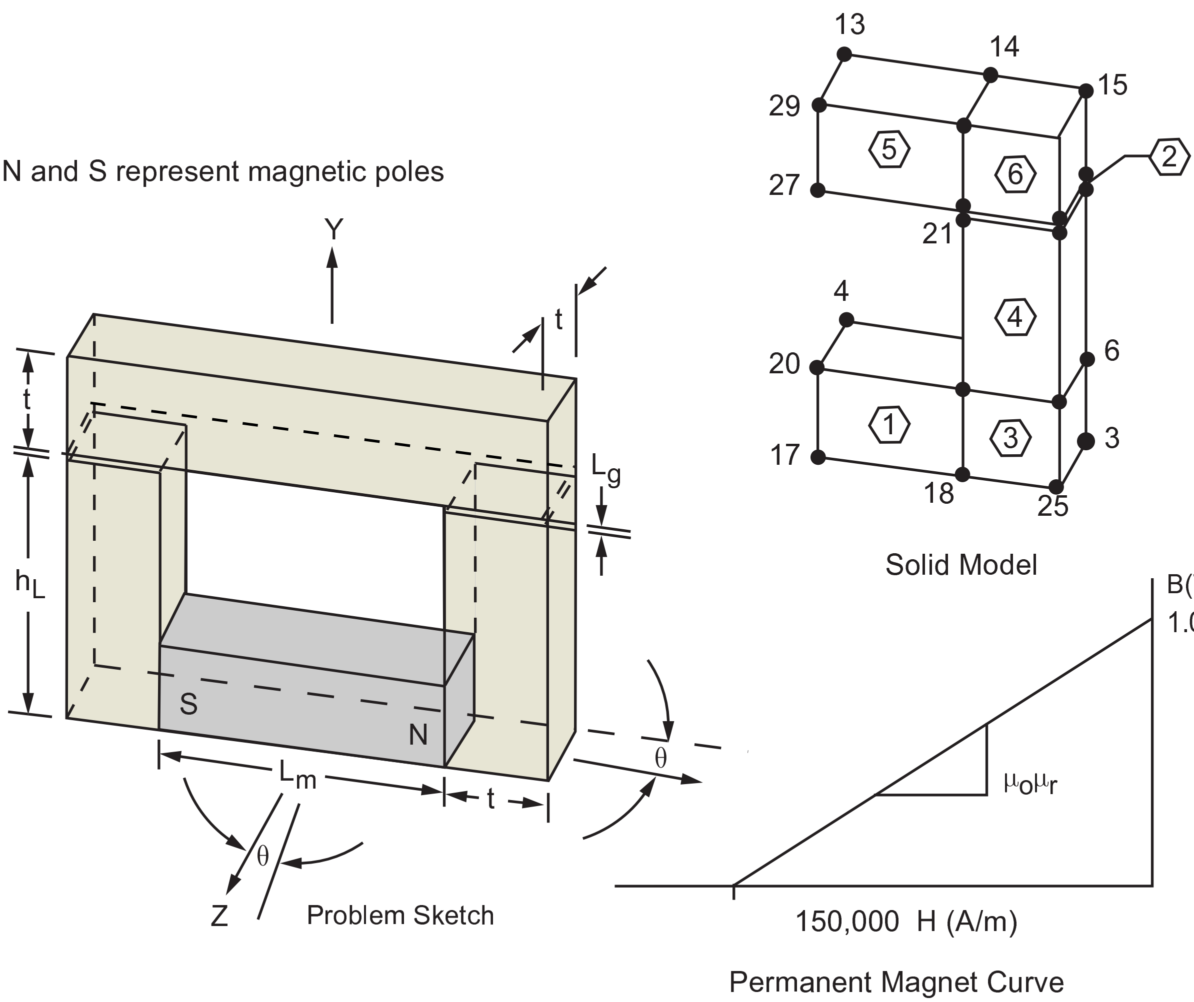
Overview

Reference:	F. C. Moon, *Magneto-Solid Mechanics*, John Wiley and Sons, Inc., New York, NY, 1984, pg. 275.
Analysis Type(s):	Magnetic Field Analysis (**ANTYPE** = 0)
Element Type(s):	Tetrahedral Coupled-Field Solid Elements (SOLID98)
Input Listing:	vm169.dat

Test Case

A permanent magnet circuit consists of a highly permeable core, a permanent magnet (the darker shading in the sketch), and an air gap. Assuming an ideal circuit with no flux leakage, determine the magnetic flux density and field intensity in the permanent magnet and the air gap.

Figure 169.1: Magnetic Circuit with Air Gap Problem Sketch



Material Properties	Geometric Properties
$B_r = 1.0$ T	$L_m = .03$ m

Material Properties	Geometric Properties
H_c = 150,000 A/m Θ = -30° (X-Z plane) μ_r = 1 x 10^5 (iron)	L_g = .001 m h_L = .03 m t = .01 m

Analysis Assumptions and Modeling Notes

The problem is solved using coupled-field solid elements (SOLID98). The permanent magnet is polarized along a line at Θ = -30° to the Z-axis in the X-Z plane. The coercive force components are calculated as MG169 = H_c cos Θ = 129,900, MGZZ = H_c sin Θ = -75,000. The permanent magnet relative permeability, μ_r, is calculated as:

$$\mu_r = \frac{B_r}{\mu_o H_o} = \frac{1}{(4\pi \times 10^{-7})(150{,}000)} = 5.30504$$

The iron is assumed to be highly permeable and is assigned a value μ_r = 1 x 10^5.

Since the device is symmetric only half of the circuit is required for modeling. At the symmetry plane the flux lines are orthogonal, so a flux-normal (Φ = 0) boundary condition is applied. With no leakage in the system, all the flux flows along a path circumventing the circuit. The flux-parallel boundary condition (δ Φ / δn = 0) holds on all other surfaces. The Reduced Scalar Potential (RSP) strategy is selected (default) since no current sources are defined. POST1 is used to extract results from the solution phase.

Results Comparison

Using SOLID98	Target	Mechanical APDL	Ratio
|B|, T (perm. magnet)	.7387	.7387	1.000
|H|, A/m (perm. magnet)	39150	39207.5539	1.001
|B|, T (air gap)	.7387	.7386	1.000
|H|, A/m (air gap)	587860	587791.6491	1.000

Figure 169.2: Vector Display of Magnetic Flux Density

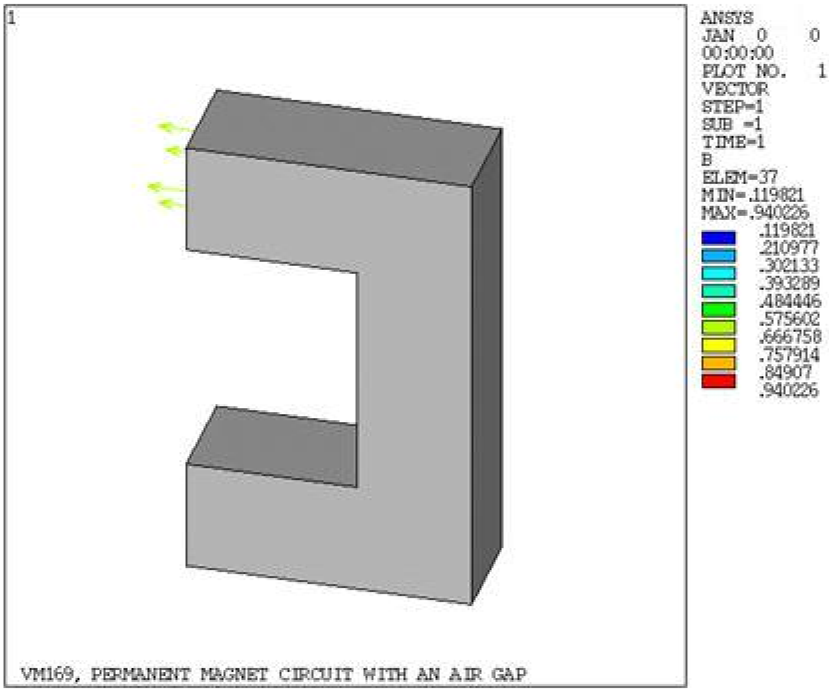
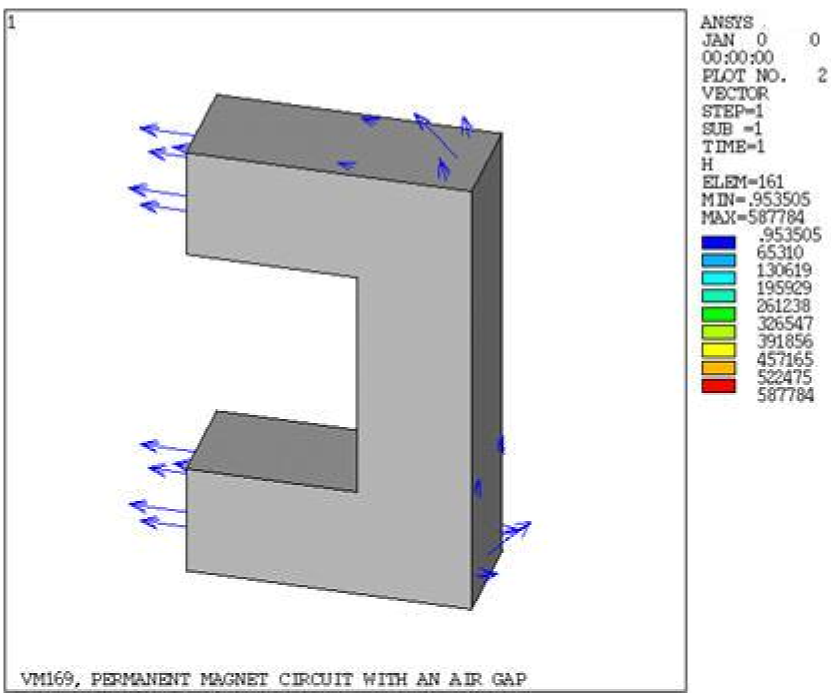


Figure 169.3: Vector Display of Magnetic Field Intensity



VM170: Magnetic Field From a Square Current Loop

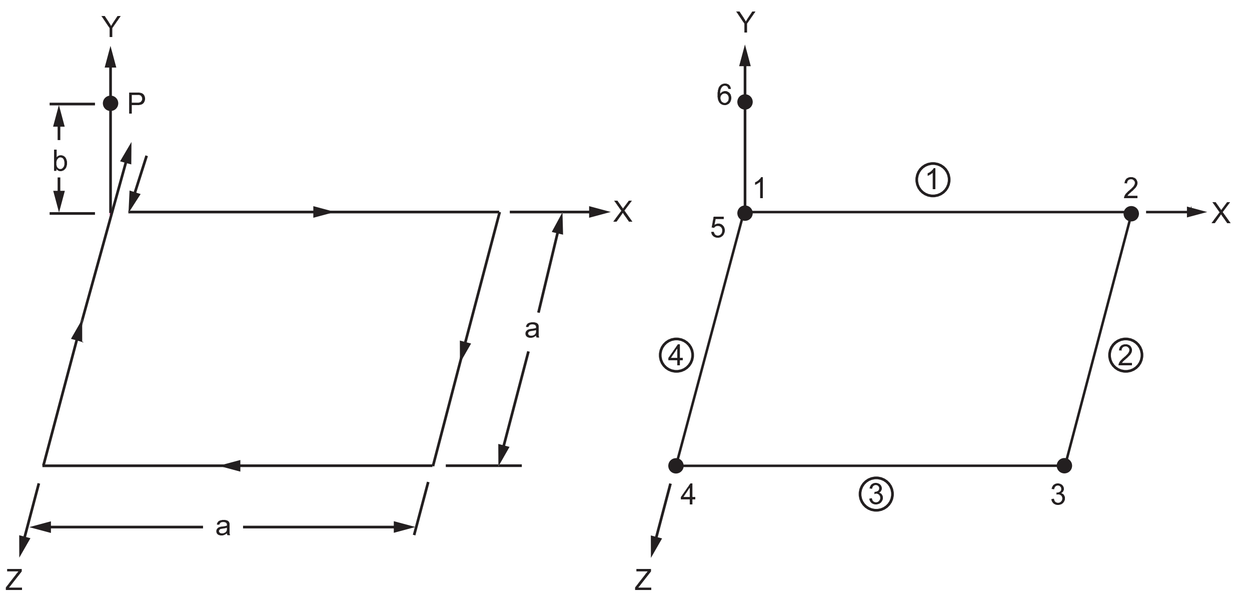
Overview

Reference:	W. B. Boast, *Principles of Electric and Magnetic Fields*, Harper & Brothers, New York, NY, 1948, pg. 199-200.
Analysis Type(s):	Coupled-field Analysis (**ANTYPE** = 0)
Element Type(s):	Coupled Thermal-Electric Line Elements (LINK68)
Input Listing:	vm170.dat

Test Case

A current, I, is carried in a square loop of side a. The space about the current is air. Determine the magnetic flux density at point P, at a height b above the current loop.

Figure 170.1: Square Current Loop Problem Sketch



Material Properties	Geometric Properties	Loading
$\mu_o = 4\ \pi \times 10^{-7}$ H/m $\rho = 4.0 \times 10^{-8}$ ohm-m	a = 1.5 m b = 0.35 m	I = 7.5 A

Analysis Assumptions and Modeling Notes

The problem requires a coupled electromagnetic field solution. LINK68 is used to create the current field in the wire loop. The current field established by the LINK68 elements is used to calculate the magnetic field at point P.

Nodes 1 and 5 overlap to create a closed current loop. The voltage at node 5 is set to zero while the current is applied to node 1.

The first solution calculates the current distribution in the loop. The **BIOT** command is then issued to calculate the magnetic field from the current distribution.

The cross-sectional area of the wire does not enter into the solution so an arbitrary area of 1.0 is input. Only one element is required per side of the square loop since the Biot-Savart integration of the magnetic field from the line element is exact. Flux density is calculated from the field intensity as B = μ_oH.

Results Comparison

Flux Density	Target	Mechanical APDL	Ratio
BX (x 10^{-6} Tesla)	2.010	2.010	1.000
BY (x 10^{-6} Tesla)	-0.662	-0.662	0.999
BZ (x 10^{-6} Tesla)	2.010	2.010	1.000

VM171: Permanent Magnet Circuit With an Elastic Keeper

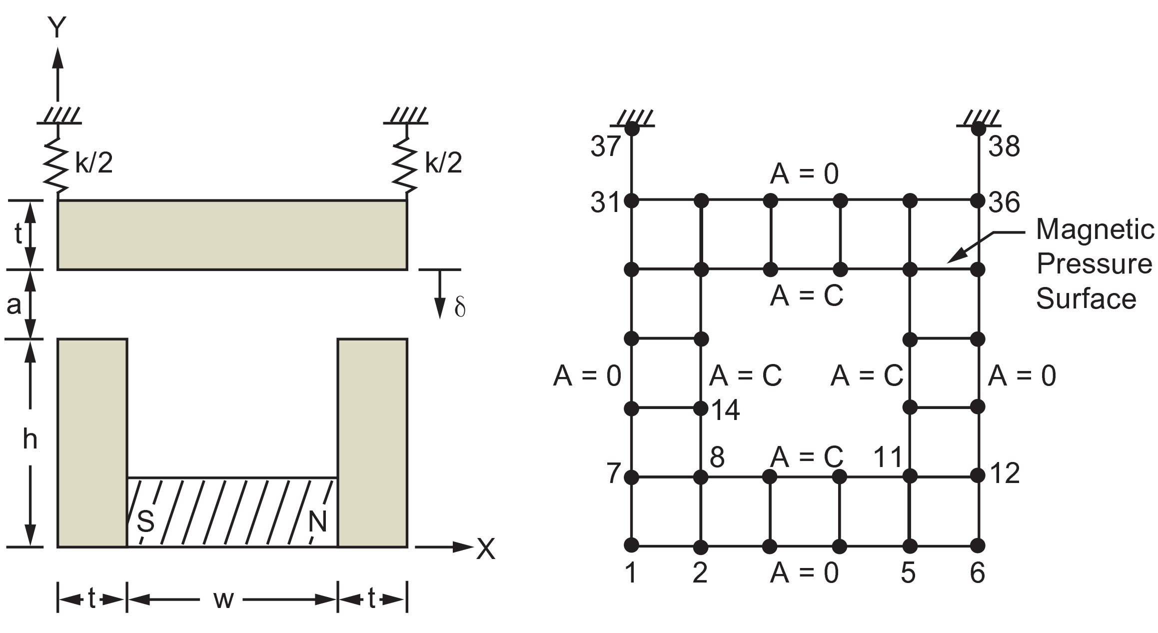
Overview

Reference:	F. C. Moon, *Magneto-Solid Mechanics*, John Wiley and Sons, Inc., New York, NY, 1984, pg. 275.
Analysis Type(s):	Coupled-field Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Coupled-Field Solid Elements (PLANE13) Spring-Damper Elements (COMBIN14)
Input Listing:	vm171.dat

Test Case

A permanent magnet circuit consisting of a highly-permeable core and a permanent magnet is used to model a relay switch. An elastic keeper is modeled with a highly permeable iron and two springs. Assuming no flux leakage, determine the equilibrium displacements, δ, of the keeper and the operating point (flux density) in the permanent magnet.

Figure 171.1: Permanent Magnet Circuit Problem Sketch



Material Properties	Geometric Properties
For permanent magnet: B_r = 1 T H_c = 150,000 A/m μ_r = 5.305 **For iron:** $\mu_r = 1 \times 10^5$ **For springs:**	h = .03 m w = .03 m t = .01 m a = .01 m

Material Properties	Geometric Properties
$k = 3.30681 \times 10^5$ N/m **For iron and permanent magnet:** $E = 10 \times 10^{10}$ N/m^2 $\nu = 0$	

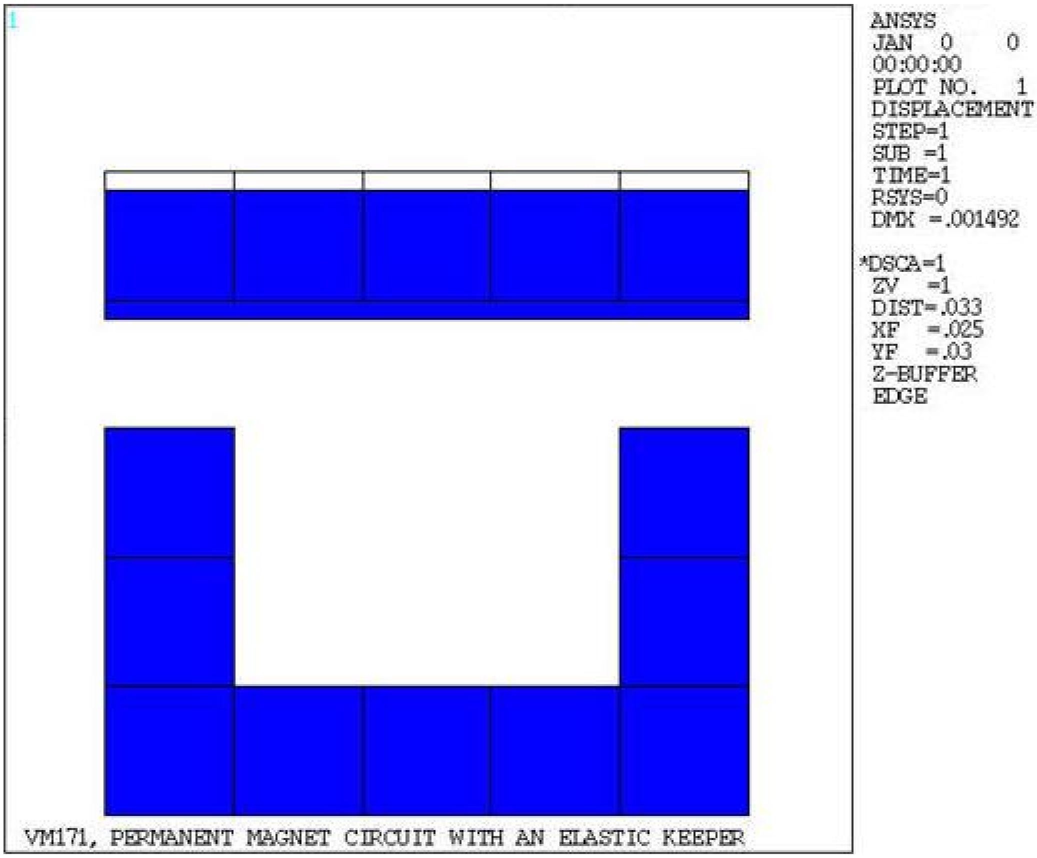
Analysis Assumptions and Modeling Notes

Since no leakage is assumed, the flux path will follow a closed loop through the iron core, permanent magnet, air gap, and keeper. The flux must follow parallel to the edges of the device, thus a flux-parallel (A = 0) boundary is set at the external nodes of the model. The inner nodes are coupled to ensure a flux-parallel boundary condition at the inner edge. The iron is assumed to be infinitely permeable and is assigned $\mu_r = 10^5$. For a permanent magnet, $\mu_o \mu_r = B_r / H_c$, therefore $\mu_r = 5.305$. The modulus of elasticity for air is assigned a negligible value (100 N/m^2) compared to that of the permeable materials. The permanent magnet structure has its displacements fixed. A magnetic pressure surface is assigned to the elements adjacent to the air-keeper interface to allow for the application of magnetic forces for structural analysis. An iterative large-deflection solution is required. Convergence criteria for structural force and magnetic current-segment is defined.

Results Comparison

	Target	Mechanical APDL	Ratio
Displacement, (m)	0.00150	0.00149	0.994
B, (T)	0.2496	0.24904	0.998

Figure 171.2: Displaced Geometry Display



VM172: Stress Analysis of a Long, Thick, Isotropic Solenoid

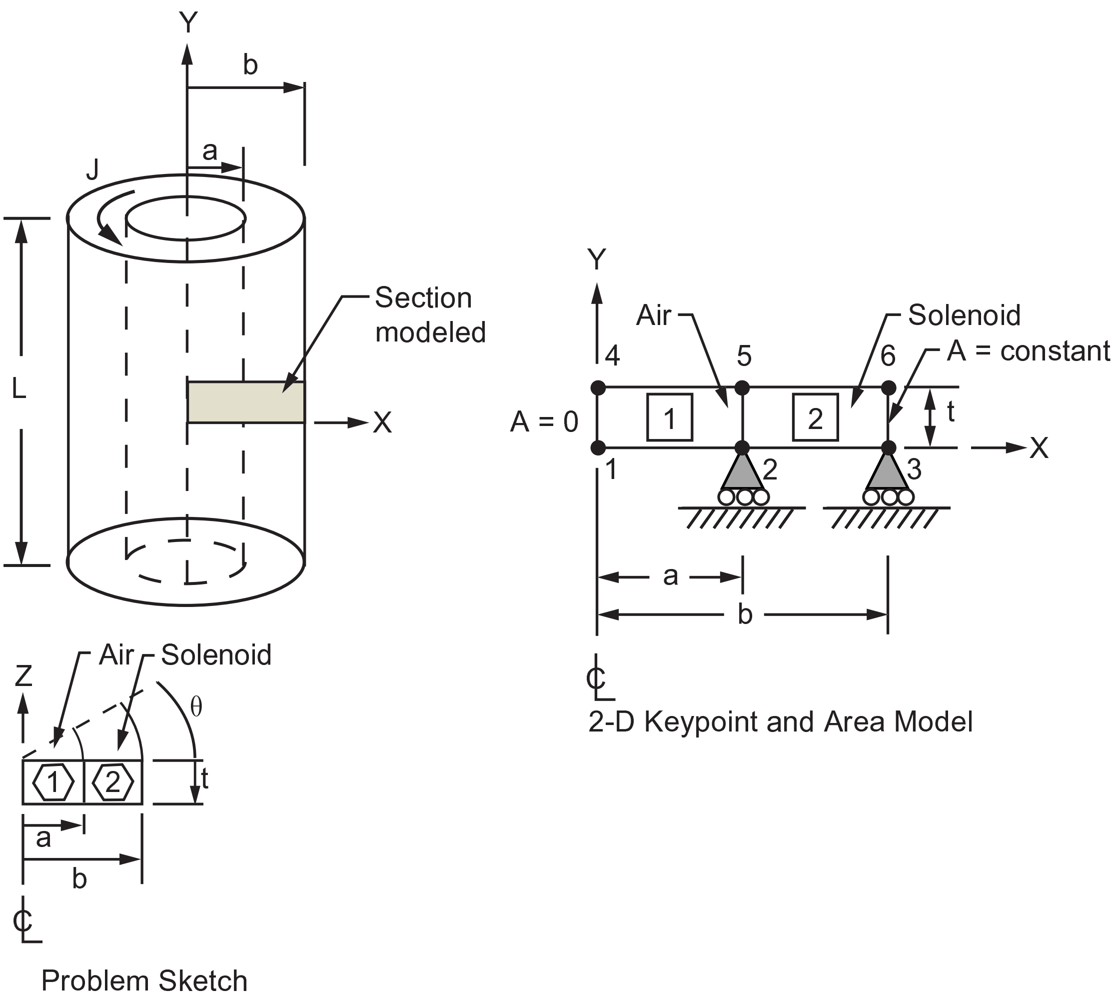
Overview

Reference:	F. C. Moon, *Magneto-Solid Mechanics*, John Wiley and Sons, Inc., New York, NY, 1984, pg. 275.
Analysis Type(s):	Coupled field Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Coupled-Field Solid Elements (PLANE13)
Input Listing:	vm172.dat

Test Case

A long, thick solenoid carries a uniform current density distribution, J. Assuming that the turns of the solenoid can be modeled as a homogeneous isotropic material with modulus of elasticity E, and Poisson's ratio ν, determine the axial magnetic flux density distribution B_θ and the circumferential stress σ_o distribution in the solenoid.

Figure 172.1: Isotropic Solenoid Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 10.76 \times 10^{10}$ N/m^2 $\upsilon = 0.35$ $\mu = \mu_o$	a = .01 m b = .02 m t = .002 m Θ = 10 degrees	$J = 1 \times 10^6$ A/m^2

Analysis Assumptions and Modeling Notes

The problem is solved first using PLANE13 elements. The length of the solenoid is assumed infinite (L = ∞), so only a section of the axisymmetric solenoid (t = .002 m, arbitrary) is required for modeling. It is assumed that the magnetic field external to the solenoid is zero, so the nodes at x = b are coupled (AZ = constant) such that the proper flux-parallel boundary condition is imposed. The flux-parallel condition at x = 0 is imposed by setting A = 0. Flux-normal boundary conditions are imposed naturally (no ANSYS input necessary) at y = 0 and y = t.

Symmetric structural boundary conditions are applied to the solenoid elements at y = 0. The nodes at y = t on the solenoid are coupled in UY to ensure symmetry. The air is modeled with 5 elements in the radial direction while the solenoid is discretized with 20 elements in the radial direction to accurately model the stress distribution.

Results Comparison

		Target[1]	Mechanical APDL	Ratio
PLANE13	B_{angle}, T @ r = .01 m	.01257	.01226	0.975
	B_{angle}, T @ r = .013 m	.008796	.008797	1.000
	B_{angle}, T @ r = .01 7m	.003770	.003769	1.000
	$Stress_o$, N/m^2 @ r = .01m	146.7	144.15	0.983
	$Stress_o$, N/m^2 @ r = .013m	97.79	97.69	0.999
	$Stress_o$, N/m^2 @ r = .017m	62.44	62.61	1.003

1. Assumed to be linearly varying through solenoid

Figure 172.2: 2-D Circumferential Stress through Solenoid Windings

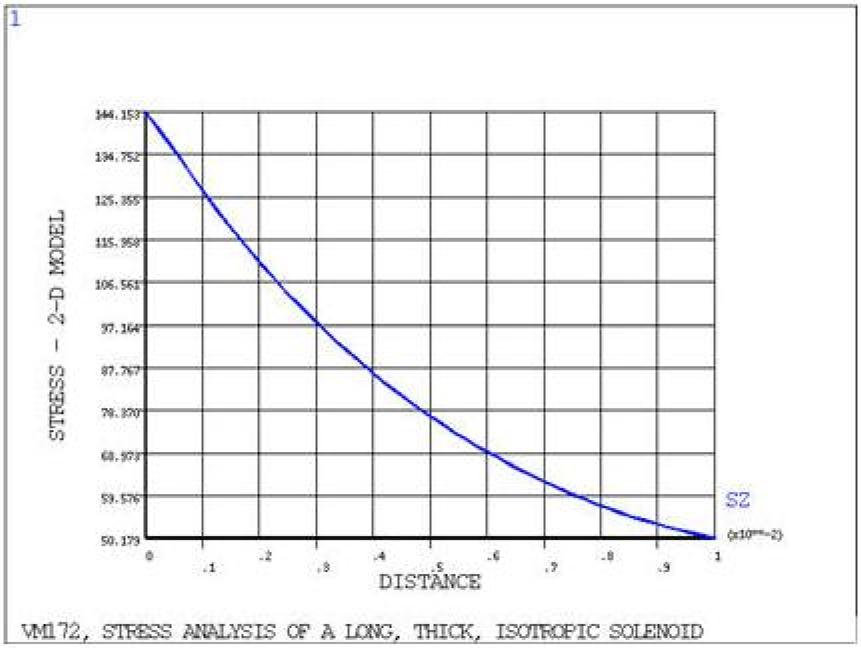
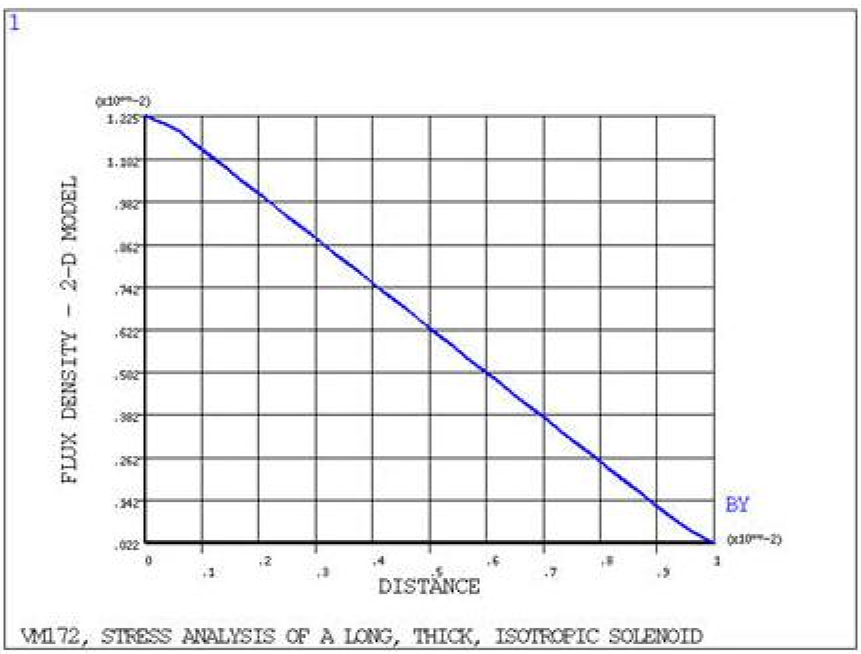


Figure 172.3: 2-D Axial Flux Density through Solenoid Windings



VM173: Centerline Temperature of an Electrical Wire

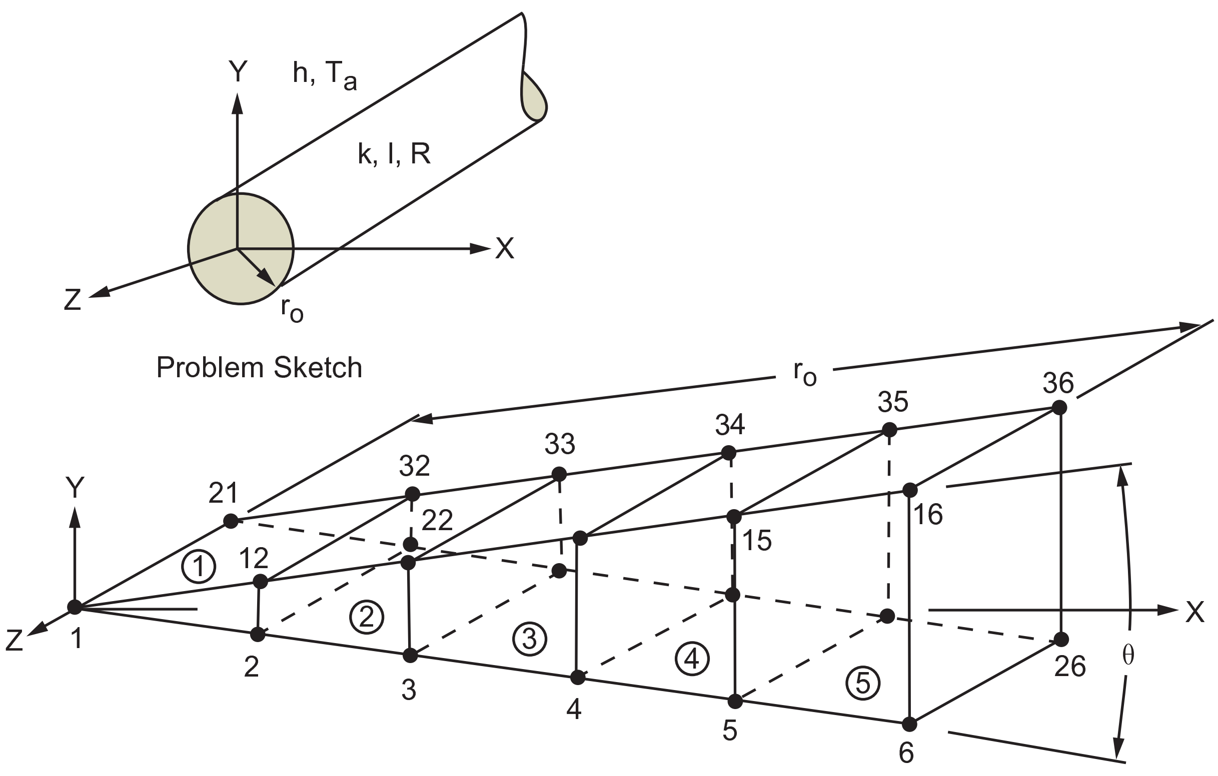
Overview

Reference:	W. M. Rohsenow, H. Y. Choi, *Heat, Mass and Momentum Transfer*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1963, pg. 106, ex. 6.5.
Analysis Type(s):	Static, Coupled-Field Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Coupled-Field Solid Elements (SOLID5)
Input Listing:	vm173.dat

Test Case

Determine the centerline temperature $T_{℄}$ and the surface temperature T_s of a bare steel wire carrying a current I and having a resistance R/l. The surface convection coefficient between the wire and the air (at temperature T_a) is h. Also determine the heat dissipation rate q.

Figure 173.1: Electrical Wire Problem Sketch



Material Properties	Geometric Properties	Loading
R = .0001 ohm/ft k = 13 Btu/hr-ft-°F h = 5 Btu/hr-ft^2-°F ρ = 8.983782 x 10^{-8} ohm-ft	ℓ = 1 in = (1/12) ft r_o = 0.375 in = 0.03125 ft Θ = 10°	I = 1000 A T_a = 70°F

Analysis Assumptions and Modeling Notes

A 1 inch axial (Z) length is chosen for convenience. Since the problem is axisymmetric, only a one-element sector is needed. A small angle Θ = 10° is used for approximating the circular boundary with a straight-sided element.

The calculated resistivity, rho = RA/I, in units of [ohms-ft] was converted to units of [(Btu/hr)/watt] using the conversion factor [3.415 (ohm-ft)] / [(Btu/hr)/watt]. With this conversion, the Joule heat units match the thermal units. The voltage drop per foot, IR/ℓ, is calculated as 0.1 volt/ft. Nodes 1 though 16 are assumed to be ground nodes for reference. The steady-state convergence procedures are used. The heat dissipation rate, q, is calculated as q = hA(T-T_a) where A = exterior surface area of the wire (parameter AREA).

Results Comparison

	Target[1]	Mechanical APDL	Ratio
Centerline Temperature, °F	419.9	418.6	0.997
T_s , °F	417.9	416.5	0.997
q, Btu/hr/ft	341.5	339.8	0.995

1. Solution recalculated

VM174: Bimetallic Beam Under Thermal Load

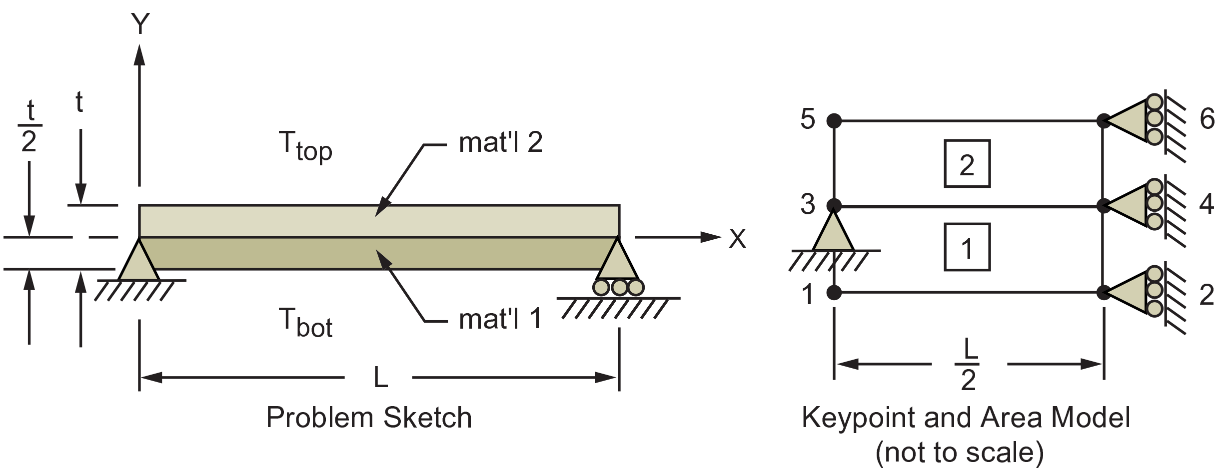
Overview

Reference:	B. A. Boley, J. H. Weiner, *Theory of Thermal Stress*, R. E. Krieger Publishing Co, Malabar, FL, 1985, pg. 429.
Analysis Type(s):	Coupled field Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Coupled-Field Solid Elements (PLANE13) 2-D 8-Node Coupled-Field Solid Elements (PLANE223)
Input Listing:	vm174.dat

Test Case

A bimetallic beam consists of two materials with different coefficients of thermal expansion, α_1 and α_2, and is initially at a reference temperature of 0°F. The beam is simply supported and a uniform temperature is applied to both surfaces. The beam is expected to undergo a large lateral deflection. Determine the midspan deflection after heating and verify the temperature T at the material interface.

Figure 174.1: Bimetallic Beam Problem Sketch



Material Properties	Geometric Properties	Loading
For each strip: $k_1 = k_2 = 5$ Btu/hr-in-°F **For material 1:** $E_1 = 10 \times 10^6$ psi $\alpha_1 = 14.5 \times 10^{-6}$ in/in°F **For material 2:** $E_2 = 10 \times 10^6$ psi $\alpha_2 = 2.5 \times 10^{-6}$ in/in°F	L = 5 in t = 0.1 in	T_{top} = 400.0°F T_{bot} = 400.0°F

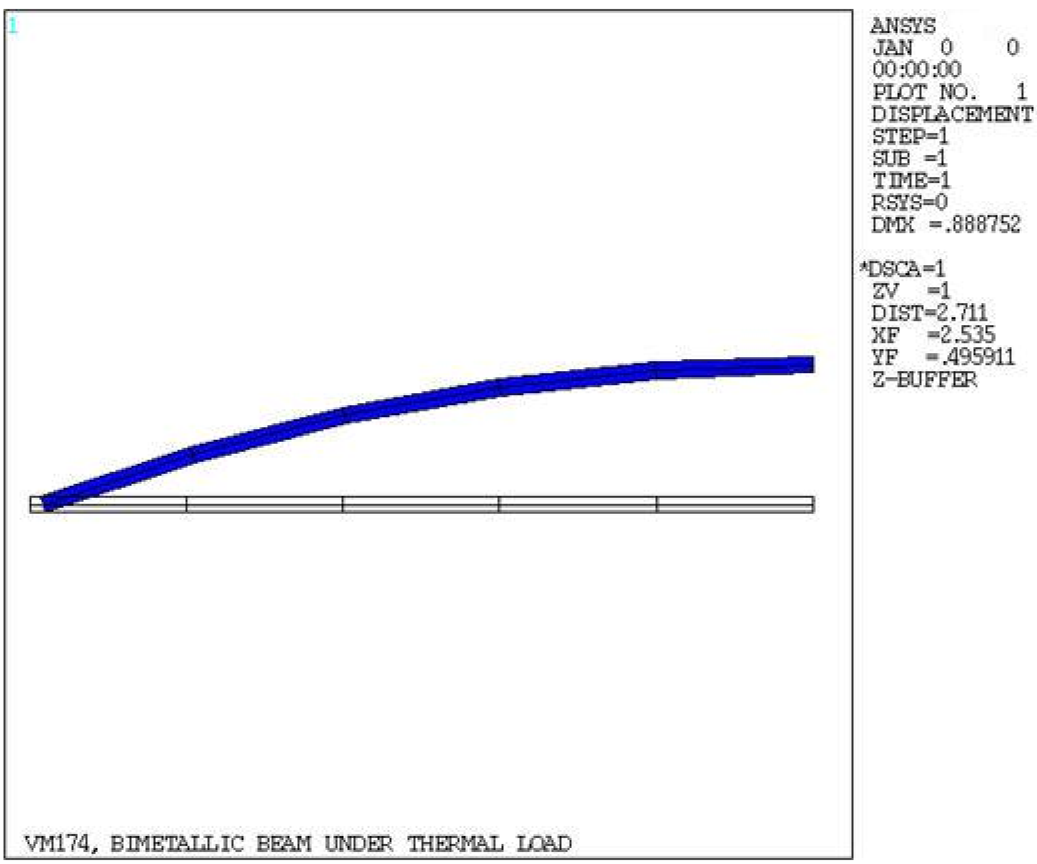
Analysis Assumptions and Modeling Notes

The problem involves a coupled thermal-stress analysis with large deflections and thus requires an iterative solution. Since the problem is symmetric, only one-half of the beam is modeled. The AZ degree of freedom is not required in this analysis and is excluded from the matrix formulation by not specifying any magnetic material properties. A convergence criteria for force is specified with a tight tolerance to converge the large deflection behavior.

Results Comparison

	Target	Mechanical APDL	Ratio
PLANE13			
y, in	0.900	0.888	0.987
T, °F	400.0	400.0	1.000
PLANE223			
y, in	0.900	0.889	0.987
T, °F	400.0	400.0	1.000

Figure 174.2: Bimetallic Beam Under Thermal Load



VM175: Natural Frequency of a Piezoelectric Transducer

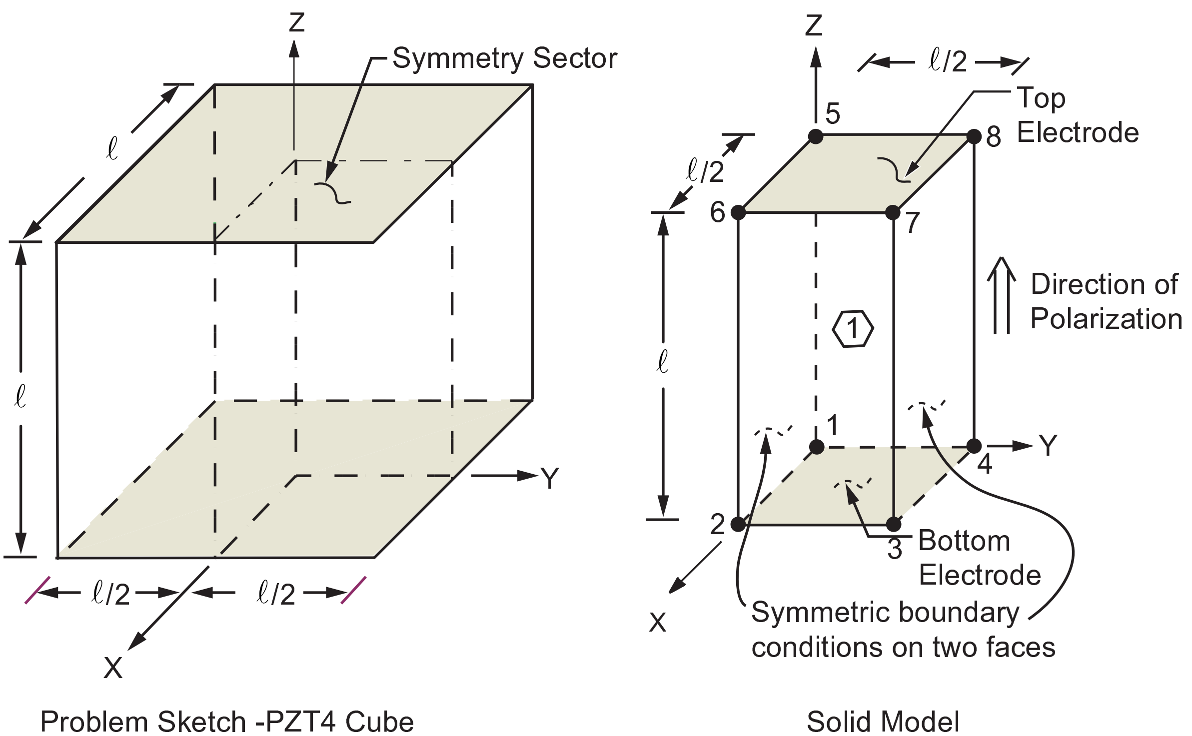
Overview

Reference:	D. Boucher, M. Lagier, C. Maerfeld, "Computation of the Vibration Modes for Piezoelectric Array Transducers Using a Mixed Finite Element Perturbation Method", *IEEE Trans. Sonics and Ultrasonics*, Vol. SU-28 No. 5, 1981, pg. 322, table 1.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	3-D Coupled-Field Solid Elements (SOLID5) 3-D 20-Node Coupled-Field Solid (SOLID226)
Input Listing:	vm175.dat

Test Case

A piezoelectric transducer consists of a cube of PZT4 material with its polarization direction aligned along the Z axis. Electrodes are placed on the two surfaces orthogonal to the polarization axis. Determine the first two coupled-mode (breathing-type deformation) natural frequencies for the short circuit (resonance) case and the open circuit (anti-resonance) case.

Figure 175.1: Piezoelectric Transducer Problem Sketch



Material Properties	Geometric Properties
ρ = 7500 kg/m^3 See "Constitutive Matrices" (p. 462)	ℓ = .02 m

Constitutive Matrices

PZT4 Dielectric Matrix [ε_r]

$$\begin{bmatrix} 804.6 & 0 & 0 \\ 0 & 804.6 & 0 \\ 0 & 0 & 659.7 \end{bmatrix}$$

PZT4 Piezoelectric Matrix [e] C/m^2

$$\begin{bmatrix} 0 & 0 & -4.1 \\ 0 & 0 & -4.1 \\ 0 & 0 & 14.1 \\ 0 & 0 & 0 \\ 0 & 10.5 & 0 \\ 10.5 & 0 & 0 \end{bmatrix}$$

PZT4 "Stiffness" Matrix [c] x 10^{-10} N/m^2

$$\begin{bmatrix} 13.2 & 7.1 & 7.3 & 0 & 0 & 0 \\ & 13.2 & 7.3 & 0 & 0 & 0 \\ & & 11.5 & 0 & 0 & 0 \\ & & & 3.0 & 0 & 0 \\ & \text{Symmetric} & & & 2.6 & 0 \\ & & & & & 2.6 \end{bmatrix}$$

Analysis Assumptions and Modeling Notes

The electroded regions represent equipotential surfaces and are not modeled explicitly. For the short-circuit case the top and bottom electrodes are grounded (voltages are set equal to zero). For the open-circuit case only the bottom electrode is grounded. The short-circuit case represents excitation by potential while the open-circuit case represents excitation by charge.

A one-quarter symmetry sector is modeled with symmetry boundary conditions applied. The mesh density selected for analysis along the axes (X, Y, Z) are (2,2,4) elements respectively. All non-specified voltage degrees of freedom are condensed out during matrix reduction to allow for electro-elastic coupling.

The KEYOPT(1) that is used does not have TEMP or MAG degrees of freedom.

The modes that produce a breathing-type deformation pattern indicate the desired results. POST1 is used to display the mode shapes for determination of the desired natural frequencies.

Results Comparison

		Target[1]	Mechanical APDL	Ratio
SOLID5				
Short Circuit	f_1, kHz	66560	66447	0.998

		Target[1]	Mechanical APDL	Ratio
SOLID5				
	f_2, kHz	88010	90709	1.031
Open Circuit	f_1, kHz	81590	84261	1.033
	f_2, kHz	93410	96988	1.038
SOLID226				
Short Circuit	f_1, kHz	66560	65122	0.978
	f_2, kHz	88010	83511	0.949
Open Circuit	f_1, kHz	81590	79922	0.980
	f_2, kHz	93410	93811	1.004

1. Experimentally measured values (f_1,f_2) represent breathing mode frequencies.

Figure 175.2: Short Circuit Case, Plot 3: First Breathing Mode using SOLID5 Elements

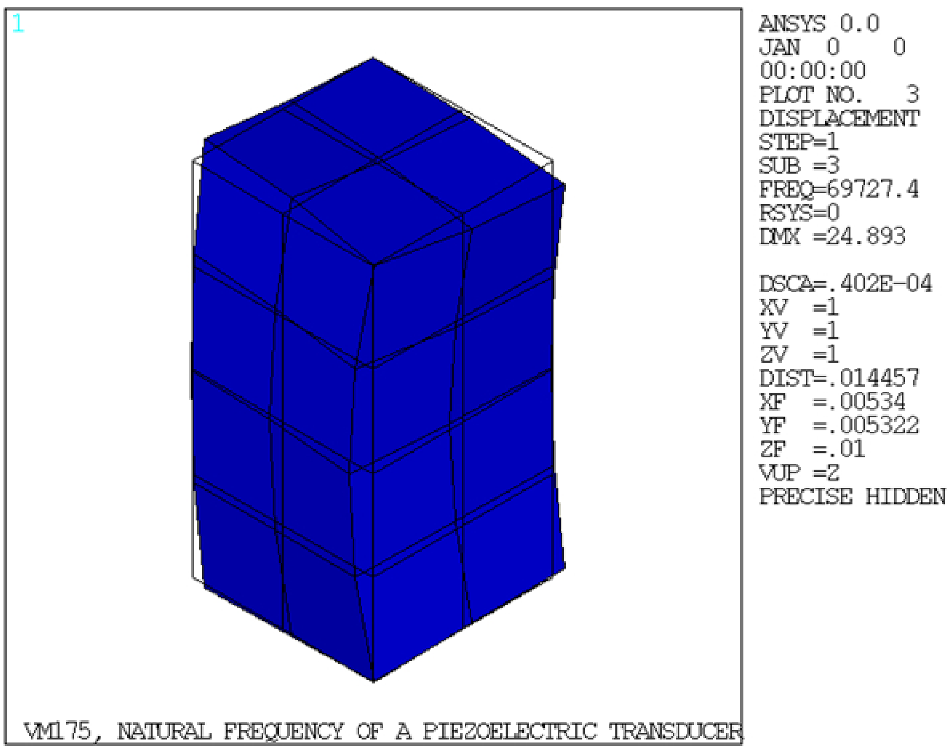


Figure 175.3: Short Circuit Case, Plot 6: Second Breathing Mode using SOLID5 Elements

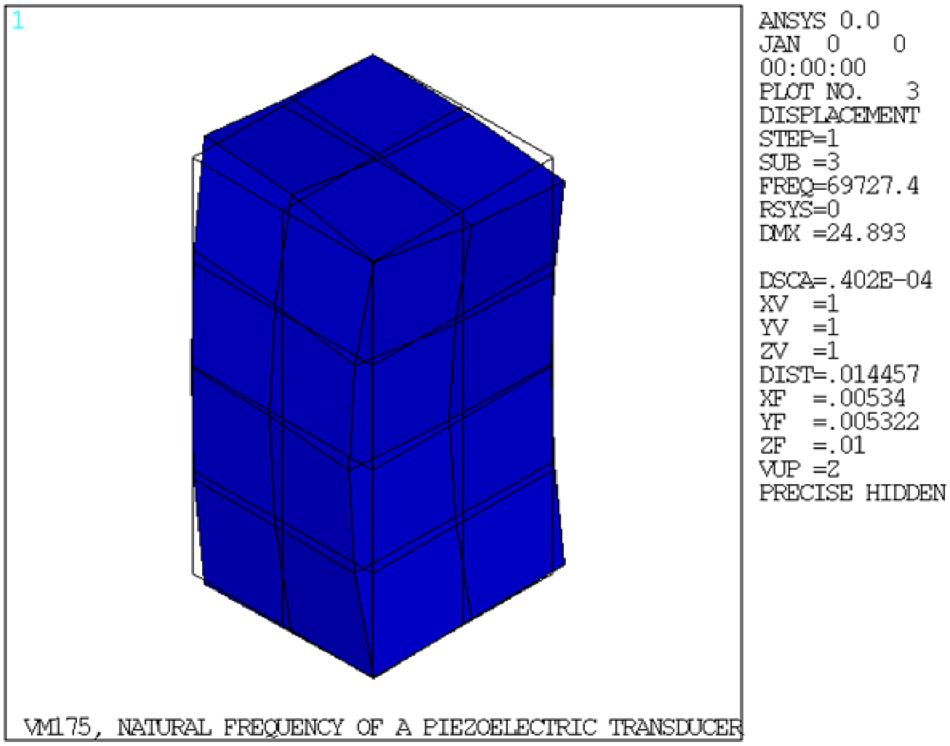


Figure 175.4: Open Circuit Case, Plot 15: First Breathing Mode using SOLID5 Elements

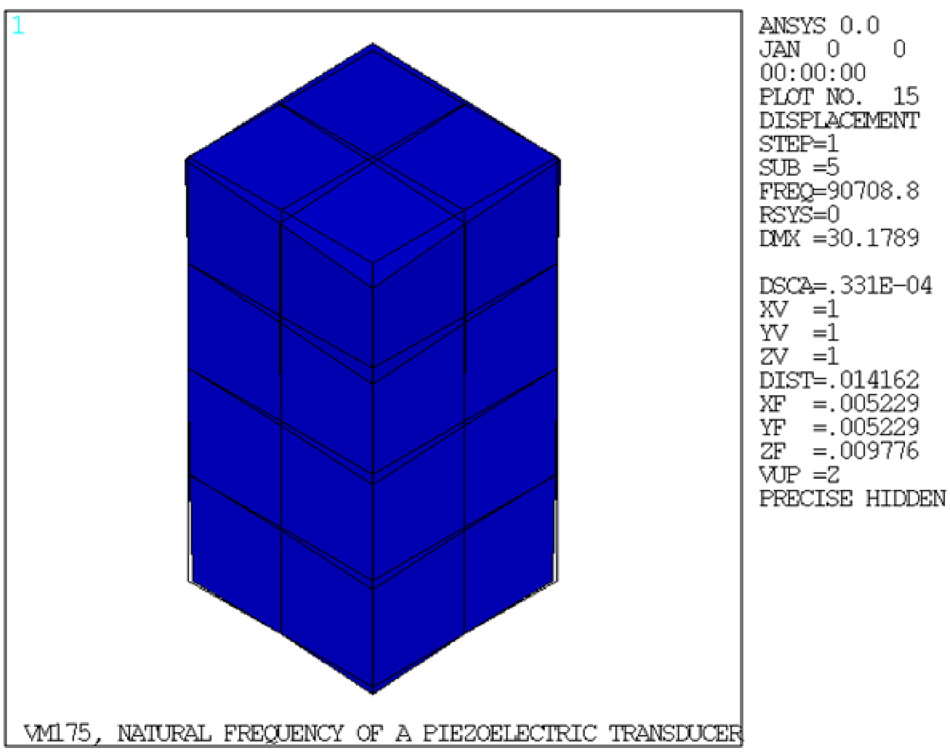


Figure 175.5: Open Circuit Case, Plot 19: Second Breathing Mode using SOLID5 Elements

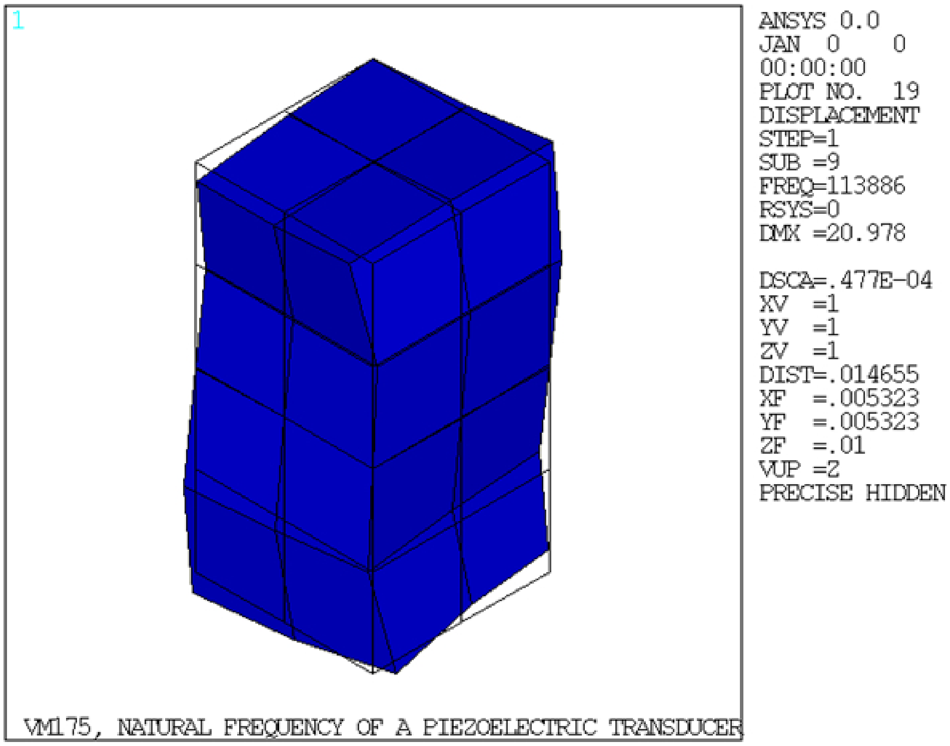


Figure 175.6: Open Circuit Case, Plot 23: Second Breathing Mode using SOLID226 Elements

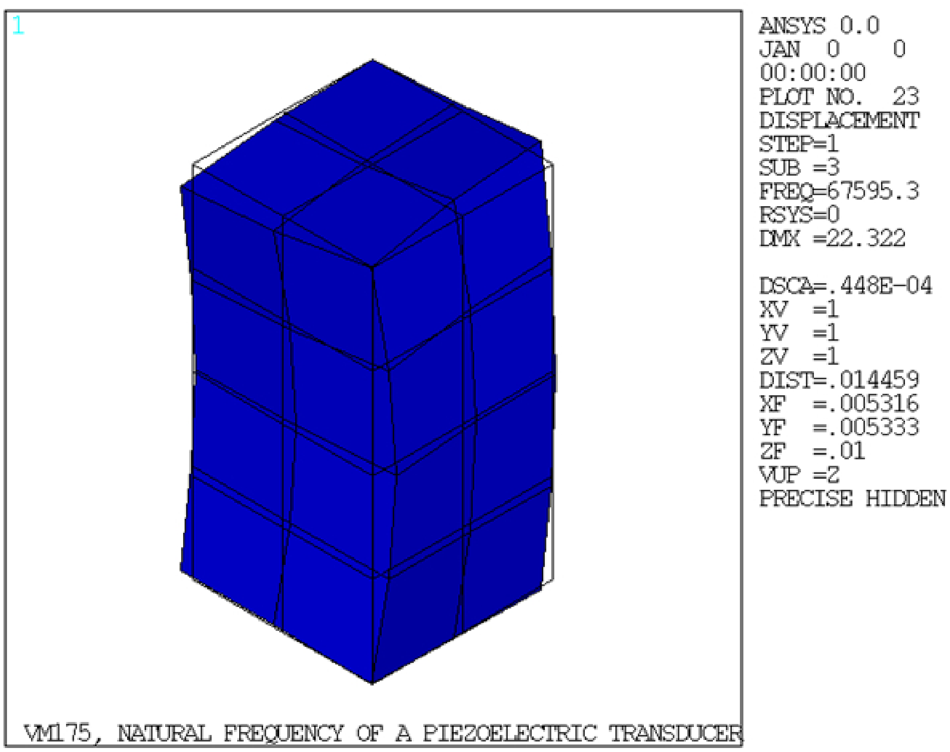


Figure 175.7: Open Circuit Case, Plot 26: Second Breathing Mode using SOLID226 Elements

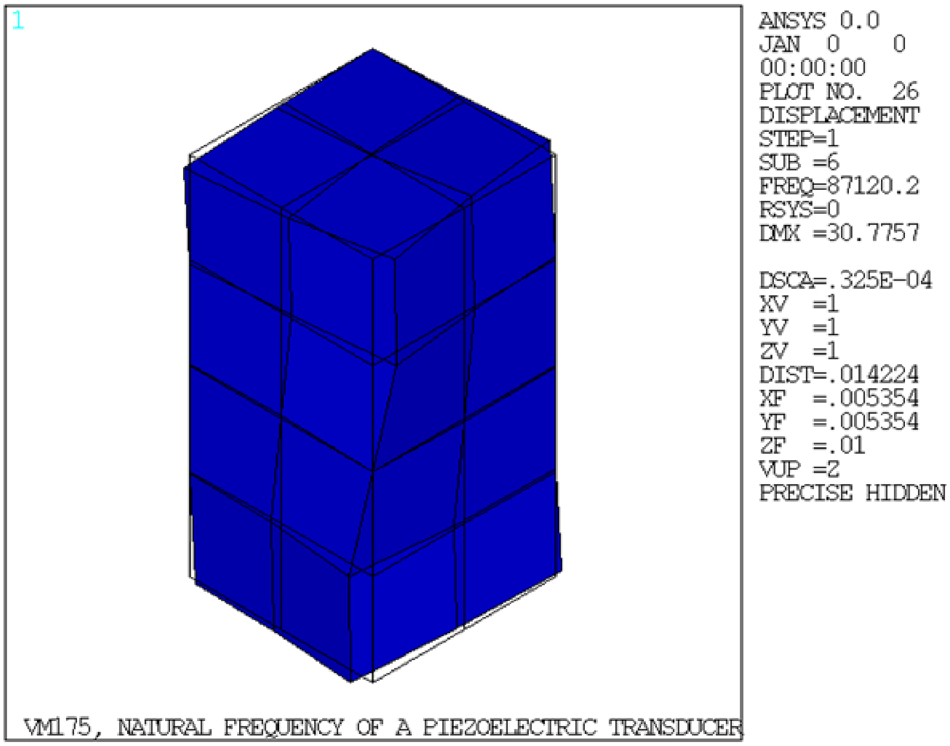


Figure 175.8: Open Circuit Case, Plot 35: Second Breathing Mode using SOLID226 Elements

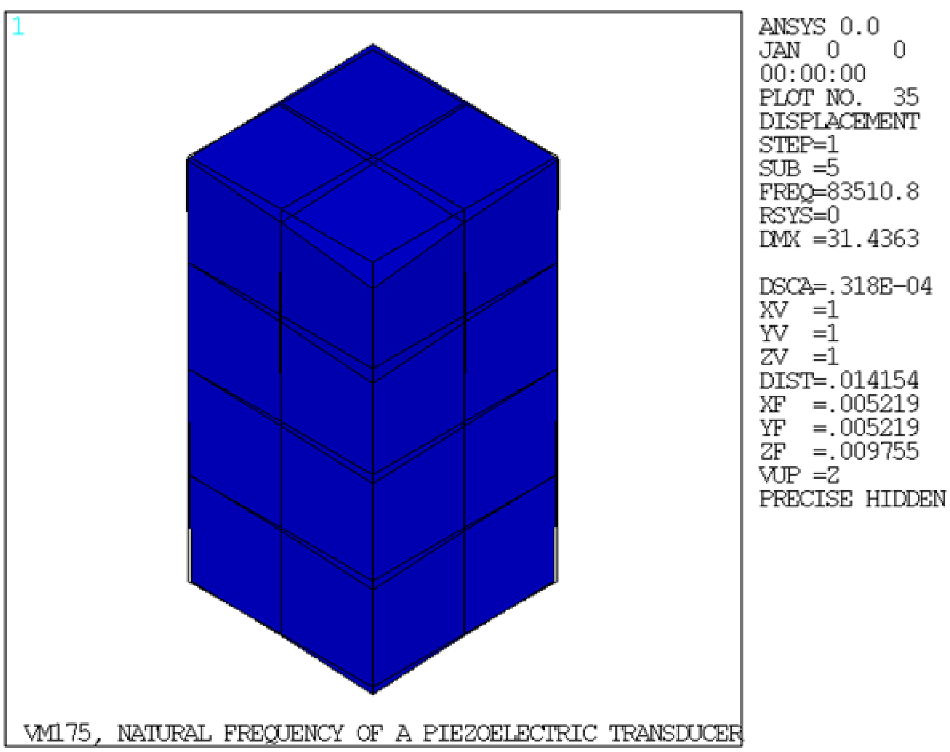
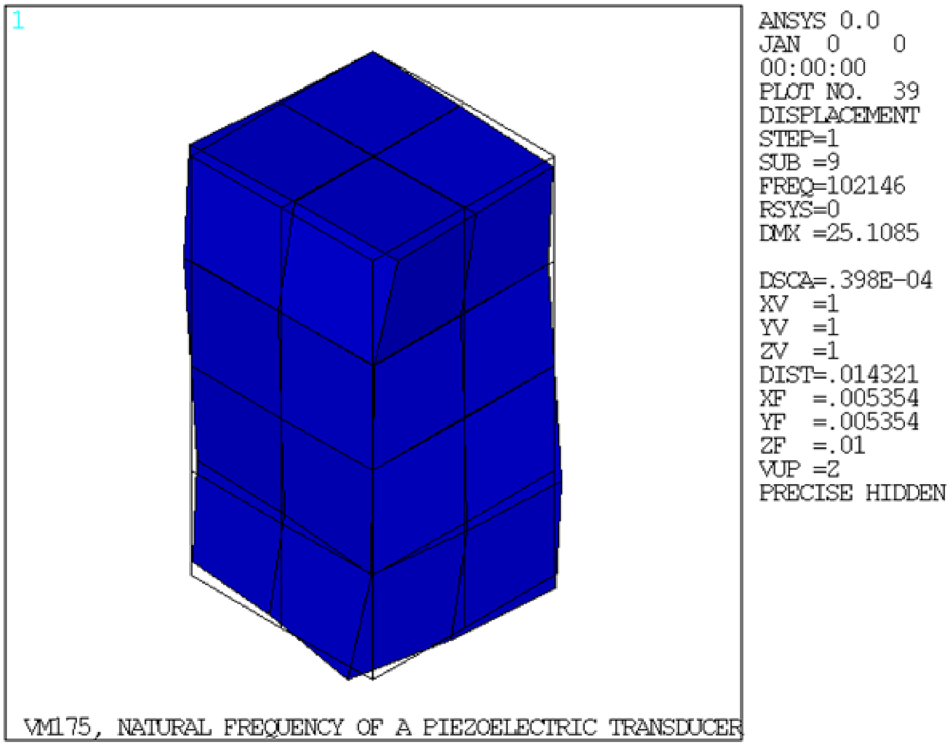


Figure 175.9: Open Circuit Case, Plot 39: Second Breathing Mode using SOLID226 Elements



VM176: Frequency Response of Electrical Input Admittance

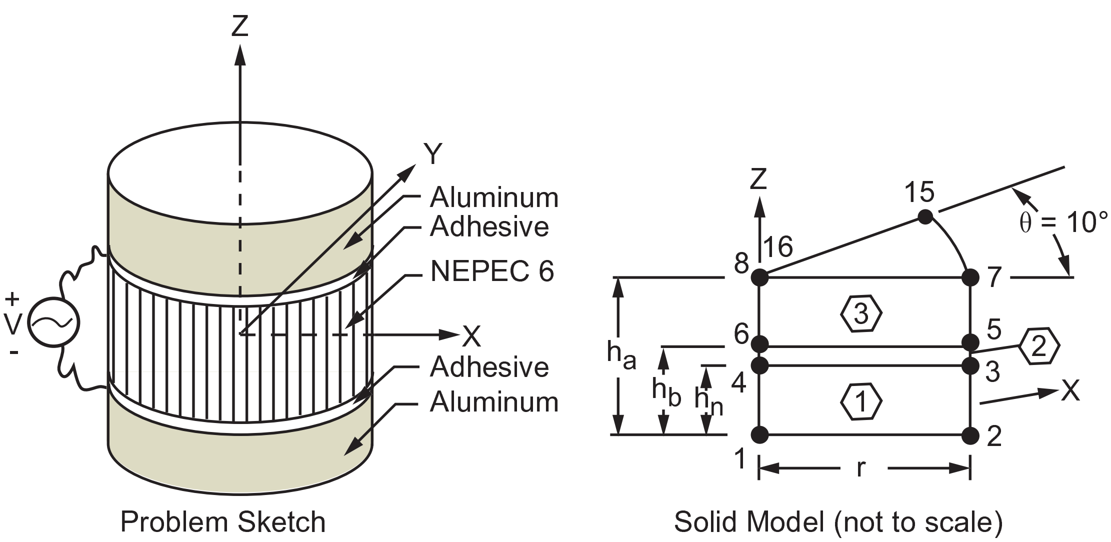
Overview

Reference:	Y. Kagawa, T. Yamabuchi, "Finite Element Simulation of a Composite Piezoelectric Ultrasonic Transducer", *IEEE Trans. Sonics and Ultrasonics*, Vol. SU-2 No. 2, 1979, pg. 81.
Analysis Type(s):	Full Harmonic Analysis (**ANTYPE** = 3)
Element Type(s):	3-D Coupled-Field Solid Elements (SOLID5) 3-D 20-Node Coupled-Field Solid (SOLID226) 3-D 20-Node Structural Solid (SOLID186)
Input Listing:	vm176.dat

Test Case

A composite piezoelectric transducer is made of a piezoceramic (NEPEC 6), aluminum, and an adhesive layer. Electrical terminals are attached to electroded surfaces of the piezoceramic where a potential V is applied. Determine the terminal input admittance Y over a frequency range spanning the first natural frequency.

Figure 176.1: Piezoelectric Transducer Problem Sketch



Material Properties	Geometric Properties	Loading
For aluminum: $E = 7.03 \times 10^{10}$ N/m $\rho = 2690$ kg/m^3 $\upsilon = 0.345$ **For adhesive:** $E = 10 \times 10^9$ N/m^2 $\rho = 1700$ kg/m^3 $\upsilon = 0.38$ **For NEPEC 6:**	$h_a = 15.275 \times 10^{-3}$ m $h_n = 5 \times 10^{-3}$ m $h_b = 5.275 \times 10^{-3}$ m $r = 27.5 \times 10^{-3}$ m	V = 1 volt

Material Properties	Geometric Properties	Loading
See "Constitutive Matrices" (p. 470)		

Constitutive Matrices

NEPEC 6 "Stiffness" Matrix [c] x 10^{-10} N/m^2

$$\begin{bmatrix} 12.8 & 6.8 & 6.6 & 0 & 0 & 0 \\ & 12.8 & 6.6 & 0 & 0 & 0 \\ & & 11.0 & 0 & 0 & 0 \\ & & & 2.1 & 0 & 0 \\ & \text{Symmetric} & & & 2.1 & 0 \\ & & & & & 2.1 \end{bmatrix}$$

NEPEC 6 Piezoelectric Matrix [e] C/m^2

$$\begin{bmatrix} 0 & 0 & -6.1 \\ 0 & 0 & -6.1 \\ 0 & 0 & 15.7 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

NEPEC 6 Dielectric Matrix [ε_r]

$$\begin{bmatrix} 993.55 & 0 & 0 \\ 0 & 993.55 & 0 \\ 0 & 0 & 993.55 \end{bmatrix}$$

Analysis Assumptions and Modeling Notes

The transducer has circumferential symmetry and is symmetric about the midplane, so the model is reduced to a single wedge of elements with an additional symmetry plane at z = 0. No internal losses (damping) are assumed. The top surface of the piezoceramic is electroded, resulting in an equipotential surface. The nodes modeling the surface have their voltage DOF coupled so that the applied potential load can be conveniently placed on a single node. The 1 volt potential load translates into a 0.5 volt potential gradient across the piezoceramic for the 1/2 symmetry model.

The TEMP and MAG degrees of freedom of SOLID5 are not used in this analysis.

Admittance Y is calculated as I/V where I is the current and V is the applied potential. The current I is related to the accumulated charge on the electrode surface as $I = j\omega\Sigma Q_i$, where ω is the operating frequency, j is $\sqrt{1}$ and ΣQ_i is the summed nodal charge (nodal reaction load). Since the nodal potentials are coupled, only the reaction "load" from the single node where the voltage is applied is required for the calculation. A series of calculations are made between 20 kHz and 54 kHz in POST26, which span the first natural frequency ($\approx$ 44 kHz). The problem is first solved using SOLID5 elements and then using SOLID186 and SOLID226 elements.

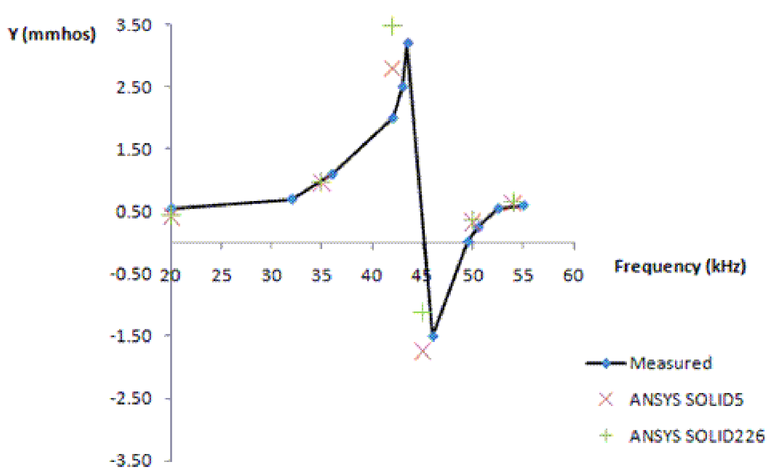
Results Comparison

	Target[1]	Mechanical APDL [2]	Ratio
SOLID5			
Y, mmhos @ 20kHz	.41	.43	1.047
Y, mmhos @ 35kHz	.90	.96	1.063
Y, mmhos @ 42kHz	2.0	2.8	1.400
Y, mmhos @ 45kHz	0.0	-1.74	0.000
Y, mmhos @ 50kHz	.39	.32	0.833
Y, mmhos @ 54kHz	.65	.63	0.962
SOLID226			
Y, mmhos @ 20kHz	.41	.43	1.056
Y, mmhos @ 35kHz	.90	.98	1.086
Y, mmhos @ 42kHz	2.0	3.48	1.741
Y, mmhos @ 45kHz	0.00	-1.13	0.000
Y, mmhos @ 50kHz	.39	.37	0.961
Y, mmhos @ 54kHz	.65	.66	1.008

1. The experimentally measured values are presented in graphical form in the reference. The results tabulated here are obtained from interpolation of the graphical data.

2. Displayed graphically in Figure 176.2: Electrical Input Admittance vs. Frequency using SOLID5 and SOLID226 Elements (p. 471).

Figure 176.2: Electrical Input Admittance vs. Frequency using SOLID5 and SOLID226 Elements



VM177: Natural Frequency of a Submerged Ring

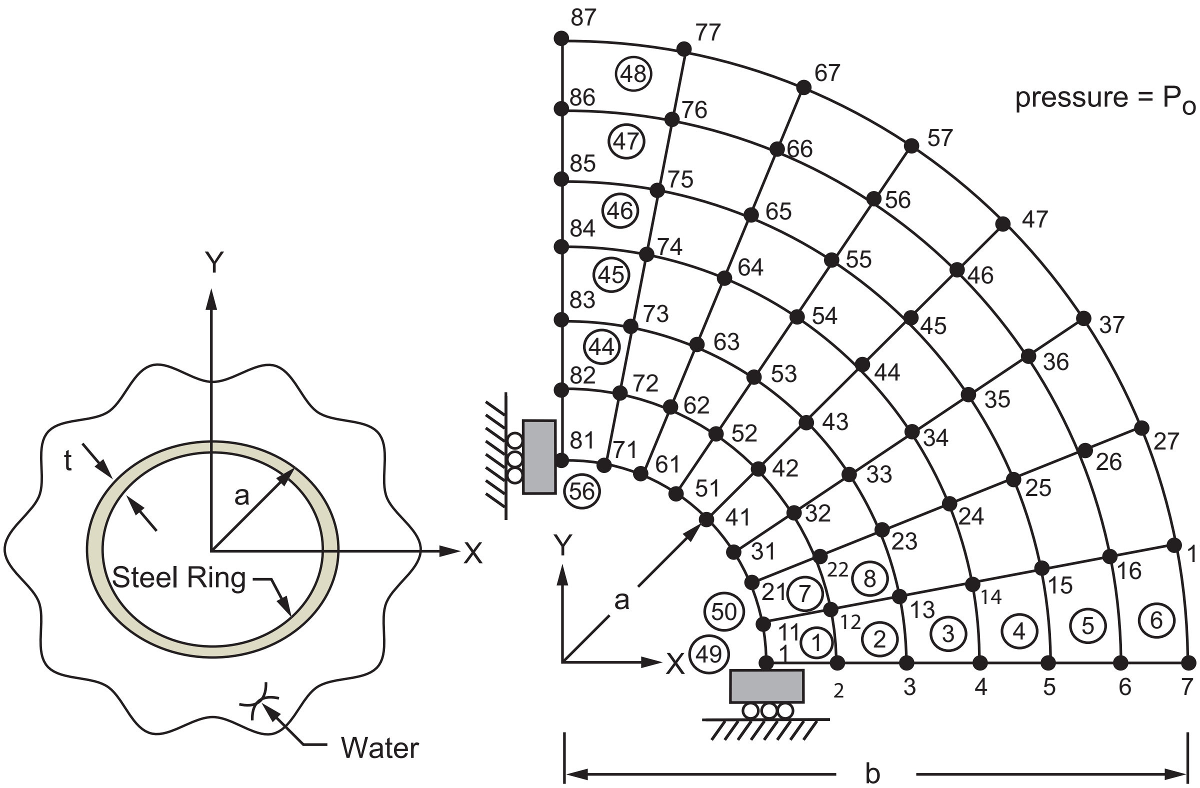
Overview

Reference:	E. A. Schroeder, M. S. Marcus, "Finite Element Solution of Fluid Structure Interaction Problems", Shock and Vibration Symposium, San Diego, CA, 1975.
Analysis Type(s):	Full Harmonic Analysis (**ANTYPE** = 3) Unsymmetric Matrix Modal Analysis (**ANTYPE** = 2)
Element Type(s):	3-D Acoustic Fluid Elements (FLUID30) Elastic Shell Elements (SHELL63) 2-D Acoustic Fluid Elements (FLUID29) 3-D 2 Node Beam (BEAM188) 4-Node Finite Strain Shell (SHELL181) 8-Node Structural Shell (SHELL281) 3-D Acoustic 20-node Fluid Elements (FLUID220) 4-D Acoustic 10-node Fluid Elements (FLUID221)
Input Listing:	vm177.dat

Test Case

A steel ring is submerged in a compressible fluid (water). Determine the lowest natural frequency for x-y plane bending modes of the fluid-structure system.

Figure 177.1: Submerged Ring Problem Sketch



Problem Sketch

Representative Finite Element Model
(Using FLUID30 and SHELL63, with lower
plane nodes shown for clarity, and using
FLUID29 and BEAM188 as a 2-D model)

Material Properties	Geometric Properties
For steel: E = 30 x 10^6 psi υ = 0.3 ρ = 0.0089 slugs per cubic inch (from reference) **For water:** C = 57480 in/sec (speed of sound in water) ρ = 0.001156 slugs per cubix inch (from reference)	a = 10 in b = 30 in t = .25 in

Analysis Assumptions and Modeling Notes

For this problem, the fluid is assumed as extending only to a finite radius b where the pressure P_o is zero and b is taken to be 30 inches. From the reference, this assumption should result in an error of less than 1% compared to the frequency for an unbounded fluid (b = ∞). The natural boundary conditions at the coordinate axes imply that $\delta P / \delta x = 0$ at x = 0 and $\delta P / \delta y = 0$ at y = 0.

This problem is solved using five separate analyses. The first uses 3-D acoustic fluid elements (FLUID30) with quadrilateral shell elements (SHELL63), the second uses 2-D acoustic fluid elements (FLUID29) with BEAM188, the third uses 3-D acoustic fluid elements (FLUID30) with quadrilateral shell elements (SHELL181), the fourth uses 3-D 20 node hexahedral acoustic fluid elements (FLUID220) with 8 node structural shell elements (SHELL281) and the fifth one uses 3-D 10 node tetrahedral fluid elements (`FLUID221`) with 8 node structural shell elements (SHELL281).

For cases 1, 3, 4, and 5, due to fluid-structure coupling involving unsymmetric matrices, the natural frequency is determined by first performing a modal solve (ANTYPE = 2), and then the first mode is excited by performing a full harmonic (ANTYPE = 3) analysis with a frequency sweep. Monitoring the displacement of key nodes over the frequency range indicates the approximate desired natural frequency as the point where the nodal displacements indicate a resonant condition.

In the second case, the lowest natural frequency is obtained using an unsymmetric matrix modal analysis (**ANTYPE** = 2) corresponding to the frequency of mode one of the frequency data from the Lanczos unsymmetric eigensolver.

A preliminary finite element analysis (not shown here) was used to estimate a narrow range in which the 1st even bending mode frequency occurs. For cases 1, 3, 4, and 5, two unit loads are arbitrarily used to excite the desired bending mode of vibration.

Results Comparison

		Target[1]	Mechanical APDL	Ratio
FLUID30 and SHELL63	f_1, Hz	10.20	10.560 < f < 10.580	1.036
FLUID29 and BEAM188	f_1, Hz	10.20	10.63	1.042
FLUID30 and SHELL181	f_1, Hz	10.20	10.640 < f < 10.660	1.044
FLUID220 and SHELL281	f_1, Hz	10.20	10.270 < f < 10.290	1.008
FLUID221 and SHELL281	f_1, Hz	10.20	10.33 < f < 10.35	1.014

1. Solution from the reference under the same assumptions mentioned in the modeling notes.

Figure 177.2: Node 1 Displacement vs. Driving Frequency Near 1st Bending Mode Natural Frequency (Full Harmonic Analysis)

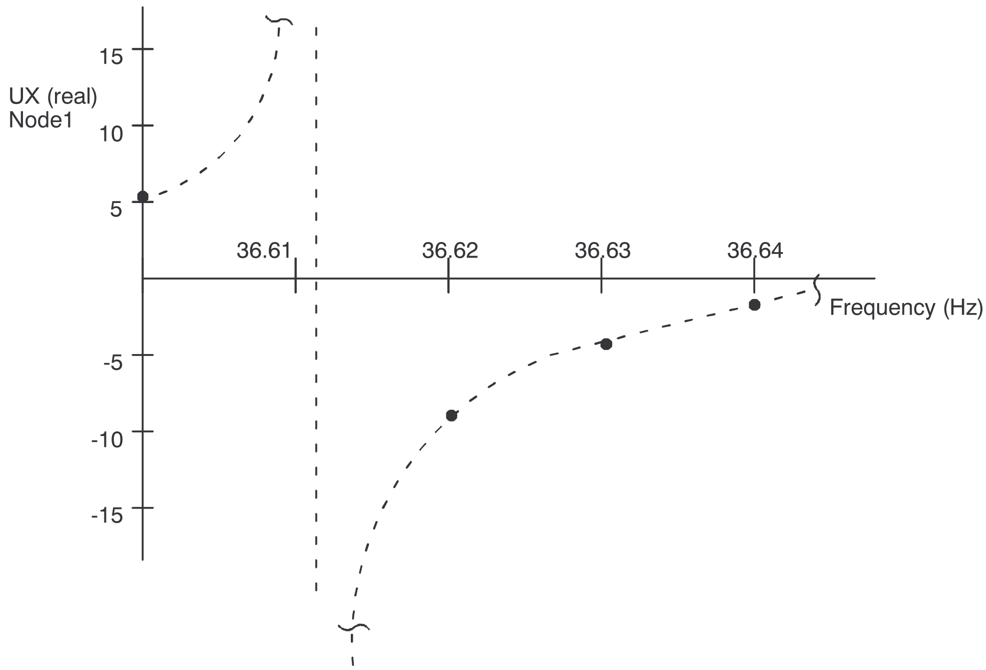


Figure 177.3: Real Displacement Component obtained from Case 1 (FLUID30 and SHELL63 Elements)

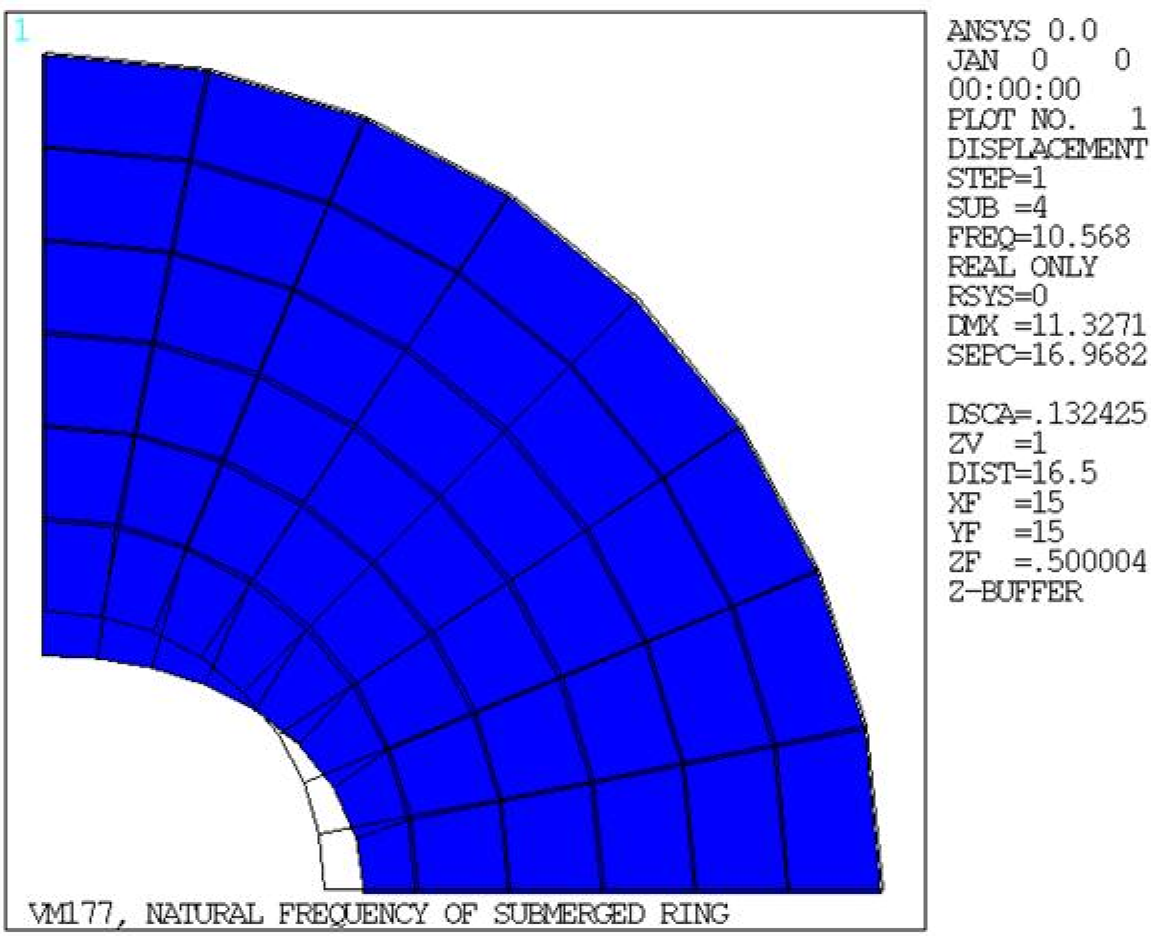
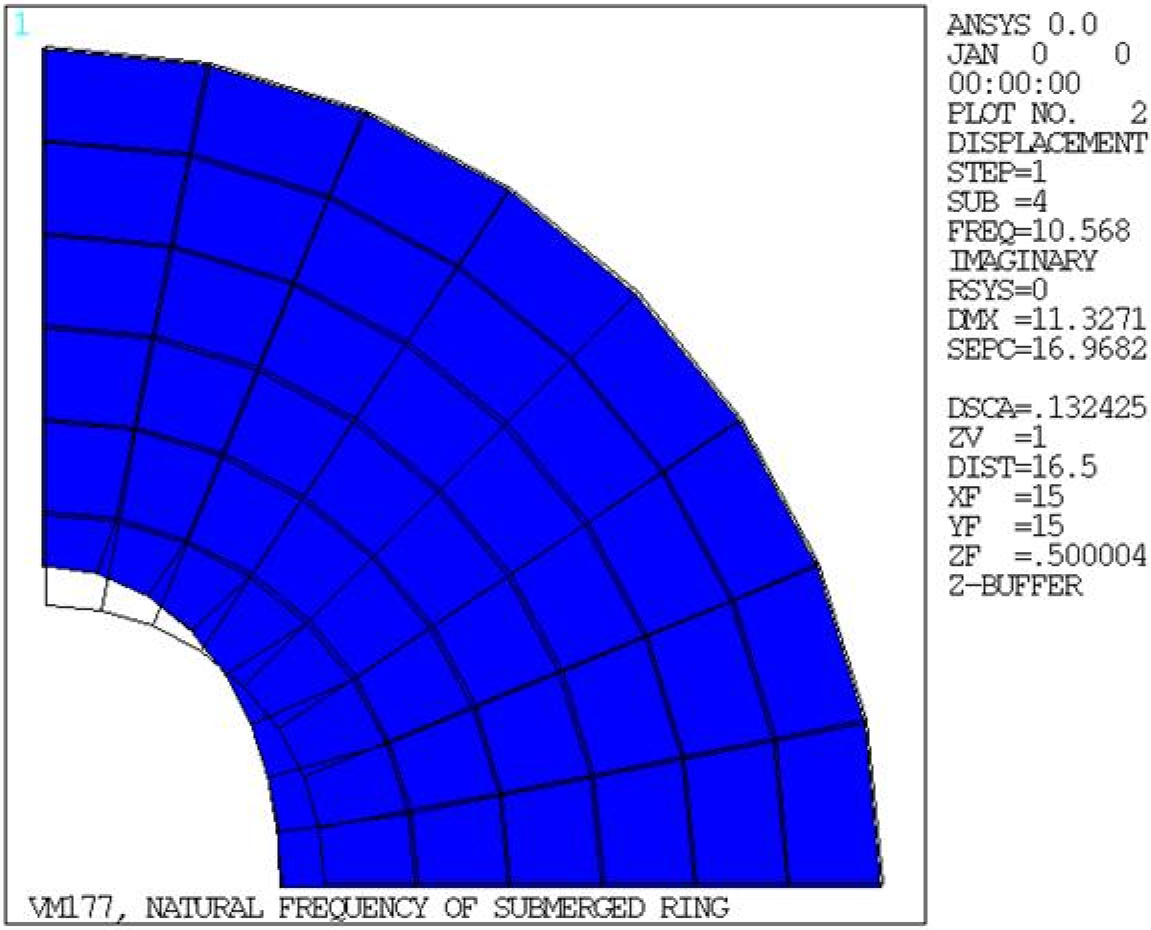


Figure 177.4: Imaginary Displacement Component obtained from Case 1 (FLUID30 and SHELL63 Elements)



VM178: 2-D Double Cantilever Beam Problem

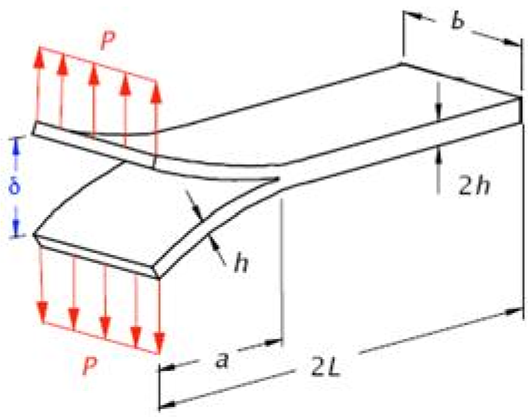
Overview

Reference:	J.F. Mandell, et al. "Prediction of delamination in wind turbine blade structural details". Journal of Solar Energy Engineering. (2003): 522-530.
Analysis Type(s):	Static (**ANTYPE**, 0)
Element Type(s):	2-D Structural Solid Elements (PLANE182)
Input Listing:	vm178.dat

Test Case

A double cantilever beam is modeled with composite material. One end of the beam is fixed, and the other end is loaded with an external force of same magnitude but with opposite direction as shown in Figure 178.1: 2-D End Notched Flexure Problem Sketch (p. 479). G computation for the cracked tip is conducted for VCCT and compared against Equation 1 in the reference.

Figure 178.1: 2-D End Notched Flexure Problem Sketch



Material Properties	Geometric Properties	Loading
E=210GPa μ=0.3	L=100mm a=60mm h=5mm b=1mm	P=10N

Analysis Assumptions and Modeling Notes

The problem is solved using 2-D PLANE182 element with plain strain element behavior. The contact is defined between the cracks. The crack tip nodes and the number of paths surrounding the crack tip nodes are defined using **CINT** command. The plate is subjected to vertical loading in the middle. G values are computed for the crack tip node.

Results Comparison

	Target	Mechanical APDL	Ratio
G	0.201	0.192	0.955

VM179: Dynamic Double Rotation of a Jointed Beam

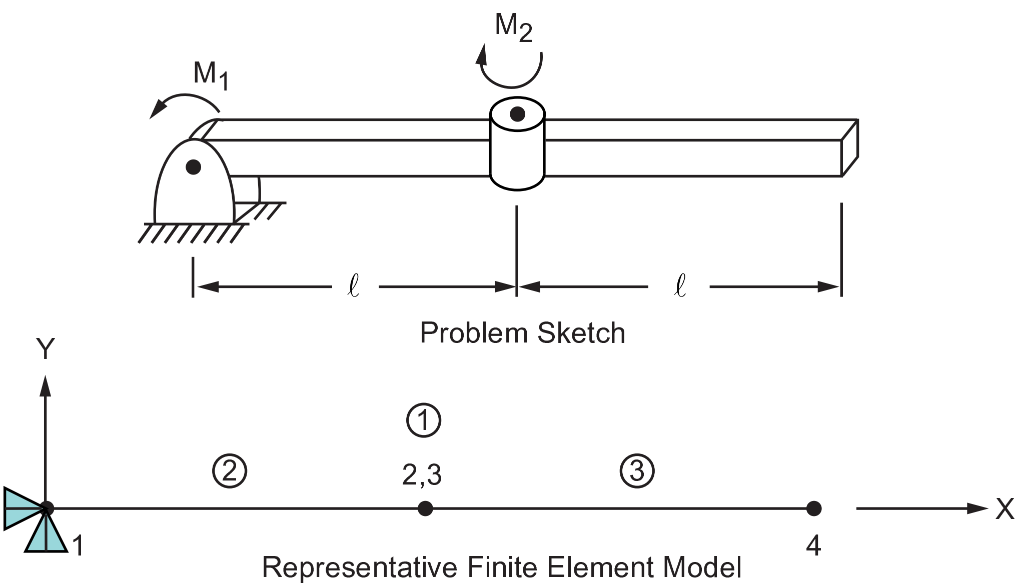
Overview

Reference:	Any basic mechanics text
Analysis Type(s):	Full Transient Dynamic Analysis (**ANTYPE** = 4 w/HHT)
Element Type(s):	Multipoint Constraint Revolute Joint Elements (MPC184) Structural Mass Elements (MASS21) 3-D 2 Node Beam (BEAM188)
Input Listing:	vm179.dat

Test Case

A torque M_1 is applied at the pinned end of an aluminum beam to cause a 90° rotation. A second torque M_2 is then applied at a revolute joint in the beam to create an out-of-plane rotation. The joint has a rotational stiffness k, inertial mass J, frictional torque T_f, and locks when a 5° rotation occurs. Structural mass elements with rotational mass are added at the joint notes. Determine the position of the beam at the end of each rotation.

Figure 179.1: Jointed Beam Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 70 \times 10^9$ N-m $\rho = 1 \times 10^{-6}$ kg/m^3 $\upsilon = 0.35$	Lock at = 5° = 0.08727 rad ℓ = 1 m	M_1 = 0.7854 N-m M_2 = 0.5 N-m

Analysis Assumptions and Modeling Notes

Since step changes in acceleration occur due to the applied step loads, load steps with small time periods are used to "ramp" the accelerations to peak values while maintaining essentially no movement in the beams. The applied moments allow the beam to come to rest in the vertical position. A restart is included to demonstrate and test this program feature.

Results Comparison

	Target	**Mechanical APDL**	**Ratio**
$Deflection_x$, in (t = 1.0)	-0.5858	-0.58534	0.999
$Deflection_y$, in (t = 1.0)	1.4142	1.41377	1.000
$Angle_2$, rad (t = 1.0)	0.7854	0.78508	1.000
$Deflection_x$, in (t = 2.0)	-2.000	-2.00047	1.000
$Deflection_y$, in (t = 2.0)	2.000	2.00000	1.000
$Angle_2$, rad (t = 2.0)	1.5708	1.57103	1.000
$Deflection_x$, in (t = 3.0)	-2.000	-2.00051	1.000
$Deflection_y$, in (t = 3.0)	1.9962	1.99619	1.000
$Deflection_z$, in (t = 3.0)	0.08716	0.08716	1.000
$Angle_x$, rad (t = 3.0)	0.08727	0.08727	1.000
$Angle_2$, rad (t = 3.0)	1.5708	1.57105	1.000

VM180: Bending of a Curved Beam

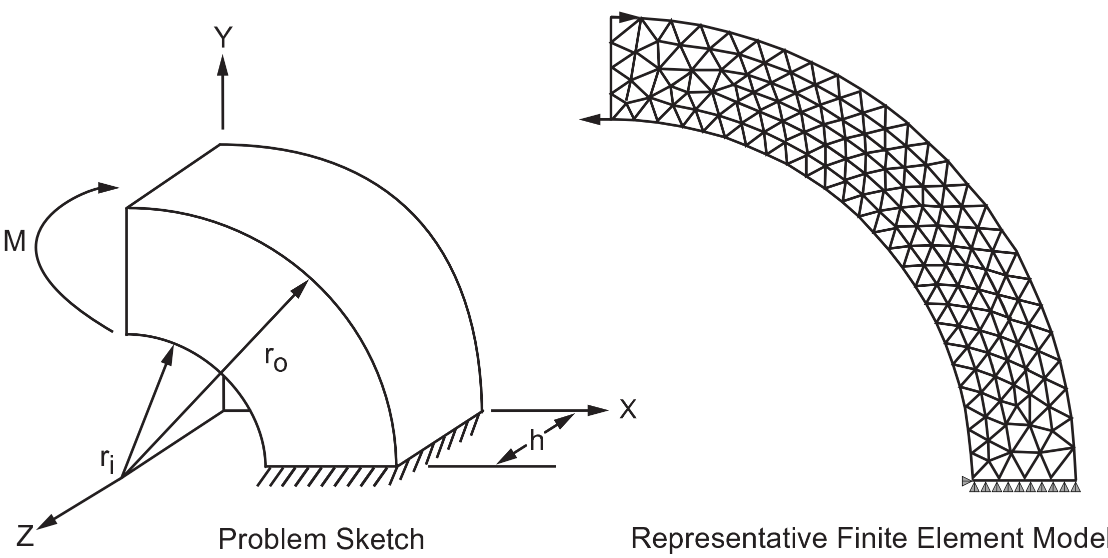
Overview

Reference:	S. Timoshenko, J. N. Goodier, *Theory of Elasticity*, 3rd Edition, McGraw-Hill Book Co. Inc., New York, NY, 1970, pg. 73, article 29.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 8-Node Structural Solid Elements (PLANE183) 2-D Elastic Beam Elements (BEAM188)
Input Listing:	vm180.dat

Test Case

A curved beam spans a 90° arc as shown. The bottom end is supported while the top end is free. For a bending moment M applied at the top end, determine the maximum tensile stress σ_t and the maximum compressive stress σ_c in the beam.

Figure 180.1: Curved Beam Problem Sketch



Material Properties	Geometric Properties	Loading
E = 30 x 10^6 psi υ = 0.0	r_i = 3.5 in r_o = 4.5 in h = 1.0 in	M = 100 in-lb

Analysis Assumptions and Modeling Notes

Beam elements with arbitrary properties are included at the free end of the curved beam for uniform transmission of the applied forces. This creates a pure bending situation except for the nodes at the free end at which stresses are ignored. POST1 is used to obtain the desired stress results.

Results Comparison

	Target	Mechanical APDL	Ratio
$Stress_t$, psi	655.0	674.5	1.030
$Stress_c$, psi	-555.0	-564.3	1.017

VM181: Natural Frequency of a Flat Circular Plate

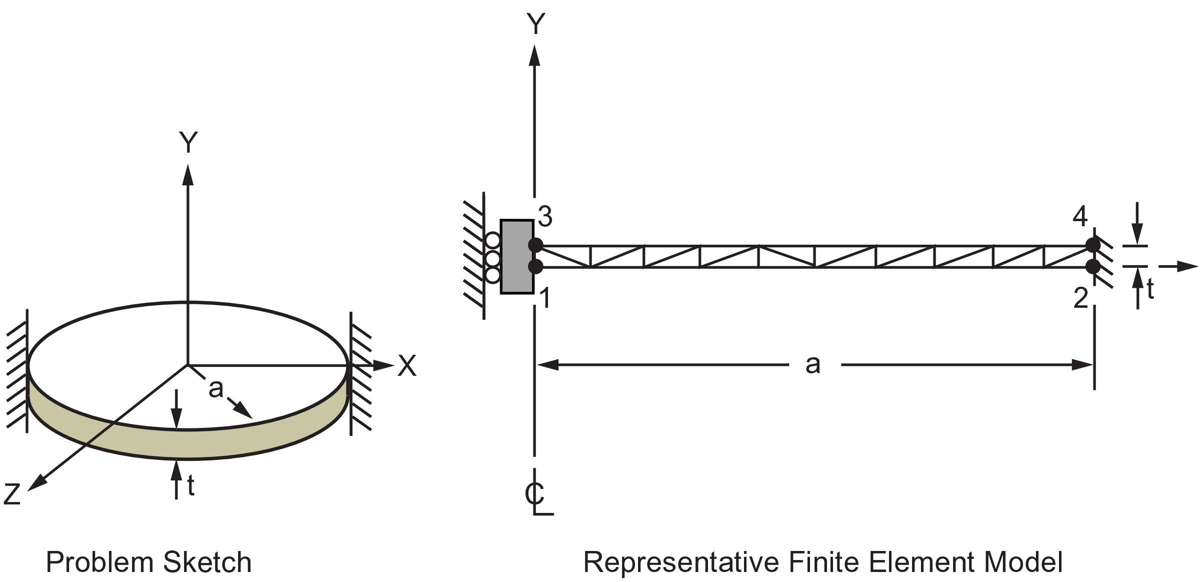
Overview

Reference:	R. D. Blevins, *Formulas for Natural Frequency and Mode Shape*, Van Nostrand Reinhold Co., New York, NY, 1979, pg. 241, no. 3.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	2-D 8-Node Structural Solid Elements (PLANE183)
Input Listing:	vm181.dat

Test Case

A circular plate with a clamped edge is allowed to vibrate freely. Determine the natural frequencies $f_{i,j}$ for the first three modes of vibration (j = 0, 1, 2) for the first harmonic (i = 0).

Figure 181.1: Flat Circular Plate Problem Sketch



Material Properties	Geometric Properties
$E = 30 \times 10^6$ psi $\upsilon = 0.3$ $\rho = .00073$ lb-sec^2/in^4	t = 0.5 in a = 17 in

Analysis Assumptions and Modeling Notes

Poisson's ratio defaults to 0.3 and is not defined with the input data.

Results Comparison

	Target	Mechanical APDL	Ratio
$f_{0,0}$, Hz	172.64	172.79	1.001
$f_{0,1}$, Hz	671.79	676.80	1.007
$f_{0,2}$, Hz	1505.07	1530.15	1.016

VM182: Transient Response of a Spring-mass System

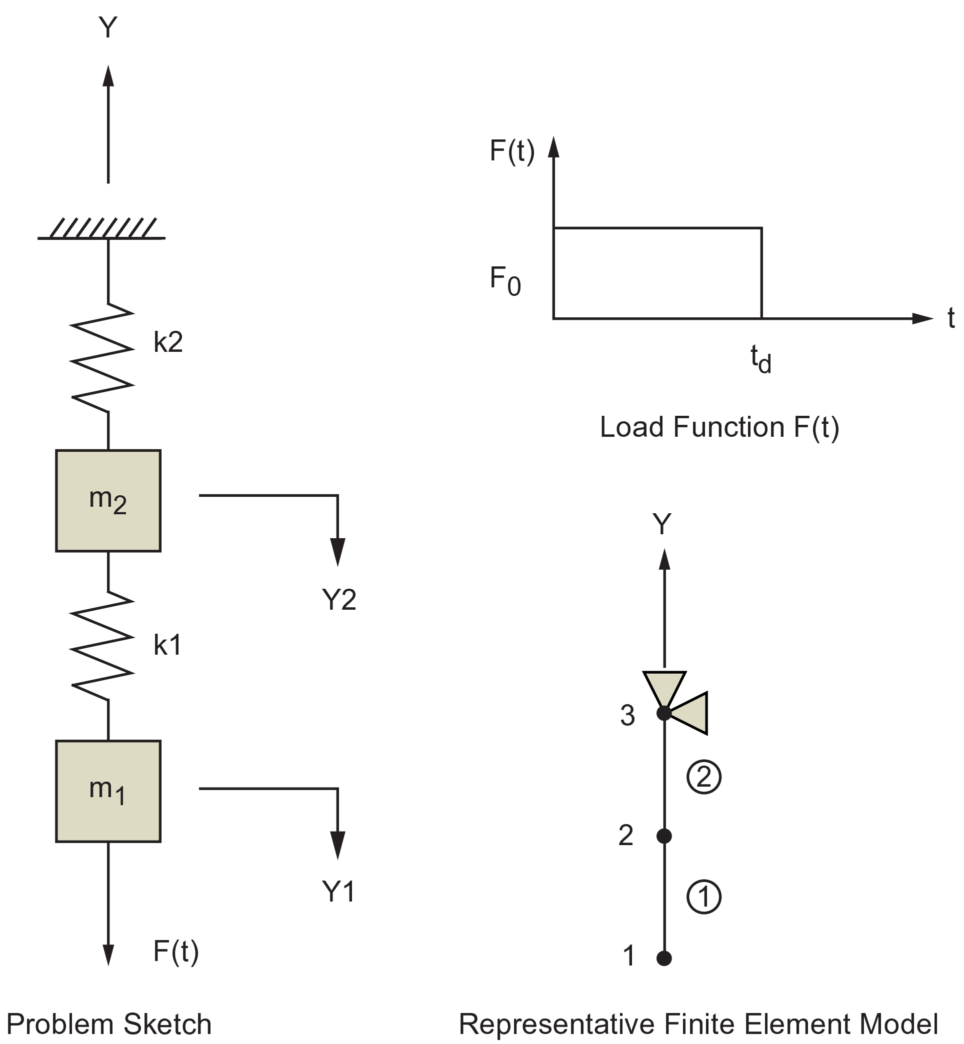
Overview

Reference:	R. K. Vierck, *Vibration Analysis*, 2nd Edition, Harper & Row Publishers, New York, NY, 1979, sec. 5-8.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2) Transient Dynamic Mode Superposition Analysis (**ANTYPE** = 4)
Element Type(s):	Combination Elements (COMBIN40)
Input Listing:	vm182.dat

Test Case

A system containing two masses, m_1 and m_2, and two springs of stiffness k_1 and k_2 is subjected to a pulse load F(t) on mass 1. Determine the displacement response of the system for the load history shown.

Figure 182.1: Spring-mass System Problem Sketch



Material Properties	Loading
k_1 = 6 N/m k_2 = 16 N/m m_1 = 2 Kg m_2 = 2 Kg	F_0 = 50 N t_d = 1.8 sec

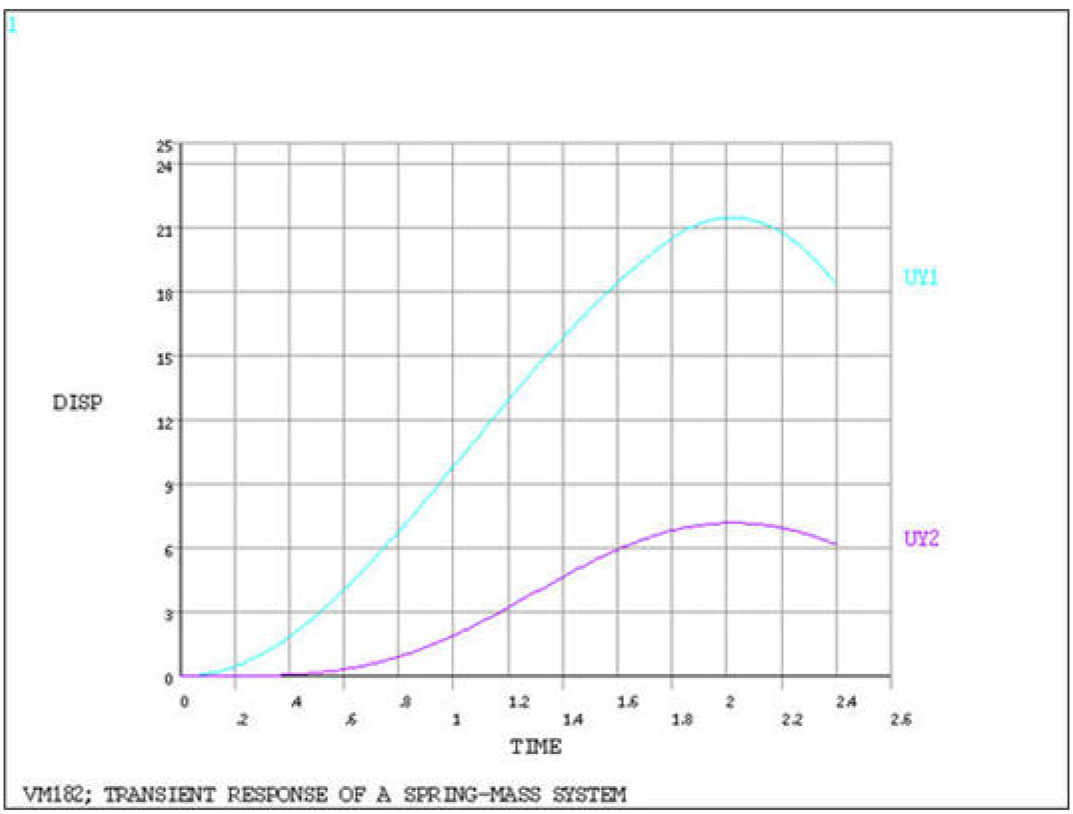
Analysis Assumptions and Modeling Notes

COMBIN40 combination elements are used to represent the springs and masses. Node locations are arbitrary. The response of the system is examined for an additional 0.6 seconds after the load is removed.

Results Comparison

	Target	Mechanical APDL	Ratio
Y_1 , m (@ t = 1.3s)	14.48	14.40	0.995
Y_2 , m (@ t = 1.3s)	3.99	3.95	0.990
Y_1 , m (@ t = 2.4s)	18.32	18.40	1.004
Y_2 , m (@ t = 2.4s)	6.14	6.16	1.004

Figure 182.2: POST26 Displacement Display



VM183: Harmonic Response of a Spring-mass System

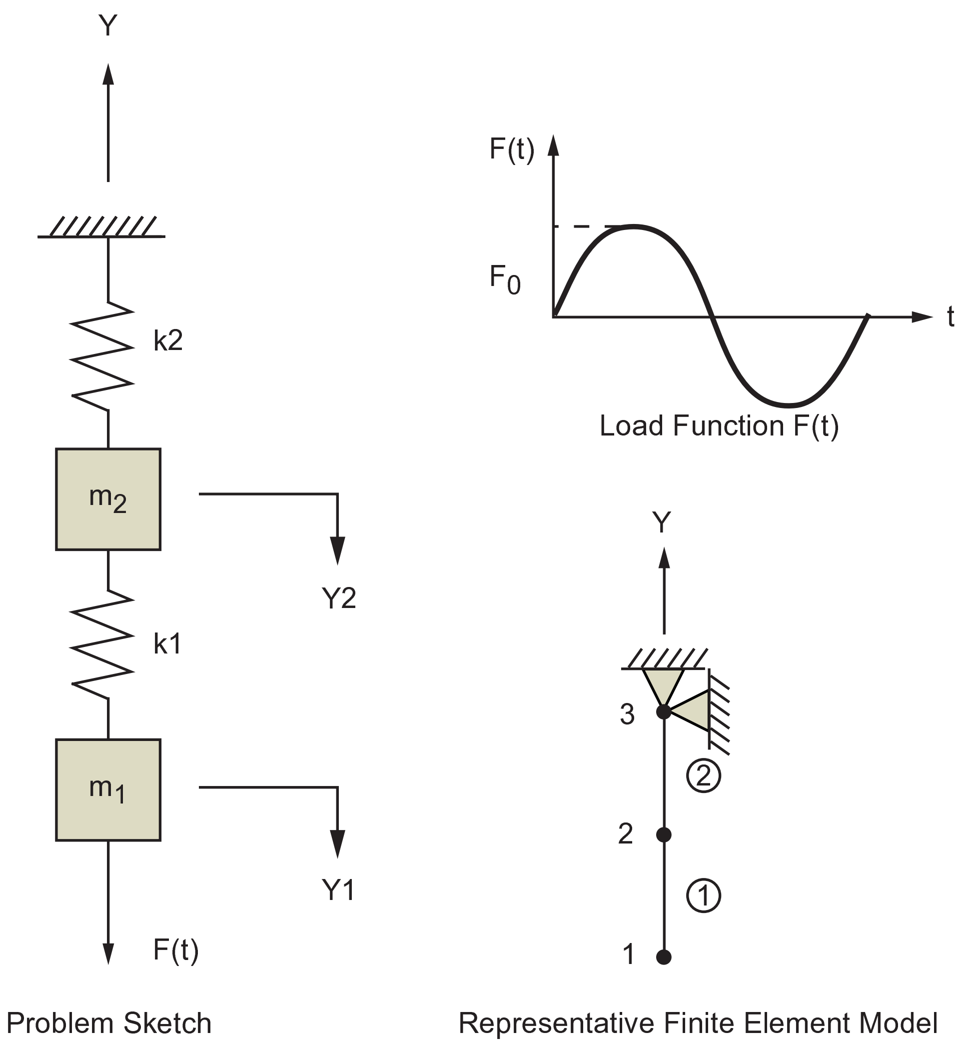
Overview

Reference:	R. K. Vierck, *Vibration Analysis*, 2nd Edition, Harper & Row Publishers, New York, NY, 1979, sec. 4-2.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2) Harmonic Mode Superposition Analysis (**ANTYPE** = 3)
Element Type(s):	Combination Elements (COMBIN40)
Input Listing:	vm183.dat

Test Case

Determine the natural frequencies of the spring-mass system shown and the displacement response when excited by a harmonic load of variable frequency from 0.1 to 1.0 Hz, with an amplitude of F_o.

Figure 183.1: Spring-mass System Problem Sketch



Material Properties	Loading
k_1 = 6 N/m k_2 = 16 N/m m_1 = m_2 = 2 kg	F_o = 50 N

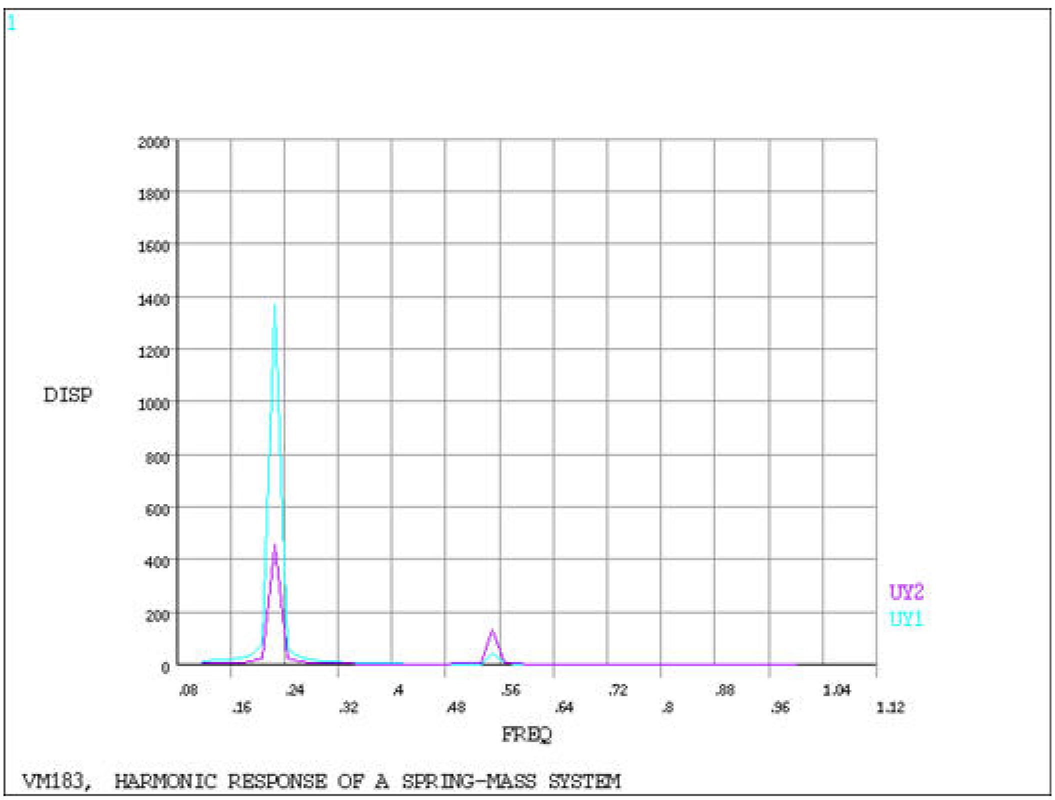
Analysis Assumptions and Modeling Notes

COMBIN40 combination elements are used to represent the springs and masses. Node locations are arbitrary.

Results Comparison

	Target	Mechanical APDL	Ratio
Y_1 , m (@ .226 Hz)	-1371.7	-1371.73	1.000
Y_2 , m (@ .226 Hz)	-458.08	-458.08	1.000
Y_1 , m (@ .910 Hz)	-0.8539	-0.8539	1.000
Y_2 , m (@ .910 Hz)	0.1181	0.1181	1.000

Figure 183.2: Displacement vs. Frequency



VM184: Straight Cantilever Beam

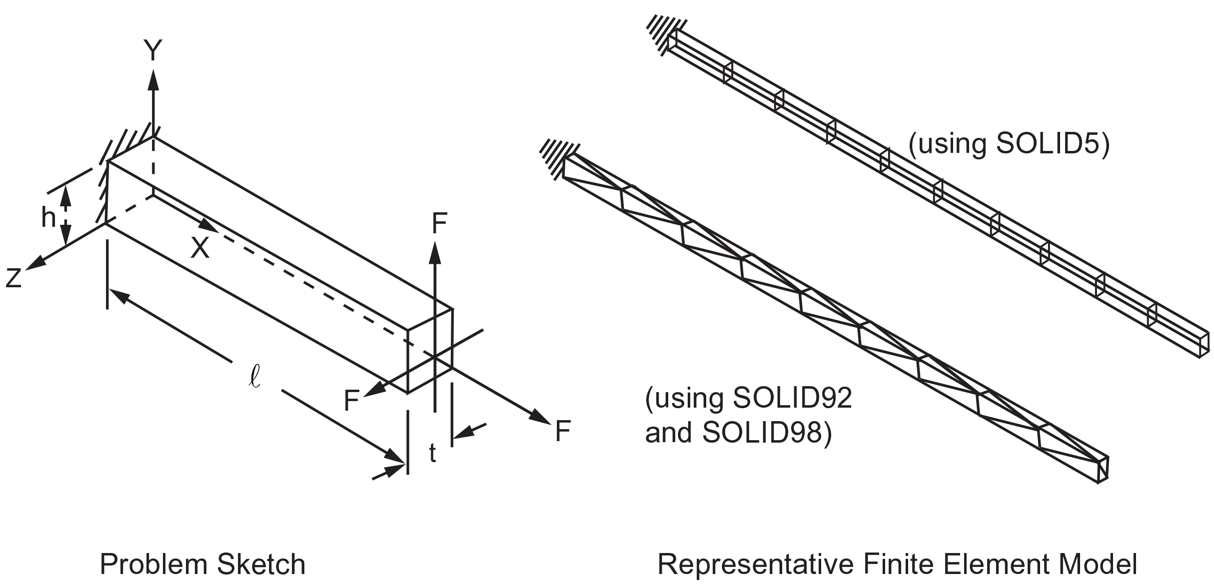
Overview

Reference:	Any Basic Mechanics of Materials Text
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Coupled-Field Solid Elements (SOLID5) 3-D 10-Node Tetrahedral Structural Solid Elements (SOLID92) Tetrahedral Coupled-Field Solid Elements (SOLID98) 3-D 10-Node Tetrahedral Structural Solid Elements (SOLID187)
Input Listing:	vm184.dat

Test Case

A beam of length ℓ, height h, and thickness t is built-in at one end and loaded at the free end with an axial force, an in-plane shear force and an out-of-plane shear force, all of magnitude F. Determine the deflections δ_x, δ_y, and δ_z at the free end due to these loads.

Figure 184.1: Straight Cantilever Beam Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 10 \times 10^6$ psi $\upsilon = 0.3$	ℓ = 6 in h = 0.2 in t = 0.1 in	F = 1 lb

Analysis Assumptions and Modeling Notes

The problem is solved in four different ways:

- using Coupled-Field Solid Elements (SOLID5)
- using Tetrahedral Solid Elements (SOLID92)
- using Tetrahedral coupled-Field Solid Elements (SOLID98)
- using Tetrahedral Solid Elements (SOLID187)

POST1 is used to directly obtain the difference between the theoretical solution and the ANSYS results in the form of a ratio, using the maximum displacement value on the free face.

Results Comparison

		Target	Mechanical APDL	Ratio
SOLID5	$Deflection_x$, in	3.000×10^{-5}	3.000×10^{-5}	0.993
	$Deflection_y$, in	0.10800	0.106830	0.989
	$Deflection_z$, in	0.43200	0.425536	0.985
SOLID92	$Deflection_x$, in	3.000×10^{-5}	3.000×10^{-5}	0.995
	$Deflection_y$, in	0.108000	0.106757	0.988
	$Deflection_z$, in	0.432000	0.425708	0.985
SOLID98	$Deflection_x$, in	3.000×10^{-5}	3.000×10^{-5}	0.995
	$Deflection_y$, in	0.108000	0.106757	0.988
	$Deflection_z$, in	0.432000	0.425708	0.985
SOLID187	$Deflection_x$, in	3.000×10^{-5}	3.000×10^{-5}	0.995
	$Deflection_y$, in	0.10800	0.106757	0.988
	$Deflection_z$, in	0.43200	0.425708	0.985

Figure 184.2: Element Display

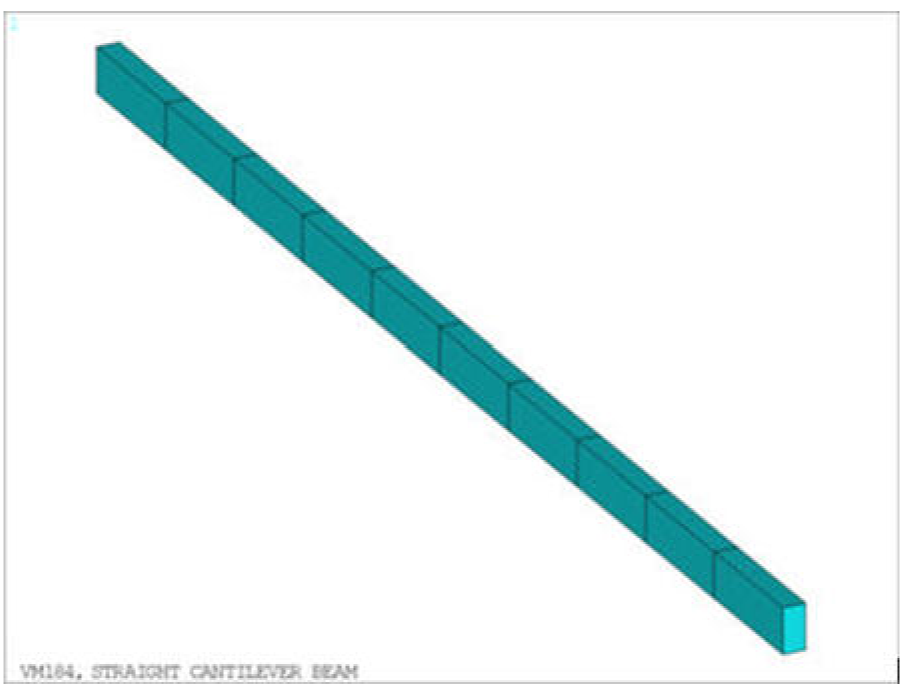
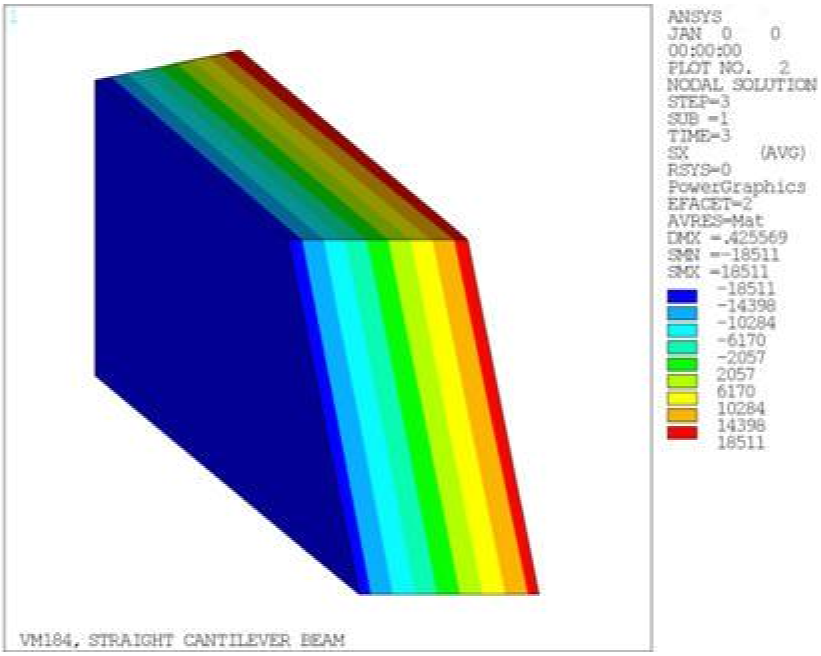


Figure 184.3: Clipped and Capped Display of Stress Contours



VM185: AC Analysis of a Slot Embedded Conductor

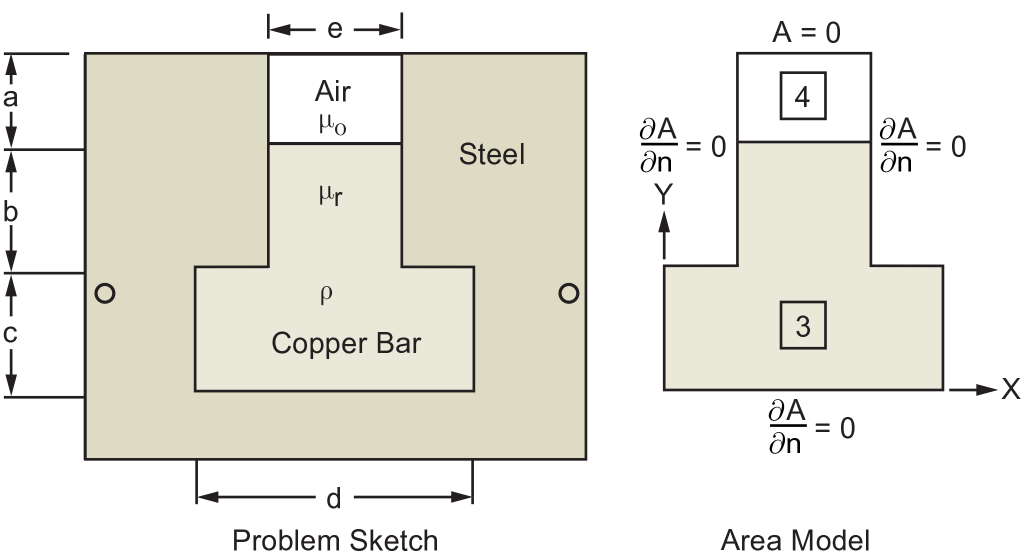
Overview

Reference:	A. Konrad, "Integrodifferential Finite Element Formulation of Two-Dimensional Steady-State Skin Effect Problems", *IEEE Trans. Magnetics*, Vol. MAG-18 No. 1, January 1982, pg. 284-292.
Analysis Type(s):	Coupled-field Analysis (**ANTYPE** = 3)
Element Type(s):	2-D Coupled-Field Solid Elements (PLANE13) 2-D 8-Node Electromagnetic Solid Elements (PLANE233)
Input Listing:	vm185.dat

Test Case

A solid copper conductor embedded in the slot of an electric machine carries a current I at a frequency ω. Determine the distribution of the current within the conductor, the source current density, the complex impedance of the conductor, and the AC/DC power loss ratio.

Figure 185.1: Slot Embedded Conductor Problem Sketch



Material Properties	Geometric Properties	Loading
$\mu_o = 4 \pi \times 10^{-7}$ H/m $\mu_r = 1.0$ $\rho = 1.724 \times 10^{-8}$ ohm-m	a = 6.45×10^{-3} m b = 8.55×10^{-3} m c = 8.45×10^{-3} m d = 18.85×10^{-3} m e = 8.95×10^{-3} m	I = 1.0 A ω = 45 Hz

Analysis Assumptions and Modeling Notes

The slot is assumed to be infinitely long, so end effects are ignored, allowing for a two-dimensional planar analysis. An assumption is made that the steel slot is infinitely permeable and thus is replaced with a flux-normal boundary condition. It is also assumed that the flux is contained within the slot, so a flux-parallel boundary condition is placed along the top of the slot.

The problem requires a coupled electromagnetic field analysis using the VOLT and AZ degrees of freedom. All VOLT DOFs within the copper conductor are coupled together to enforce the correct solution of the source current density component of the total current density. The eddy current component of the total current density is determined from the AZ DOF solution. The current may be applied to a single arbitrary node in the conductor, since they are all coupled together in VOLT.

The complex impedance of the slot is calculated in POST1 from the equation

$$Z = \frac{V}{I} = \frac{\rho J_s^{Re}}{I} + j\frac{\rho J_s^{Im}}{I}$$

where V = voltage drop, J_s^{Re} and J_s^{Im} are real and imaginary components of the source current density (obtained from the solution results in the database file). The real component of the impedance represents the AC resistance R_{ac} per unit length. The DC resistance per unit length R_{dc} is calculated as ρ/A. The AC/DC power loss ratio is calculated as R_{ac}/R_{dc}. The problem is solved first using PLANE13 elements then using PLANE233 elements.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
PLANE13			
J_s^{Re}	10183	10123.54	0.994
J_s^{Im}	27328	27337.36	1.000
Impedance (Ohm/m) x 10^{-6}	175 + j471	175 + j471	0.997, 1.001
Loss Ratio	2.33[1]	2.387	1.025
PLANE233			
J_s^{Re}	10183	10187.33	1.000
J_s^{Im}	27328	27326.18	1.000
Impedance (Ohm/m) x 10^{-6}	175 + j471	176 + j471	1.004, 1.00
Loss Ratio	2.33[1]	2.40	1.031

1. Target solution based on graphical estimate.

Figure 185.2: Flux Lines using PLANE13 Elements

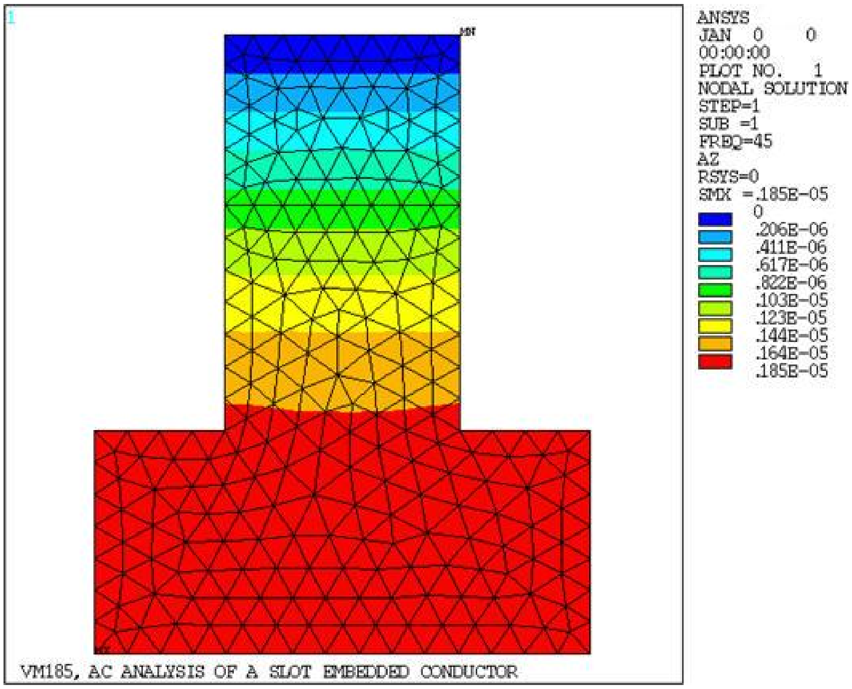


Figure 185.3: Total Current Density using PLANE13 Elements

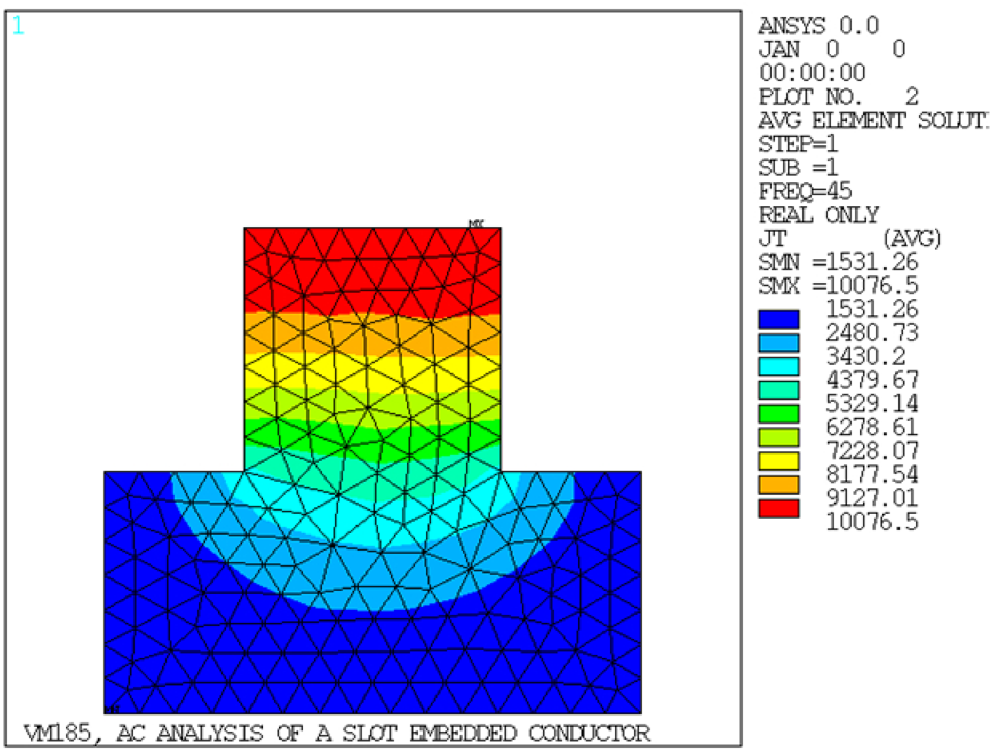


Figure 185.4: Eddy Current Density using PLANE13 Elements

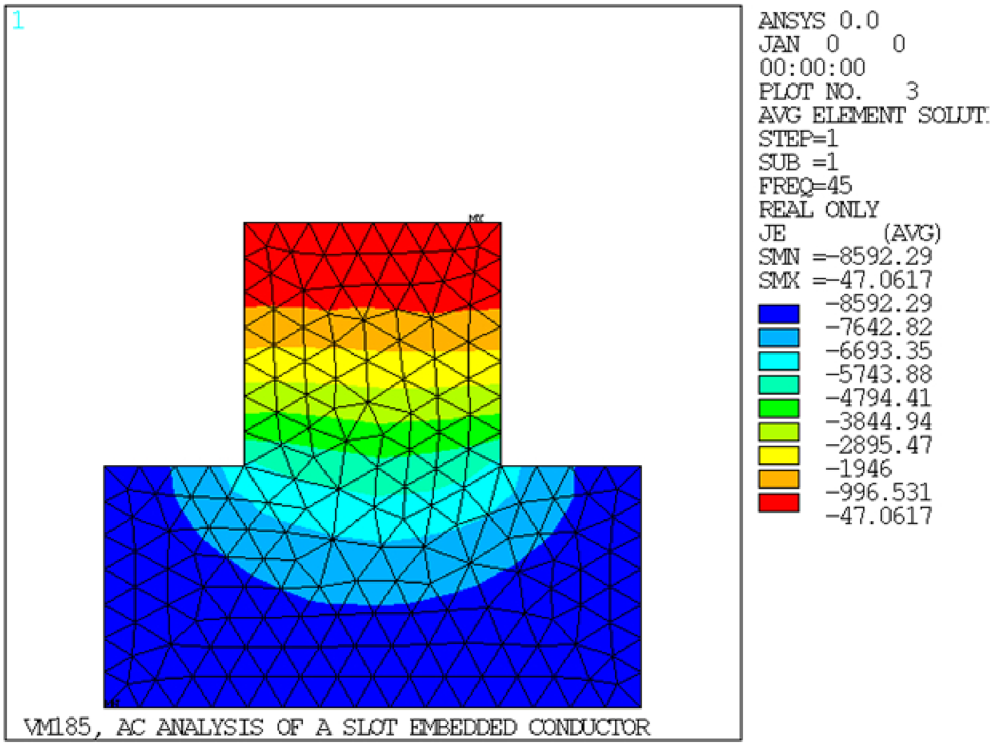
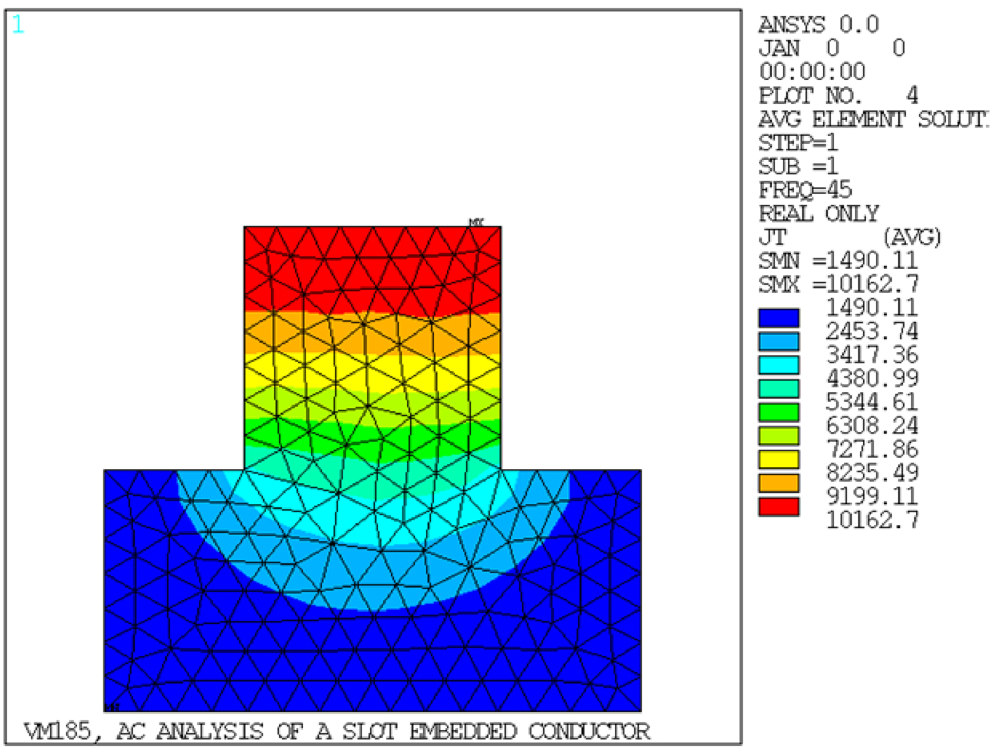


Figure 185.5: Eddy Current Density using PLANE233 Elements



VM186: Transient Analysis of a Slot Embedded Conductor

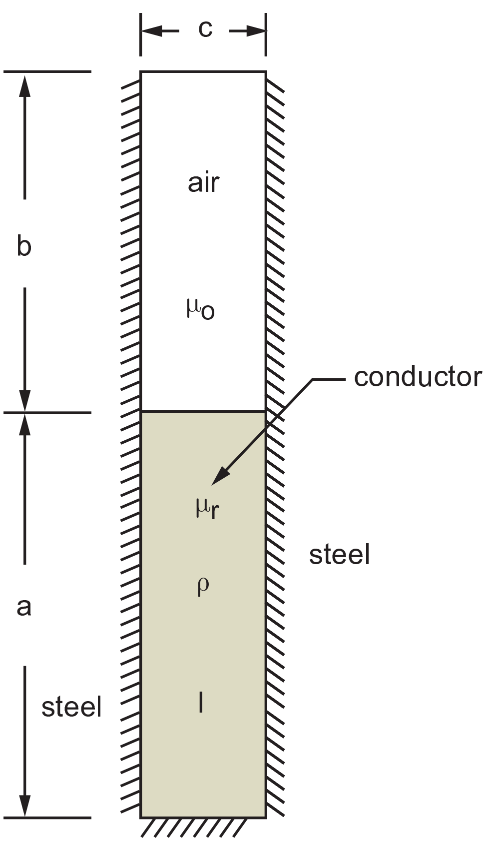
Overview

Reference:	A. Konrad, "Integrodifferential Finite Element Formulation of Two-Dimensional Steady-State Skin Effect Problems", *IEEE Trans. Magnetics*, Vol. MAG-18 No. 1, January 1982.
Analysis Type(s):	Transient Magnetic Field Analysis (**ANTYPE** = 4)
Element Type(s):	2-D Coupled-Field Solid Elements (PLANE13) 2-D 8-Node Electromagnetic Solid Elements (PLANE233)
Input Listing:	vm186.dat

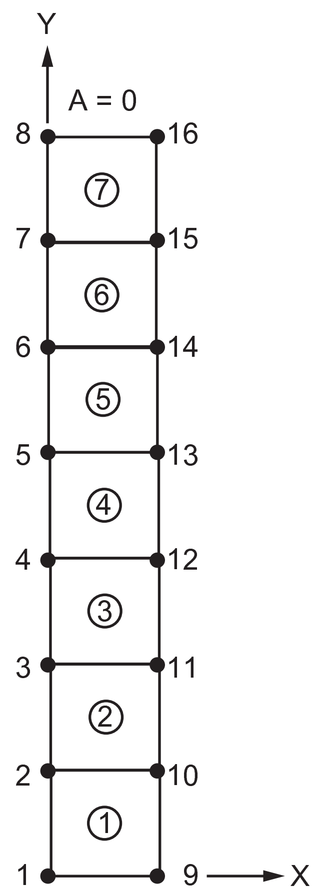
Test Case

A solid conductor embedded in the slot of a steel electric machine carries a sinusoidally varying current I. Determine the vector magnetic potential solution after 3/4 and 1 period of the oscillation frequency. In addition, display the time-varying behavior of the total input current, the source current component, and the eddy current component.

Figure 186.1: Slot Embedded Conductor Problem Sketch



Problem Sketch



Representative Finite Element Model

Material Properties	Geometric Properties	Loading
$\mu_o = 1.0$ $\mu_r = 1.0$ $\rho = 1.0$	a = 4 b = 3 c = 1	I = 4 A ω = 1 rad/sec

Analysis Assumptions and Modeling Notes

The slot is assumed to be infinitely long so that end effects are ignored, allowing for a two-dimensional planar analysis. An assumption is made that the steel containing the slot is infinitely permeable and so is replaced with a flux-normal boundary condition. It is also assumed that the flux is contained within the slot, so a flux-parallel boundary condition is placed along the top of the slot. The problem is stated in non-dimensional terms with properties given as unit values to match the reference.

The problem requires a coupled electromagnetic field analysis using the VOLT and AZ degrees of freedom. All VOLT DOF's within the conductor are coupled together to enforce the correct solution of the source current density component of the total current density. The eddy current component of the total current density is determined from the AZ DOF solution. The current is applied to a single arbitrary node in the conductor, since they are all coupled together in VOLT.

An initial solution is performed at a very small time step of 1×10^{-8} sec to establish a null field solution. Since no nonlinear properties are present, the **NEQIT** command is set to 1.0, suppressing equilibrium iterations at each time point. Eighty-one load steps are set up at constant time increments to accurately model the time-varying field solution. The Jacobian solver option is arbitrarily chosen.

PLANE13 elements can be used to output the eddy (IE), source (IS), and total current (IT), but PLANE233 can only output the total current (IT).

Results Comparison

Vector Potential	Target	Mechanical APDL	Ratio
PLANE13			
@ node 1 (t = 3pi/2)	-15.18	-15.03	0.990
@ node 4 (t = 3pi/2)	-14.68	-14.66	0.998
@ node 7 (t = 3pi/2)	-4.00	-4.00	1.00
@ node 1 (t = 2pi)	-3.26	-3.21	0.985
@ node 4 (t = 2pi)	-0.92	-0.91	0.994
@ node 7 (t = 2pi)	0	0	1.000
PLANE233			
@ node 1 (t = 3pi/2)	-15.18	-15.03	0.990
@ node 4 (t = 3pi/2)	-14.68	-14.66	0.998
@ node 7 (t = 3pi/2)	-4.00	-4.00	1.00
@ node 1 (t = 2pi)	-3.26	-3.21	0.985
@ node 4 (t = 2pi)	-0.92	-0.91	0.994
@ node 7 (t = 2pi)	0	0	1.000

Figure 186.2: Eddy, Source and Total Current using PLANE13 Elements

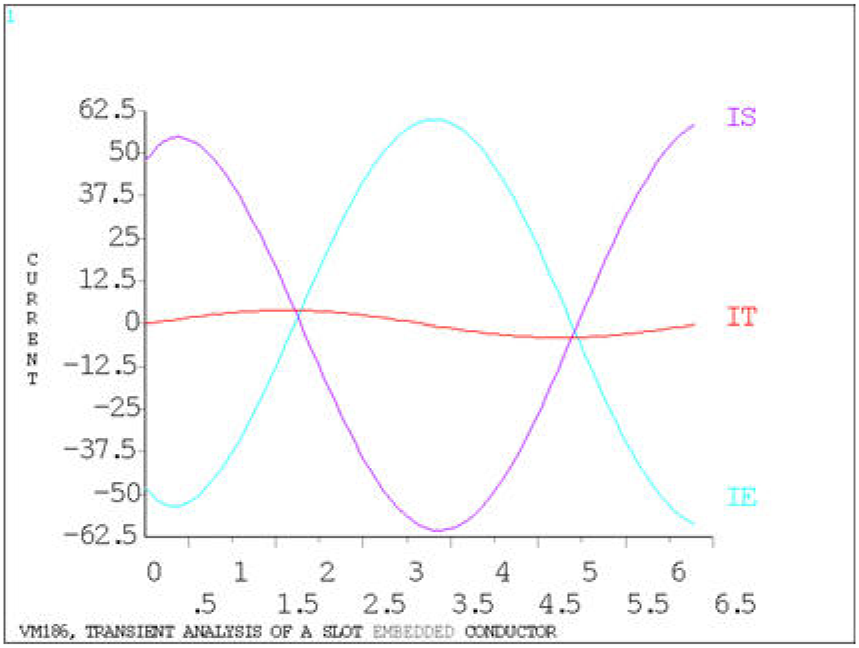
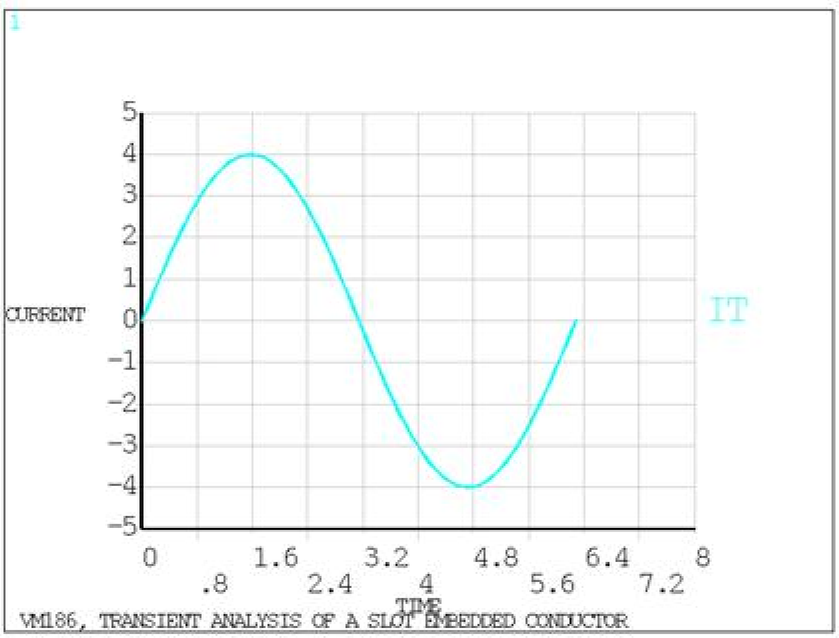


Figure 186.3: Total Current using PLANE233 Elements



VM187: Bending of a Curved Beam

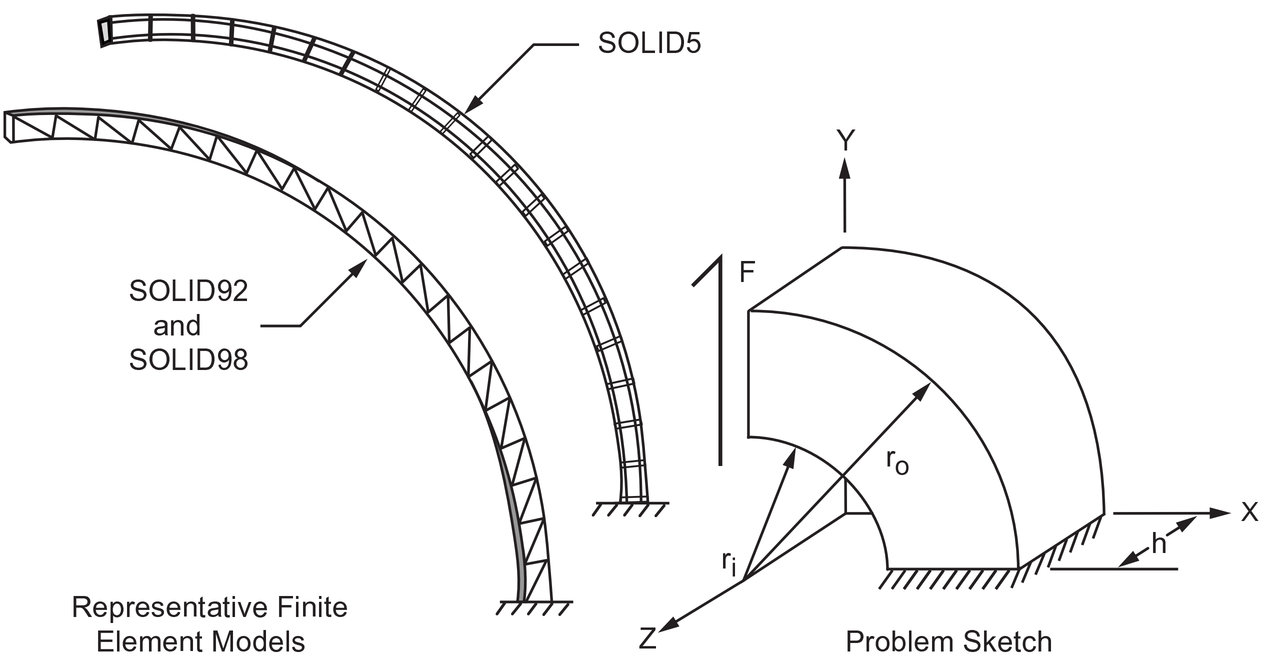
Overview

Reference:	R. J. Roark, *Formulas for Stress and Strain*, 4th Edition, McGraw-Hill Book Co., Inc., New York, NY, 1965, pg. 166, example.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Coupled-Field Solid Elements (SOLID5) 3-D 10-Node Tetrahedral Structural Solid Elements (SOLID92) Tetrahedral Coupled-Field Solid Elements (SOLID98) 3-D 10-Node Tetrahedral Structural Solid Elements (SOLID187)
Input Listing:	vm187.dat

Test Case

A curved beam spans a 90° arc as shown. A shear load F is applied to the top end while the bottom end is built-in. Determine the deflection d at the free end.

Figure 187.1: Bending of a Curved Beam Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 10 \times 10^6$ psi $\upsilon = 0.25$	$r_i = 4.12$ in $r_o = 4.32$ in $h = 0.1$ in	F = 1 lb

Analysis Assumptions and Modeling Notes

The problem is solved in four different ways:

- using Coupled-Field Solid Elements (SOLID5)

- using Tetrahedral Solid Elements (SOLID92)
- using Tetrahedral Coupled-Field Solid Elements (SOLID98)
- using Tetrahedral Solid Elements (SOLID187)

For the tetrahedral elements, the nodes at the free end are coupled and the shear force applied to the prime node.

Postprocessing is used to directly obtain the difference between the target solution and the ANSYS results in the form of a ratio.

Results Comparison

	Target	Mechanical APDL	Ratio
Deflection, in (SOLID5)	0.08854	0.088136	0.995
Deflection, in (SOLID92)	0.08854	0.088333	0.998
Deflection, in (SOLID98)	0.08854	0.088333	0.998
Deflection, in (SOLID187)	0.08854	0.088333	0.998

VM188: Force Calculation on a Current Carrying Conductor

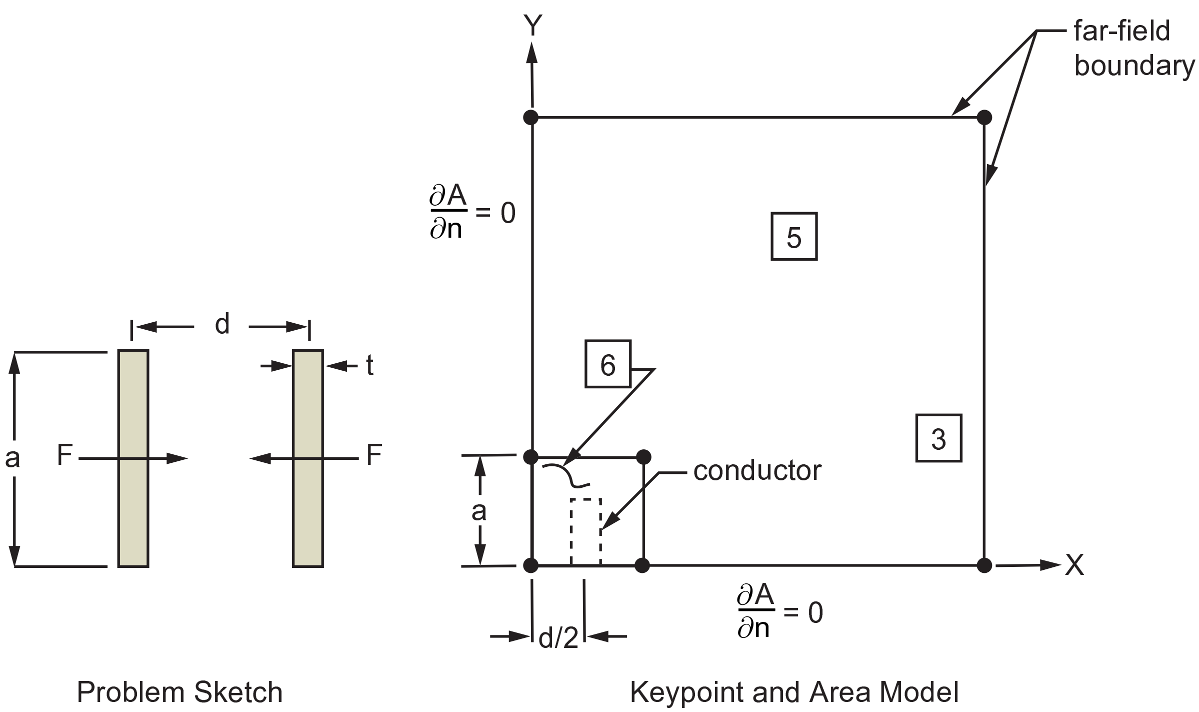
Overview

Reference:	F. C. Moon, *Magneto-Solid Mechanics*, John Wiley and Sons, Inc., New York, NY, 1984, pg. 418.
Analysis Type(s):	Static Magnetic Field Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 8-Node Magnetic Solid Elements (PLANE53) 2-D 8-Node Electromagnetic Solid Elements (PLANE233) 2-D Infinite Boundary Elements (INFIN9)
Input Listing:	vm188.dat

Test Case

Two rectangular conductors, separated by centerline-to-centerline distance d, are carrying equal out-of-plane currents, I. Determine the resulting force F on the conductors.

Figure 188.1: Current Carrying Conductor Problem Sketch



Material Properties	Geometric Properties	Loading
$\mu_r = 1$ $\mu_o = 4\pi \times 10^{-7}$ H/m	d = .010 m a = .012 m t = .002 m	I = 24 A

Analysis Assumptions and Modeling Notes

Due to the symmetric nature of the magnetic field, a 1/4 symmetry model is generated. The far-field boundaries are meshed with an infinite boundary element to model the unbounded field behavior. The lower order infinite elements are meshed first so that the higher order plane elements will appropriately drop their midside nodes during meshing.

Lorentz forces $(\bar{J} \times \bar{B})$ in the conductor are calculated for each element and are available from the post data file. In PLANE53, virtual work forces are also calculated via specification of virtual displacements (MVDI). A third method of obtaining the force on a body is through the use of the Maxwell stress tensor. Forces in this manner are obtained from a surface integral (line integral in 2-D analysis) defined using the path calculation capabilities in POST1 and macro FOR2-D. Flux lines are displayed via the macro PLF2-D.

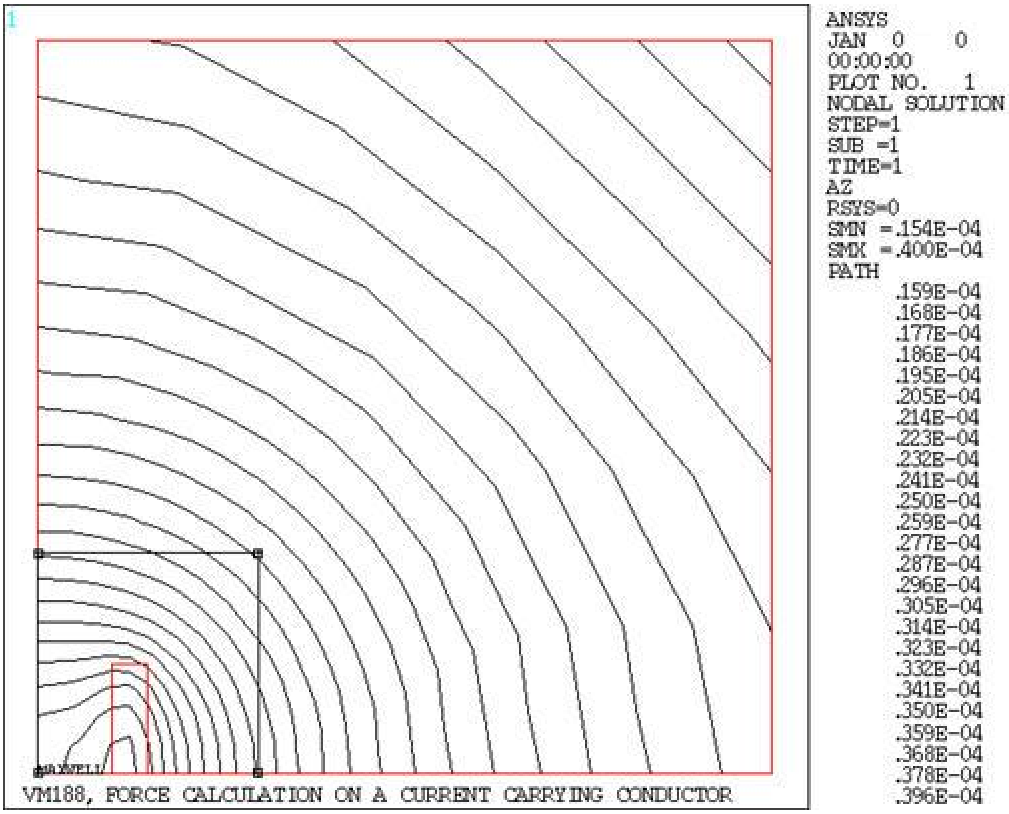
The applied source current density is calculated as I/at = 2A/(12 x 2) x 10^{-6} m^2 = 1 x 10^6 A/m^2.

To ensure that a surface integral for force calculations will yield acceptable results, a fine mesh is used for area 6 in the region of the surface integral path.

Results Comparison

	Target	Mechanical APDL	Ratio
PLANE53			
F, N/m (Lorentz)	-0.009684	-0.009719	1.004
F, N/m (Maxwell)	-0.009684	-0.009676	0.999
F, N/m (Virtual Work)	-0.009684	-0.009719	1.004
PLANE233			
F, N/m (Lorentz)	-0.009684	-0.009718	1.003
F, N/m (Maxwell)	-0.009684	-0.009718	1.003

Figure 188.2: Magnetic Flux Lines Near Conductor using PLANE53 elements



Path of the integral is highlighted.

VM189: Stress Relaxation of a Chloroprene Rubber

Overview

Reference:	Dal, H. et al. "Bergstrom-Boyce model for nonlinear finite rubber viscoelasticity : theoretical aspects and algorithmic treatment for the FE method". *Computational Mechanics*. 2009, 44: 809-823
Analysis Type(s):	Static (**ANTYPE** = 0)
Element Type(s):	3-D Structural Solid Elements (SOLID185)
Input Listing:	vm189.dat

Test Case

A uniaxial compression test with intermittent relaxation time is performed on a block modeled with Chloroprene rubber. The block is subjected to true strain rates of $\dot{\varepsilon} = -0.002s^{-1}$ and $\dot{\varepsilon} = -0.1s^{-1}$ with 120s relaxation time at $\varepsilon = -0.3$ and $\varepsilon = -0.6$, respectively. Figure 189.2: Time History of Displacement Loadings (p. 510) shows the loading history. The true stress computed for load steps 1,3,5,6 and 8 are compared against the reference solution.

Figure 189.1: Uniaxial Loading Problem Sketch

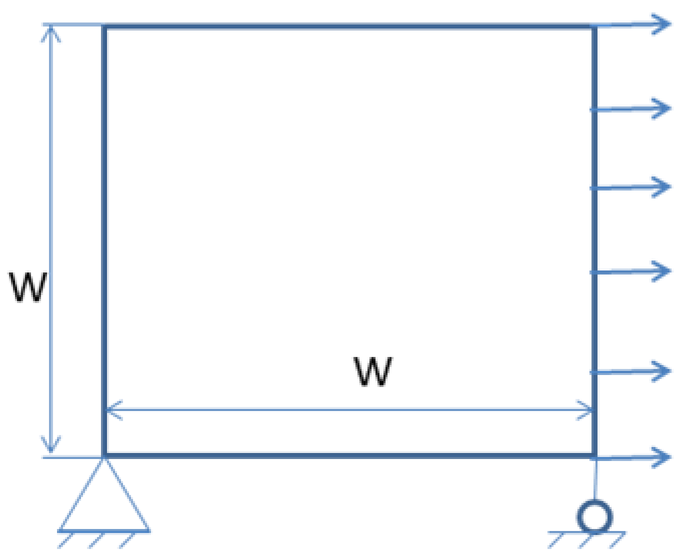
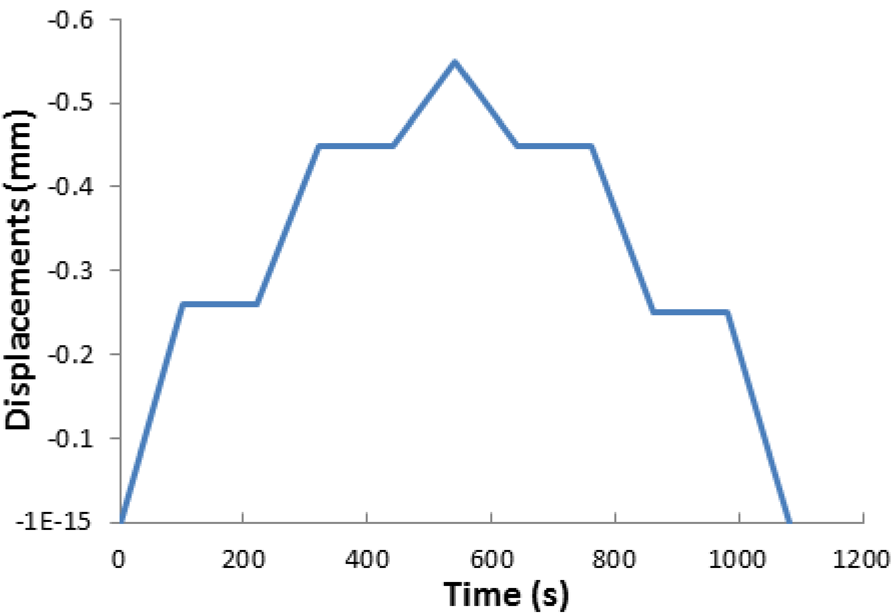


Figure 189.2: Time History of Displacement Loadings



Material Properties	Geometric Properties	Loading
Parameters for Bergstrom-Boyce model: μ_0=0.60 MPa N_0=8 μ_1=0.96MPa N_1=8 $^{3}{}_0 / \dot{\tau}^{m}_{base} = 7s^{-1}Mpa^{-m}$ c=-1 m=4	W=1mm	1. Compressed 0.26mm within 100s 2. Relaxation 120s 3. Compressed to 0.45mm within 100s 4. Relaxation 120s 5. Compressed to 0.55mm within 100s 6. Returns to displacement -0.45mm within 100s 7. Relaxation 120s 8. Returns to displacement -0.26mm within 100s 9. Relaxation 120s 10. Returns to initial state within 100s

Analysis Assumptions and Modeling Notes

The problem is solved using 3-D SOLID185 elements. The Bergstrom-Boyce material is defined by **TB**,BB. The block is subjected to one cycle of uniaxial compression testing with intermittent relaxation time. The stress for load steps 1,3,5,6 and 8 are acquired using ***GET** in **/POST1**.

Results Comparison

	Mechanical APDL	Target	Ratio
Set 1	-0.638 MPa	-0.650 MPa	0.981
Set 3	-1.191 MPa	-1.160 MPa	1.026
Set 5	-1.583 MPa	-1.580 MPa	1.002
Set 6	-0.859 MPa	-0.840 MPa	1.022
Set8	-0.392 MPa	-0.400 MPa	0.981

VM190: Ferromagnetic Inductor

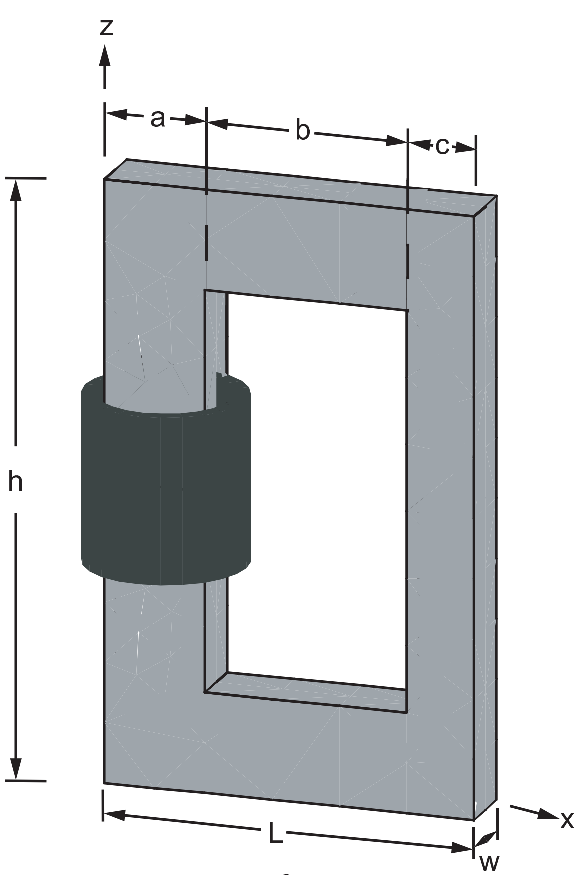
Overview

Reference:	S. J. Chapman, *Electric Machinery Fundamentals*, McGraw-Hill Book Co., Inc., New York, NY, 1985, pg. 14, ex. 1-1.
Analysis Type(s):	Static Magnetic Field Analysis (**ANTYPE** = 0)
Element Type(s):	Tetrahedral Coupled-Field Solid Elements (SOLID98) 3-D Infinite Boundary Elements (INFIN47) Current Source Elements (SOURC36)
Input Listing:	vm190.dat

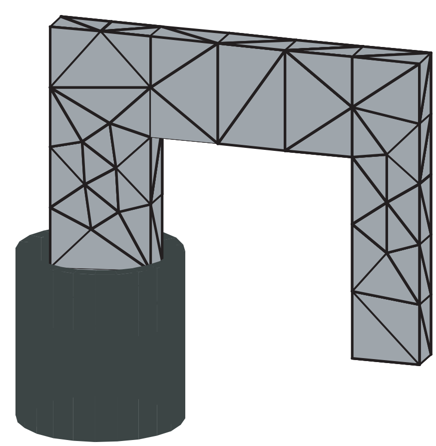
Test Case

A ferromagnetic core is wound with a 200-turn coil wrapped around one leg. Determine the mmf drop in the iron core for a coil current of 1 ampere.

Figure 190.1: Ferromagnetic Inductor Problem Sketch



Problem Sketch



Representative Finite Element Model (excluding air)

Material Properties	Geometric Properties	Loading
u_r = 2500 (iron)	h = 60 cm L = 55 cm	I = 1.0 Ampere

Material Properties	Geometric Properties	Loading
	w = 10 cm a = 15 cm b = 30 cm c = 10 cm	

Analysis Assumptions and Modeling Notes

Since the core material has finite permeability air is modelled to a small distance away from the core. The open boundary is modelled with an infinite surface element at the edge of the air region. The model employs 1/4 symmetry (about the Y and Z planes). The current source is modelled by a coil primitive. Dimensions of the coil are arbitrarily chosen since they have no bearing on the mmf calculations.

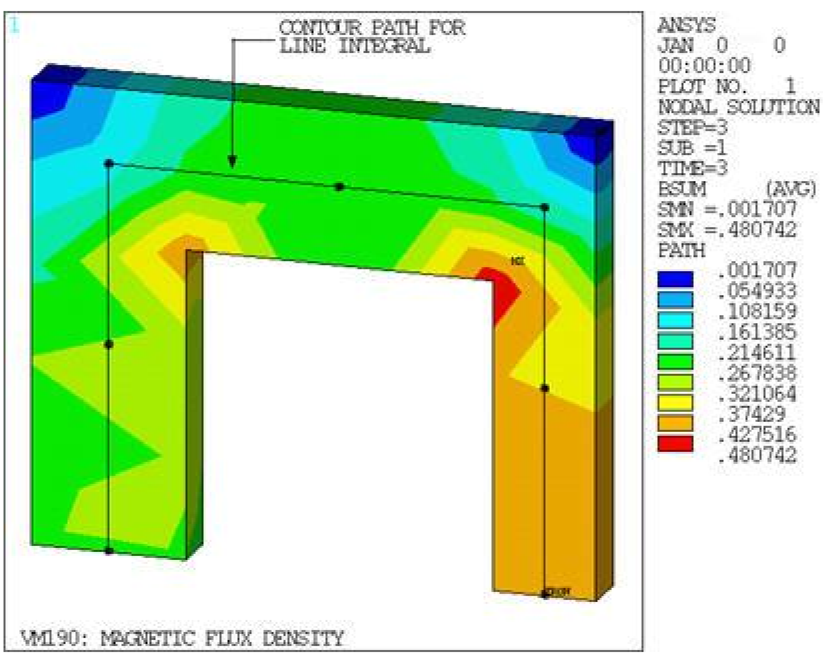
The iron core, linked by a coil, has no air-gap, hence a multiply-connected domain exists requiring the use of the Generalized Scalar Potential (GSP) formulation. The GSP strategy requires three solution steps, controlled by the **MAGOPT** command.

The mmf drop in the iron is calculated by a line integral around the iron core. According to Ampere's law, $\int H \bullet d\ell = I$, where H is the field intensity, and I is the enclosed current (or mmf drop). The integral is set up and calculated using the path logic in POST1.

Results Comparison

	Target	Mechanical APDL	Ratio
mmf drop (A-t)	200	198.85	0.994

Figure 190.2: Magnetic Flux Density



VM191: Hertz Contact Between Two Cylinders

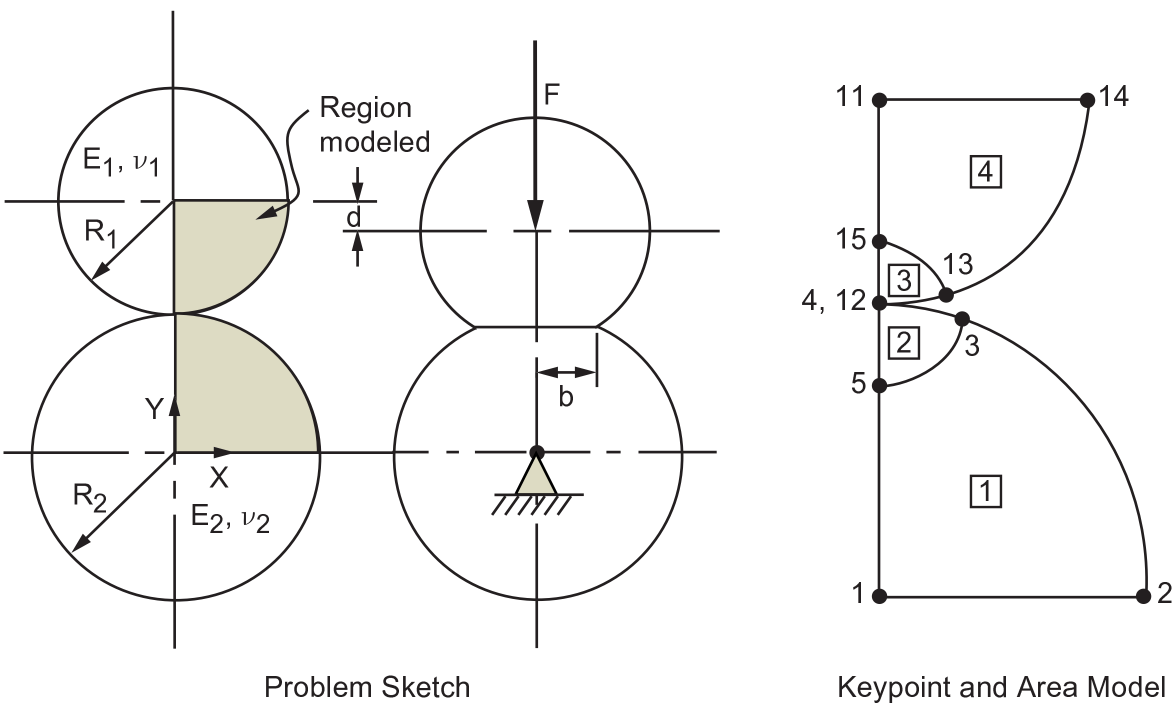
Overview

Reference:	N. Chandrasekaran, W. E. Haisler, R. E. Goforth, "Finite Element Analysis of Hertz Contact Problem with Friction", *Finite Elements in Analysis and Design*, Vol. 3, 1987, pp. 39-56.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D/3-D Node-to-Surface Contact Elements (CONTA175) 2-D Structural Solid Elements (PLANE182) 3-D Structural Solid Elements (SOLID185)
Input Listing:	vm191.dat

Test Case

Two long cylinders of radii R_1 and R_2, in frictionless contact with their axes parallel to each other are pressed together with a force per unit length, F. Determine the semi-contact length b and the approach distance d.

Figure 191.1: Hertz Contact Between Two Cylinders Problem Sketch



Material Properties	Geometric Properties	Loading
Cylinder 1: E_1 = 30000 N/mm^2 ν_1 = 0.25 **Cylinder 2:** E_2 = 29120 N/mm^2	R_1 = 10 mm R_2 = 13 mm	F = 3200 N/mm

Material Properties	Geometric Properties	Loading
$\nu_2 = 0.3$		

Analysis Assumptions and Modeling Notes

Each analysis uses two load steps; in the first load step a small imposed displacement is used on the upper cylinder to engage contact, whereas in the second load step the imposed displacement is deleted and the force load is applied.

The problem is solved in four different ways:

Contact Algorithm: Augmented Lagrangian - KEYOPT(2) = 0

- 2-D analysis with PLANE182 and CONTA175
- 3-D analysis with SOLID185 and CONTA175

Contact Algorithm: Lagrange Multiplier - KEYOPT(2) = 3

- 2-D analysis with PLANE182 and CONTA175
- 3-D analysis with SOLID185 and CONTA175

Plane stress condition is modeled using a unit thickness slice through the cylinders. The region modeled is shown shaded in the problem sketch. The **ESURF** command is used to automatically generate the contact and target elements between "contactor" nodes on the upper cylinder and "target" nodes on the lower cylinder. The default value of contact stiffness FKN is chosen while performing a solution using Augmented Lagrangian contact algorithm (KEYOPT(2) = 0) whereas no contact stiffness input is required to be specified while performing a solution using Lagrange Multiplier contact algorithm (KEYOPT(2) = 3).

Results Comparison

		Target	Mechanical APDL	Ratio
CONTA175 - Algorithm: Augmented Lagrangian KEYOPT(2) = 0				
PLANE182	d,mm	-0.4181	-0.4183	1.000
	b,mm	1.20	1.1609	0.967
SOLID185	d,mm	-0.4181	-0.4191	1.002
	b,mm	1.20	1.1609	0.967
CONTA175 - Algorithm: Lagrange Multiplier KEYOPT(2) = 3				
PLANE182	d,mm	-0.4181	-0.4181	1.000
	b,mm	1.20	1.1609	0.967
SOLID185	d,mm	-0.4181	-0.4190	1.002
	b,mm	1.20	1.1609	0.967

VM192: Cooling of a Billet by Radiation

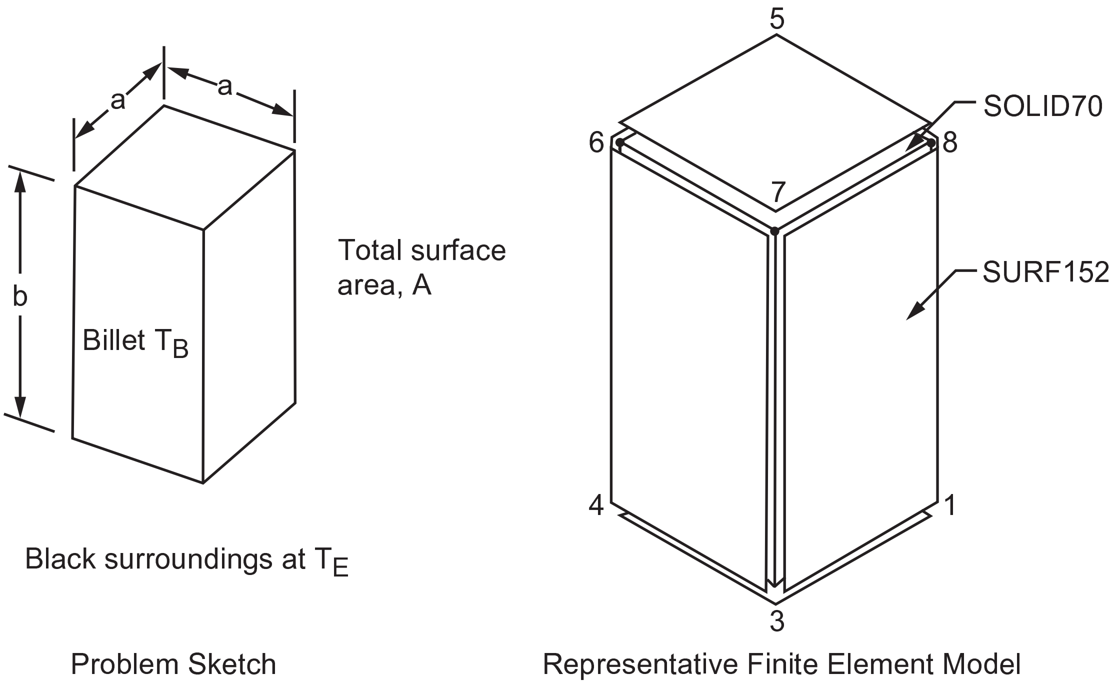
Overview

Reference:	R. Siegel, J. R. Howell, *Thermal Radiation Heat Transfer*, 2nd Edition, Hemisphere Publishing Corporation, 1981, pg. 229, problem 21.
Analysis Type(s):	Transient Analysis (**ANTYPE** = 4)
Element Type(s):	3-D Thermal Solid Elements (SOLID70) 3-D Thermal Surface Effect Elements (SURF152)
Input Listing:	vm192.dat

Test Case

A carbon steel billet is initially at a temperature T_B and is supported in such a manner that it loses heat by radiation from all its surfaces to surroundings at temperature T_E. Determine the temperature T_B of the billet at the end of 3.7 hours.

Figure 192.1: Cooling of a Billet by Radiation Problem Sketch



Material Properties	Geometric Properties	Loading
C = 0.11 Btu/lb-°R ρ = 487.5 lb/ft^3 ε = emissivity = 1.0 Stefan-Boltzmann constant = 0.1712x10^{-8} Btu/hr-ft^2-R^4	a = 2 ft b = 4 ft	T_E = 70°F (530°R) T_B = 2000°R (at t = 0)

Analysis of Assumptions and Modeling Notes

The billet is modeled using a single SOLID70 element overlaid with a SURF152 element on each of its faces. The surface elements have a common extra node representing the surrounding space. An arbitrary value is selected for the billet conductivity. The form factor from the billet to surrounding space is input as unity.

Results Comparison

Time = 3.7 hr	Target	Mechanical APDL	Ratio
T_B, °R	1000.0	1002.5	1.002

VM193: Adaptive Analysis of 2-D Heat Transfer with Convection

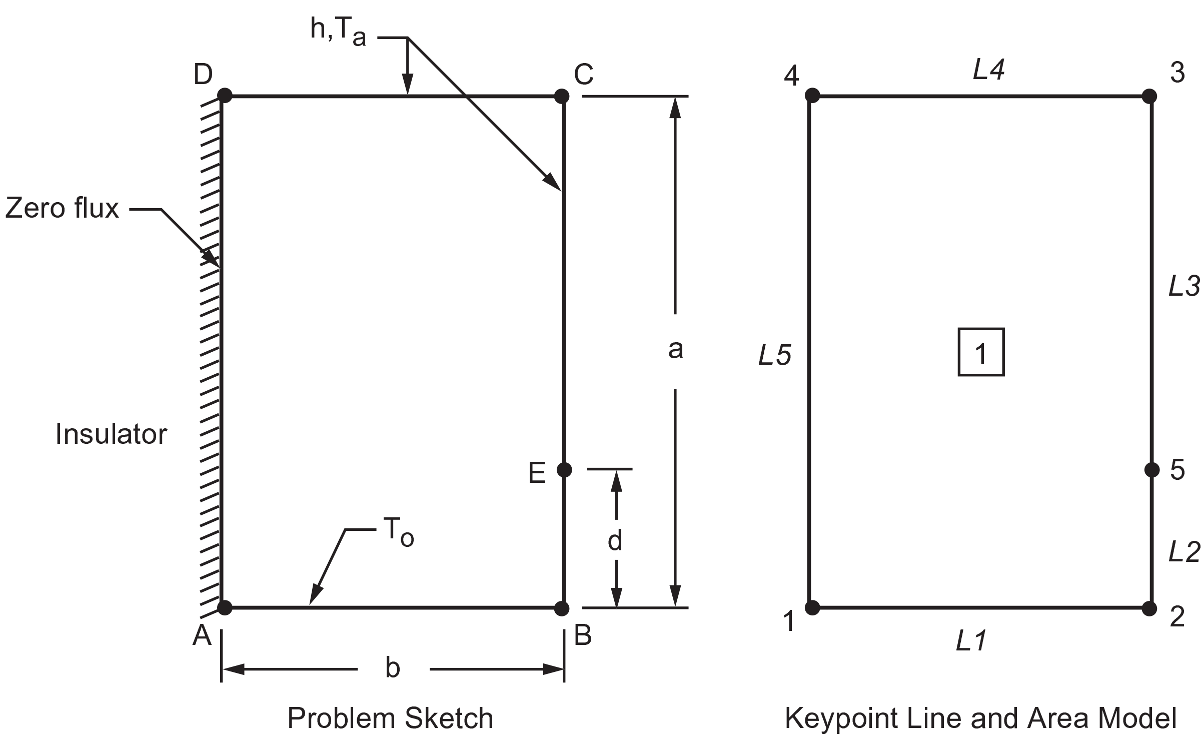
Overview

Reference:	NAFEMS, "The Standard NAFEMS Benchmarks", Rev. No. TSNB, National Engineering Laboratory, E. Kilbride, Glasgow, UK, August, 1989, Test No. T4.
Analysis Type(s):	Steady-state Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Thermal Solid Elements (PLANE55)
Input Listing:	vm193.dat

Test Case

Determine the temperature at point E in a long slab of rectangular cross-section subjected to the thermal loads shown below.

Figure 193.1: 2–D Heat Transfer with Convection Problem Sketch



Material Properties	Geometric Properties	Loading
$k = 52.0$ W/m-°C $h = 750.0$ W/m^2-°C	$a = 1.0$ m $b = 0.6$ m $d = 0.2$ m	$T_o = 100$°C $T_a = 0$°C

Analysis Assumptions and Modeling Notes

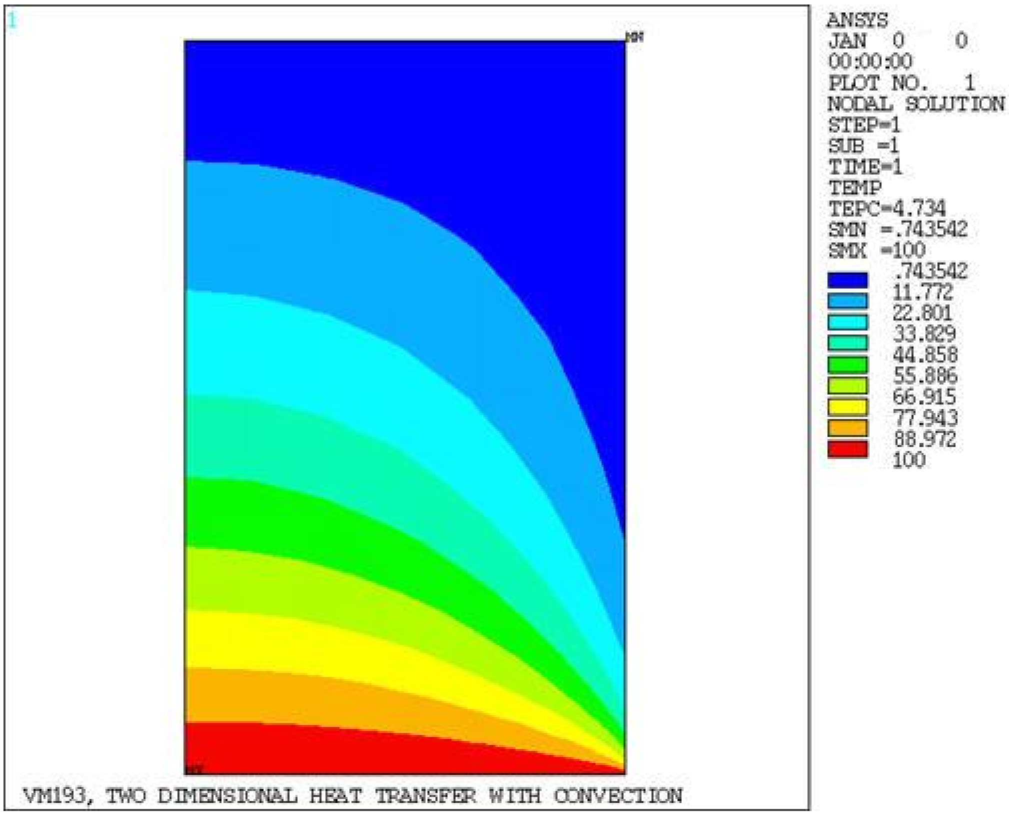
Due to the conflicting boundary conditions, this problem has a singularity at point B, leading to a high gradient of temperature from point B to E. The adaptive meshing solution technique is used to obtain the solution to this problem within 10 adaptive loops such that the error in the thermal energy norm over the entire model is within 5%.

The model is created using solid model entities. A keypoint is specified at target location E to ensure that a node is created at that location. All boundary conditions are applied on the solid model. The ADAPT macro is used to invoke the automatic adaptive meshing procedure.

Results Comparison

	Target	Mechanical APDL	Ratio
T, °C at point E	18.3	18.2	0.995

Figure 193.2: Temperature Contour Plot



VM194: Element Birth/Death in a Fixed Bar

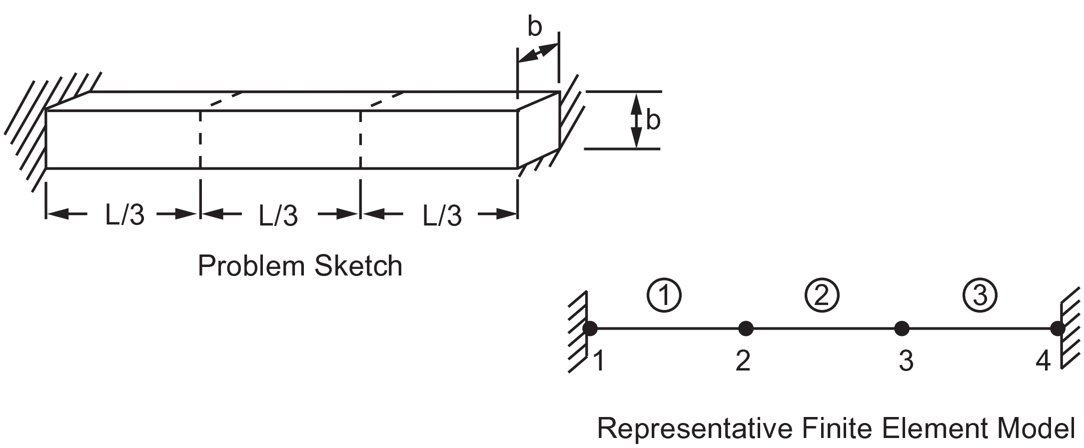
Overview

Reference:	Any standard mechanics of materials text
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Spar (or Truss) LINK180
Input Listing:	vm194.dat

Test Case

A bar of uniform cross-section, fixed at both ends and subjected to a uniform thermal load (ΔT) has its center third removed. This is followed by replacing the removed part in a "strain-free" condition and then removing the uniform thermal load. Determine the axial stresses and the thermal strains in the three sections of the bar at the end of this sequence of loading operations.

Figure 194.1: Fixed Bar with Thermal Loading Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi α = 0.00005 in/in-°F	L = 10 in b = 1 in	Load Step 1: ΔT = 100°F Load Step 2: Elem 2 dead Load Step 3: Elem 2 alive Load Step 4: ΔT = 0°F

Analysis Assumptions and Modeling Notes

The REFT material property is used to model "rebirth" of the "dead" element such that no thermal strains exist at birth. This is achieved by specifying the value of REFT equal to the uniform temperature of the bar (100°F). Removing the thermal load in the subsequent final load step therefore results in relieving the thermal strains in elements 1 and 3. Element 2 on the other hand, experiences a thermal load of ΔT = -100°F resulting in a negative thermal strain.

Results Comparison

Load Step No. 4	Target	Mechanical APDL[1]	Ratio
$Stress_x$, psi	150,000[1]	150,000	1.000
$Strain_{th}$, (elem1, 3)	0.0	0.0	-
$Strain_{th}$, (elem 2)	-0.005	-0.005	1.000

1. Uniform for all elements.

VM195: Toggle Mechanism

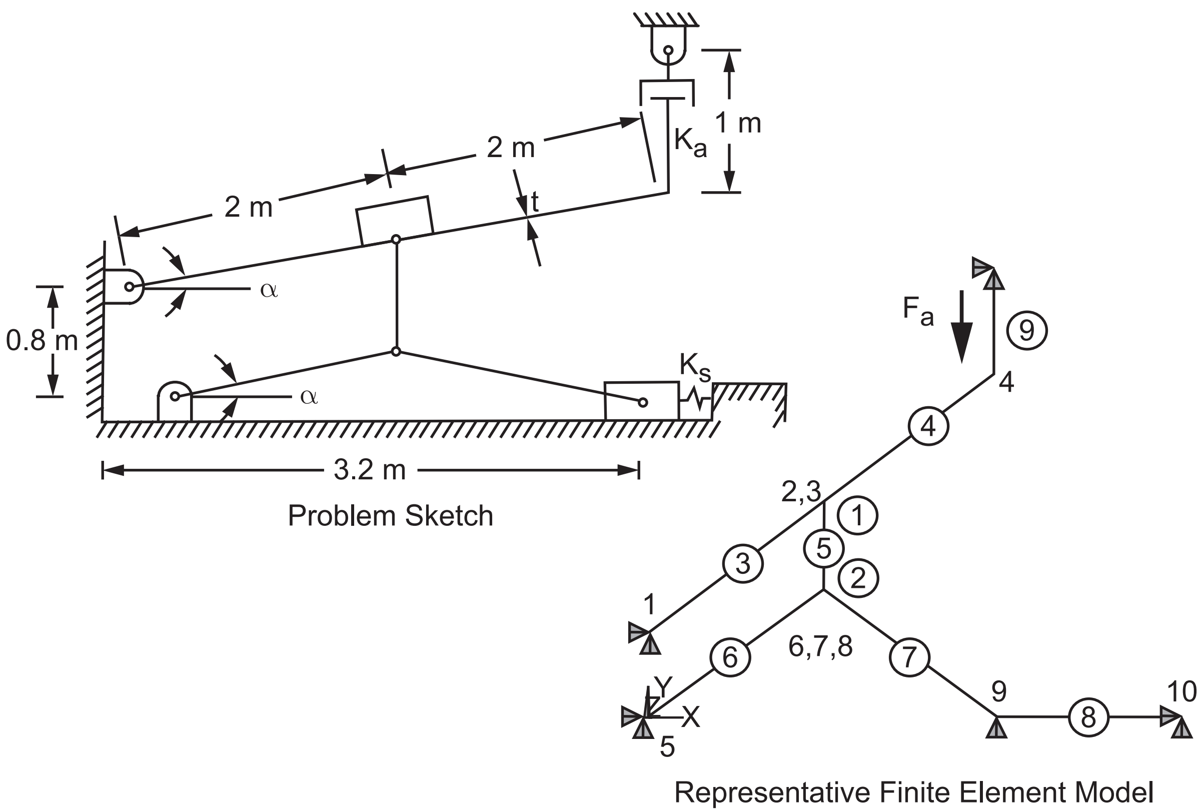
Overview

Reference:	G. H. Martin, *Kinematics and Dynamics of Machines*, 2nd Edition, McGraw-Hill Book Co., Inc., New York, NY, 1982, pp. 55-56, fig. 3-22.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Multipoint constraint Revolute Joint Elements (MPC184) 3-D 2 Node Beam (BEAM188) Spring-Damper Elements (COMBIN14) Linear Actuator Elements (LINK11)
Input Listing:	vm195.dat

Test Case

Determine the maximum force (F_{max}) of a toggle mechanism acting upon a resisting spring.

Figure 195.1: Toggle Mechanism Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 1 \times 10^9$ N/m^2	$t = 0.1$ m $K_s = 166.67$ N/m $K_a = 100/d$ N/m $\alpha = 36.87°$	$F_a = 100$ N

Analysis Assumptions and Modeling Notes

This beam is modeled with a square cross-section (width/height is set to 0.1m).

A linear actuator is used to apply a force, F_a, and move the toggle mechanism. The actuator force is increased by 2% to ensure complete mechanism motion. The actuator must expand a distance, d = 2.4928 m, to move the mechanism to the maximum force position. Either a force or a displacement could have been applied with the actuator.

The maximum force exerted by the mechanism upon the spring occurs when the lower links are colinear and parallel to the input lever. The revolute joint connecting the two lower links locks up when a stop engages, after a rotation of 2 α degrees, to simulate the self-locking behavior of the mechanism.

Results Comparison

	Target	Mechanical APDL	Ratio
F_{max}	-133.33	-133.32[1]	1.000
UY, Node 4	-2.40	-2.40	1.001
UX, Node 9	0.80	0.80	1.000

1. Spring force in element 10 (COMBIN14)

VM196: Counter-Balanced Loads on a Block

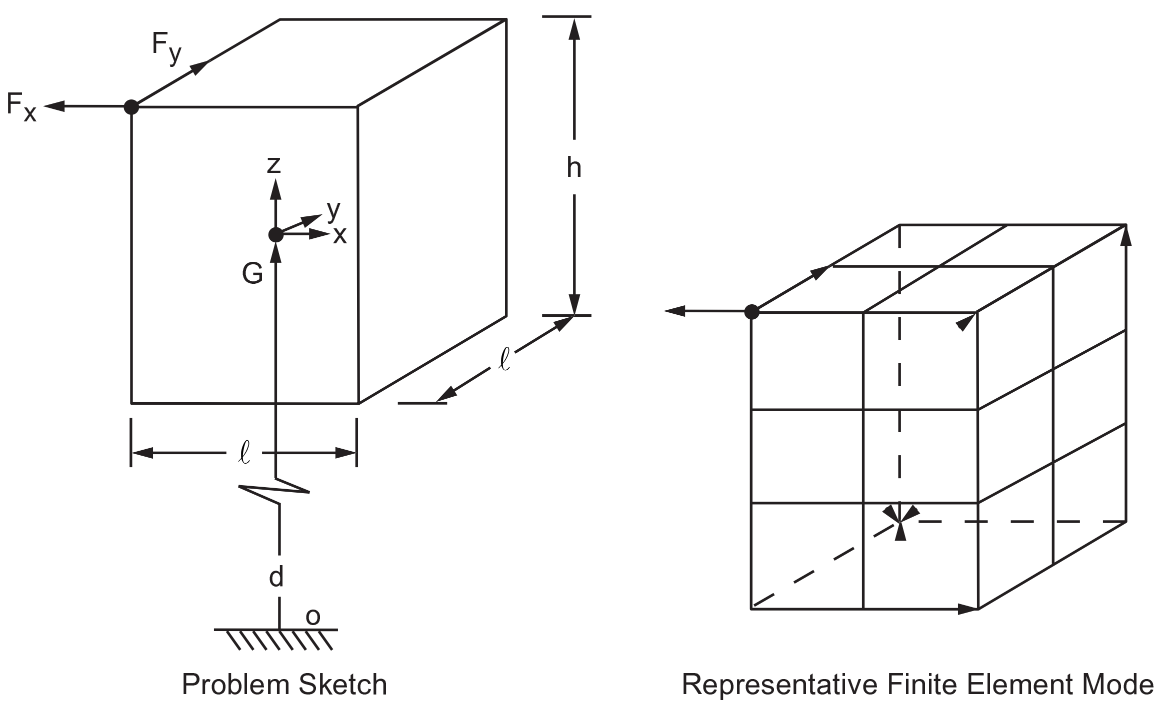
Overview

Reference:	Any basic mechanics text
Analysis Type(s):	Static Analysis (**ANTYPE** = 0), Inertia Relief
Element Type(s):	3-D Structural Solid Elements (SOLID45) 3-D Structural Solid Elements (SOLID185)
Input Listing:	vm196.dat

Test Case

Determine the free-body moments (MX, MY, MZ) about the origin and the rotational accelerations (ω_x, ω_y, ω_z) at the center of mass of an aluminum block due to the forces FX and FY shown.

Figure 196.1: Counter-Balanced Loads on a Block Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 70 \times 10^9$ N/m^2 $\rho = 2712$ kg/m^3	h = 3 m ℓ = 2 m d = 300 m	FX = -2000 N FY = 3000 N

Analysis Assumptions and Modeling Notes

The problem is solved in two different ways:

- using 3-D solid elements (SOLID45)
- using 3-D solid elements (SOLID185)

The block must be constrained such that no rigid body motions occur. In a 3-D structure, six DOF must be constrained to prevent free-body motion by translation or rotation. The inertia relief algorithm is used to calculate accelerations to counterbalance the applied loads resulting in net zero values for the sum of the reaction forces.

Results Comparison

	Target	Mechanical APDL	Ratio
SOLID45			
MX (N-m)	-909000	-909000	1.000
MY (N-m)	-606000	-606000	1.000
MZ (N-m)	-5000	-5000	1.000
Rotational accelerations$_x$ (rad/sec^2)	-0.12764	-0.12764	1.000
Rotational accelerations$_y$ (rad/sec^2)	-0.085092	-0.085092	1.000
Rotational accelerations$_z$ (rad/sec^2)	-0.23046	-0.23046	1.000
SOLID185			
MX (N-m)	-909000	-909000	1.000
MY (N-m)	-606000	-606000	1.000
MZ (N-m)	-5000	-5000	1.000
Rotational accelerations$_x$ (rad/sec^2)	-0.12764	-0.12764	1.000
Rotational accelerations$_y$ (rad/sec^2)	-0.085092	-0.085092	1.000
Rotational accelerations$_z$ (rad/sec^2)	-0.23046	-0.23046	1.000

VM197: IGES Write/Read for Thick-Walled Cylinder

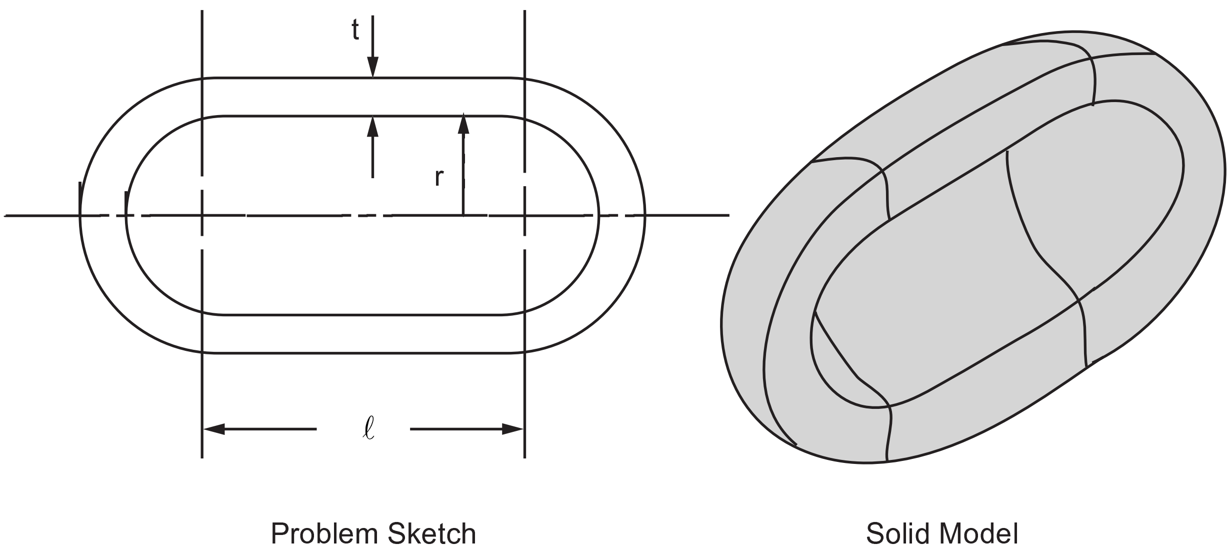
Overview

Reference:	Any basic geometry text
Analysis Type(s):	Geometric Primitives, IGES Write/Read
Element Type(s):	None
Input Listing:	vm197.dat

Test Case

Create a thick-walled cylinder with spherical end caps using geometric primitives. Write the geometry to an IGES file. Read the geometry back in from the IGES files. Validate the correctness of the geometry by examining its volume.

Figure 197.1: Thick-Walled Cylinder Problem Sketch



Geometric Properties
r = 20 in t = 10 in ℓ = 50 in

Analysis Assumptions and Modeling Notes

Only one half of the model is created. The volume is obtained with the ***GET** command and is compared to the theoretical volume which is calculated using parameters.

Results Comparison

	Target	Mechanical APDL	Ratio
Volume	79063.	79068.	1.000

VM198: Large Strain In-plane Torsion Test

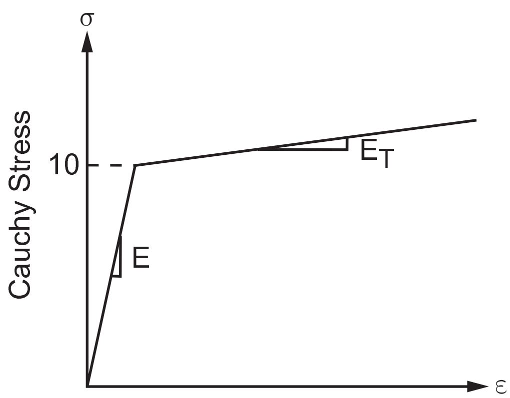
Overview

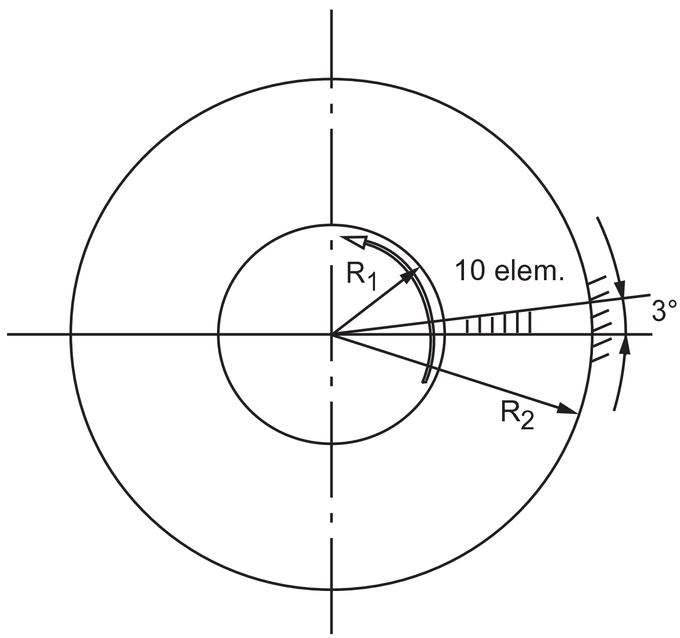
Reference:	J. C. Nagtegaal, J. E. DeJong, "Some Computational Aspects of Elastic-Plastic Strain Analysis", *Intl J. of Numerical Methods in Engineering*, Vol. 17, 1981, pp. 15–41.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4-Node Structural Solid Elements (PLANE182) 2-D 8-Node Structural Solid Elements (PLANE183) 3-D 8-Node Structural Solid Elements (SOLID185)
Input Listing:	vm198.dat

Test Case

A hollow, thick-walled, long cylinder made of an elastoplastic material is under an in-plane torsional loading which causes the inner surface of the cylinder to undergo a rotation of 60°. Find the maximum shear stress (τ_{max}) developed at the inner surface at the end of loading.

Figure 198.1: Large Strain In-plane Problem Sketch





Material Properties	Geometric Properties	Loading
E = 7200 psi μ = 0.33 σ_{yp} = 10 psi E_T = 40 psi	R_1 = 10 in R_2 = 20 in	Θ = 60° At nodes on the inner surface in 10 equal load steps along the circumference

Analysis Assumptions and Modeling Notes

The problem is solved three times, each time with a different element type. The element types used are PLANE182 (2-D 4-node structural solid element), PLANE183 (2-D,8-node structural solid element), and SOLID185 (3-D 8-node structural solid element). The plasticity is modeled using the bilinear isotropic hardening rule.

The plane strain condition is assumed along the length of the cylinder. Due to the axisymmetric loading, only a small portion (3° span) of the cross-section is modeled each time using ten elements. Nodal rotations and displacement couplings are employed to ensure the circumferential symmetry in the deformed configuration.

To illustrate the dynamic substitution of a parameter value, an alphanumeric character parameter (element type name) is used in the **/TITLE** command. In addition, a character parameter for degrees of freedom is used in the **CP** commands and in the macro SOLD.

POST1 is used to obtain the displaced configuration at the end of loading. The maximum shear stress is computed from the solution results in POST26. In order to be consistent with the reference solution, the maximum shear stress in a negative direction is observed.

Results Comparison

		Target	**Mechanical APDL**	**Ratio**
PLANE182	Shear Stress$_{max}$, psi	-48.0	-46.5	0.969
PLANE183	Shear Stress$_{max}$, psi	-48.0	-45.9	0.956
SOLID185	Shear Stress$_{max}$, psi	-48.0	-46.3	0.964

Figure 198.2: Typical Element Deformation Display Using PLANE182 Elements

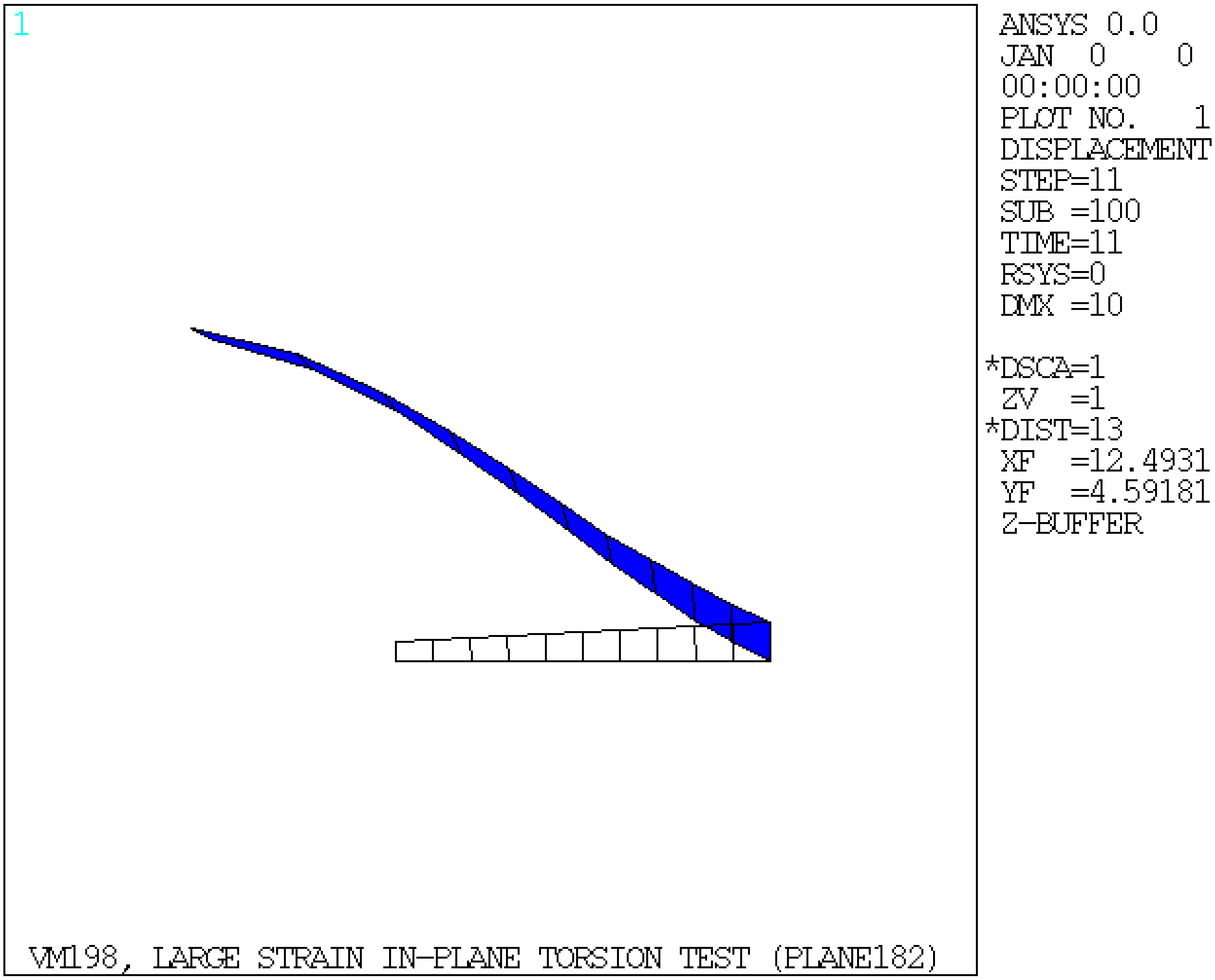
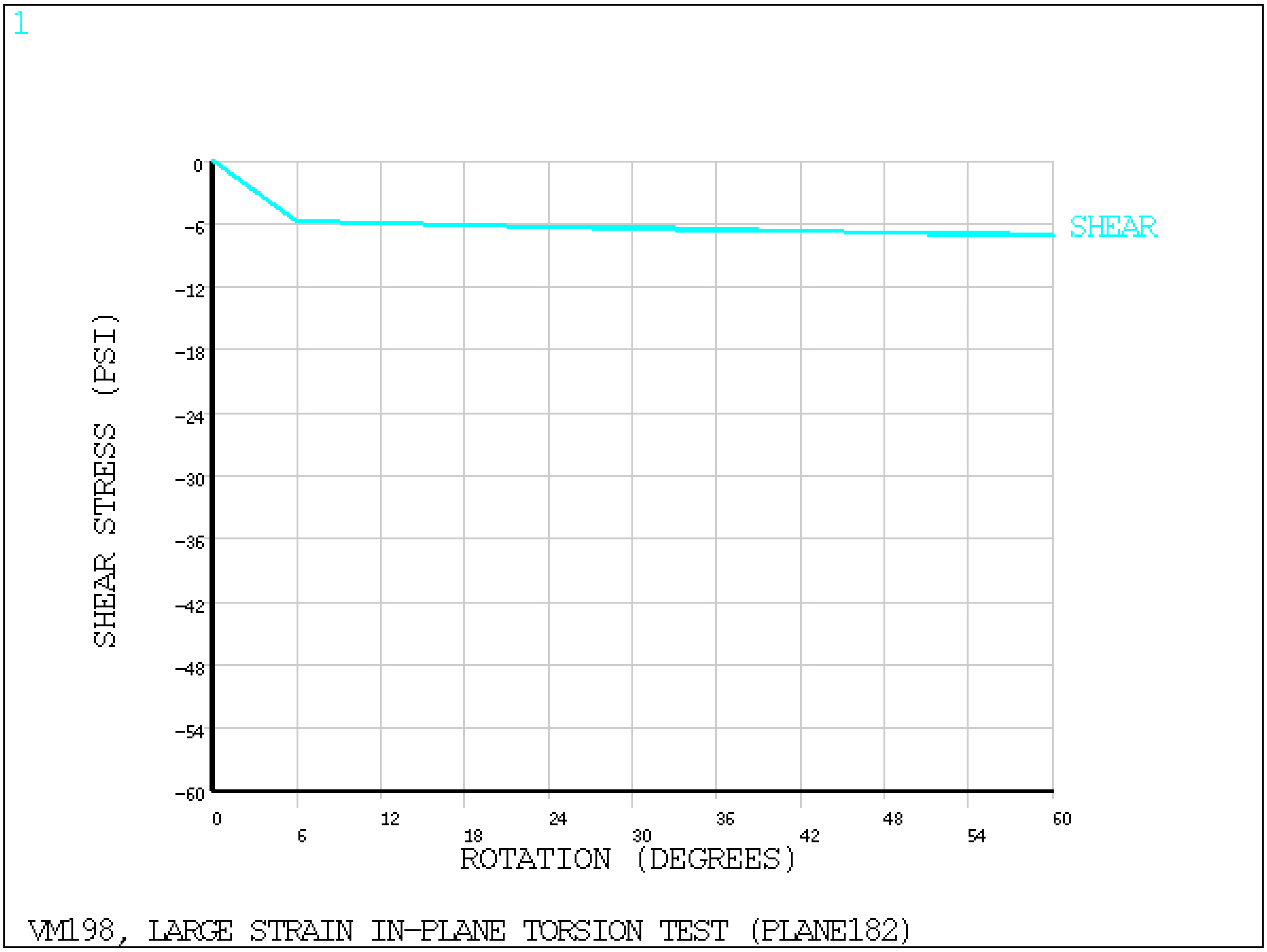


Figure 198.3: Typical Stress vs. Rotation Display Using PLANE182 Elements



VM199: Viscoplastic Analysis of a Body (Shear Deformation)

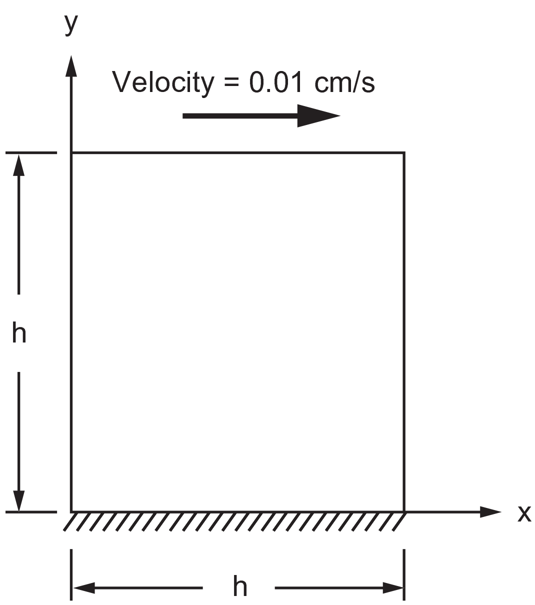
Overview

Reference:	B. Lwo, G. M. Eggert, "An Implicit Stress Update Algorithm Using a Plastic Predictor", Submitted to Computer Methods in Applied Mechanics and Engineering, January 1991.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4-Node Structural Solid Elements (PLANE182) 2-D 8-Node Structural Solid Elements (PLANE183) 3-D 8-Node Structural Solid Elements (SOLID185)
Input Listing:	vm199.dat

Test Case

A cubic shaped body made up of a viscoplastic material obeying Anand's law undergoes uniaxial shear deformation at a constant rate of 0.01 cm/s. The temperature of the body is maintained at 400°C. Find the shear load (F_x) required to maintain the deformation rate of 0.01 cm/sec at time equal to 20 seconds.

Figure 199.1: Shear Deformation Problem Sketch



Material Properties	Geometric Properties	Loading
E_x (Young's Modulus) = 60.6 GPa υ (Poisson's Ratio) = 0.4999 S_o = 29.7 MPa Q/R = 21.08999E3 K A = 1.91E7 s^{-1}	h = 1 cm thickness = 1 cm	Temp = 400°C = 673°K Velocity (x-direction) = 0.01 cm/sec @ y = 1 cm Time = 20 sec

Material Properties	Geometric Properties	Loading
ξ = 7.0 m = 0.23348 h_o = 1115.6 MPa $\hat{S}$ = 18.92 MPa η = 0.07049 a = 1.3		

Analysis Assumptions and Modeling Notes

The problem is solved three times, each time with a different element type. The element types used are PLANE182 (2-D 4-node structural solid element), PLANE183 (2-D 8-node structural solid element), and SOLID185 (3-D 8-node structural solid element). The rate dependent viscoplastic model proposed by Anand is used in this problem.

The plane strain condition is assumed along the Z-axis. The velocity of 0.01 cm/sec in X-direction is achieved by applying x-displacement of 0.2 cm in 20 seconds. The shear load is computed from the solution results in POST26.

Results Comparison

		Target[1]	Mechanical APDL	Ratio
PLANE182	F_x, N	845.00	842.74	0.997
PLANE183	F_x, N	845.00	842.74	0.997
SOLID185	F_x, N	845.00	842.74	0.997

1. Obtained from graphical solution

VM200: Viscoelastic Sandwich Seal Analysis

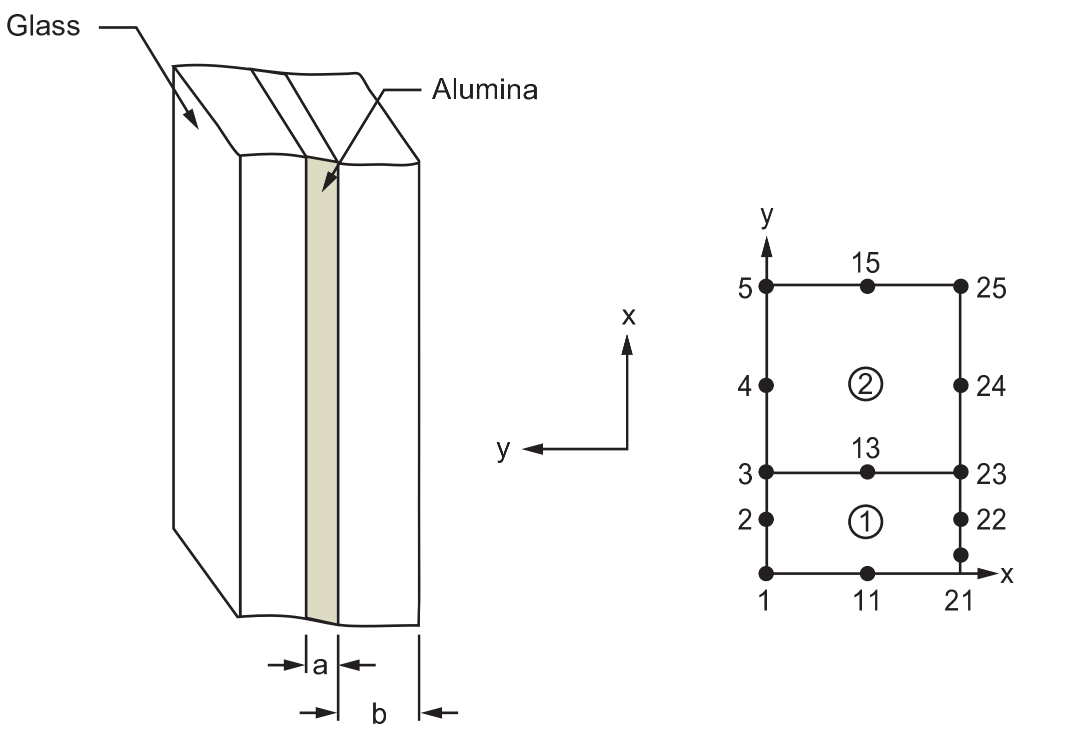
Overview

Reference:	T. F. Soules, R. F. Busbey, S. M. Rekhson, A. Markkovsky, M. A. Burkey, "Finite Element Calculations of Residual Stresses in Glass Parts Using MARC", General Electric Company (Nela Park), Report # 86-LRL-2022, Cleveland, OH, March 1986.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 8-Node Structural Solid Elements (PLANE183) 3-D 20-Node Structural Solid Elements (SOLID186)
Input Listing:	vm200.dat

Test Case

A sandwich seal made of an alumina plate with G-11 glass cladding on both sides is cooled at 3° per minute from 618°C to 460°C and held isothermally for four hours. The seal is further cooled at 3° per minute to 18°C. FInd the maximum in-plane stress (σ_{max}) developed in the seal along with the corresponding temperature.

Figure 200.1: Viscoelastic Sandwich Seal Problem Sketch



Problem Sketch

Representative 2-D Finite Element Model (not to scale)

Material Properties	Geometric Properties	Loading
Material: G-11 Glass **Material Variables** H/R (°K) = 6.45e4	a = 0.05 cm b = 0.325 cm	Reference Temp. = 618°C Temp. Offset = 273

Material Properties	Geometric Properties	Loading
X = 0.53 **No. of Maxwell Elements = 6** **For Volume Decay Function** C_{fi} = 0.108, 0.443, 0.166, 0.161, 0.046, 0.076 τ_{fi} = 3.00, 0.671, 0.247, 0.091, 0.033, 0.008 C_{li} = 3.43e-5 C_{gi} = 64.7e-7, 0.02e-7 T_{fi}(°) = 618, 618, 618, 618, 618, 618, GXY(0) = 2.79e4 GXY(∞) = 0.0 K(0), MPa = 6.05e4 K(∞), MPa = 6.05e4 **No. of Maxwell Elements for Shear Modulus Relaxation = 3** C_{smi} = 0.422, 0.423, 0.155 λ_{smi} = 0.0689, 0.0065, 0.0001 **No. of Maxwell Elements for Bulk Modulus Relaxation = 0** **Material: Alumina** **Material Variables** C_{gi} = 52.6e-7, 0.119e-7, -1.0e-11 GXY(0), MPa = 1.435e5 GXY(∞), MPa = 1.435e5 K(0), MPa = 3.11e5 K(∞), MPa = 3.11e5 See Viscoelastic Material Constants in the *Material Reference* for more explanation regarding the material parameters.		**Load Step 1;** Uniform Temp. (TUNIF) = 618°C **Load Step 2:** TUNIF = 460°C TIME = 3160 sec. **Load Step 3:** TUNIF = 460°C TIME = 17560 sec. **Load Step 4:** TUNIF = 18°C TIME = 26400 sec.

Analysis Assumptions and Modeling Notes

The problem is solved first using 2-D structural solid elements (PLANE183) and then using 3-D structural solid elements (SOLID186).

In the 2-D case, due to the fact that the stresses will be the same in X and Z directions because of symmetry, an axisymmetric analysis is performed with the nodal degrees of freedom coupled in appropriate directions. The radial thickness of 0.2 cm is arbitrarily selected. Nodes 21 through 25 are coupled in the X-direction (radial coupling). Nodes with the same Y-location are coupled in Y-direction (axial coupling).

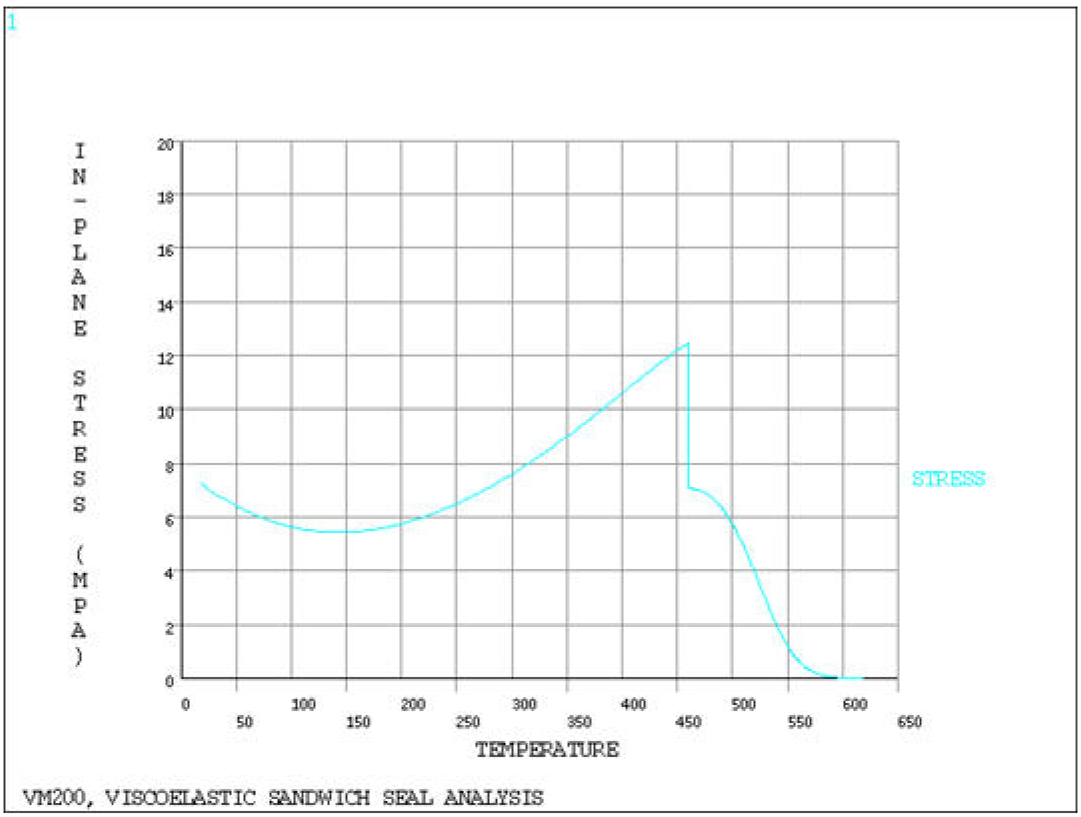
In the 3-D case, an arbitrary thickness of 0.2 cm is assumed in both Y and Z directions. Nodal degrees of freedom are coupled in appropriate directions to simulate the correct physical behavior in the finite element model.

The alumina is not a viscoelastic material, however, its material properties are input using viscoelastic format so that only one element type (PLANE183 in 2-D and SOLID186 in 3-D) can be used for both materials. Also, note that the viscoelastic material does not require the **MP** command for inputting the material properties. POST26 is used to extract the results from the solution phase.

Results Comparison

		Target	Mechanical APDL	Ratio
PLANE183	$Stress_{max}$, MPa	12.5	12.5	1.002
	Temp, °C	460.0	460.0	1.000
SOLID186	$Stress_{max}$, MPa	12.5	12.6	1.004
	Temp, °C	460.0	460.0	1.000

Figure 200.2: In-plane Stress Versus Temperature



VM201: Rubber Cylinder Pressed Between Two Plates

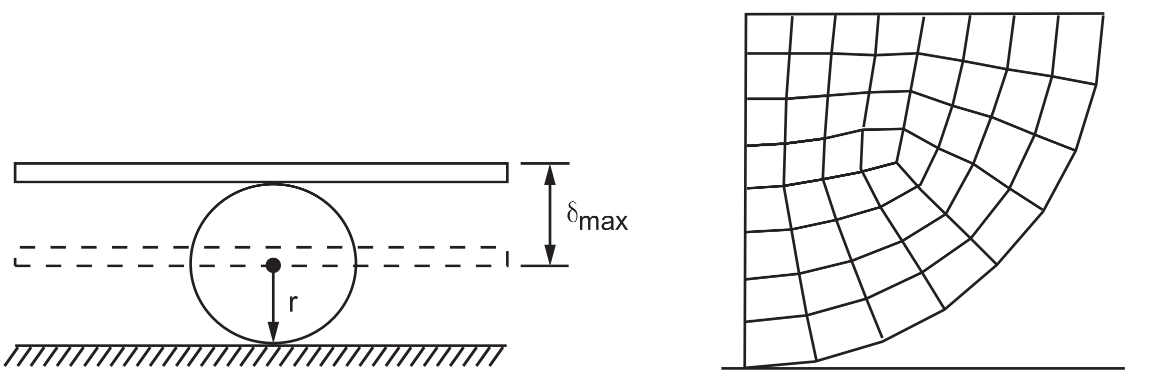
Overview

Reference:	T. Tussman, K-J Bathe, "A Finite Element Formulation for Nonlinear Incompressible Elastic and Inelastic Analysis", *Computers and Structures*, Vol. 26 Nos 1/2, 1987, pp. 357-409.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4-Node Structural Solid Elements (PLANE182) 3-D 8-Node Structural Solid Elements (SOLID185) 2-D Target Segment Element (TARGE169) 3-D Target Segment Element (TARGE170) 2-D/3-D Node-to-Surface Contact Elements (CONTA175) Meshing Facet (MESH200)
Input Listing:	vm201.dat

Test Case

A long rubber cylinder is pressed between two rigid plates using a maximum imposed displacement of δ_{max}. Determine the force-deflection response.

Figure 201.1: Rubber Cylinder Problem Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
Mooney-Rivlin Constants C1 = 0.293 MPa C2 = 0.177 MPa	r = 200 mm	δ_{max} = 200 mm

Analysis Assumptions and Modeling Notes

A plane strain solution is assumed based on the geometry of the problem. Due to geometric and loading symmetry, the analysis can be performed using one quarter of the cross section. All nodes on the left edge (X = 0) are constrained, UX = 0. All nodes on the top edge (y = 0) are coupled in UY. An imposed displacement of -0.1 m acts upon the coupled nodes.

This problem was solved in several ways:

- A 2-D model using PLANE182 with CONTA175 elements
- A 3-D model using SOLID185 with CONTA175 elements
- A 2-D model using PLANE182 with CONTA175 element and solved using the Lagrange Multiplier method.
- A 3-D model using SOLID185 with CONTA175 element and solved using the Pure Lagrange Multiplier method.

In the 3-D case, a MESH200 element is used as the target face for the automatic generation of contact elements. The target surface is given a high contact stiffness (KN = 2000 MPa) to model a rigid surface and no contact stiffness is required to be specified while performing the solution using Lagrange Multipliers method.

Results Comparison

	Target[1]	Mechanical APDL	Ratio
PLANE182 with 2-D CONTA175			
Force at Displacement = 0.1 (N)	250.00	266.05	1.064
Force at Displacement = 0.2 (N)	1400.00	1397.06	0.998
SOLID185 with 3-D CONTA175			
Force at Displacement = 0.1 (N)	250.00	258.77	1.035
Force at Displacement = 0.2 (N)	1400.00	1398.79	0.999
PLANE182 with 2-D CONTA175 with KEYOPT (2) = 3			
Force at Displacement = 0.1 (N)	250.00	266.20	1.065
Force at Displacement = 0.2 (N)	1400.00	1400.42	1.000
SOLID185 with 3-D CONTA175 with KEYOPT (2) = 4			
Force at Displacement = 0.1 (N)	250.00	266.40	1.066
Force at Displacement = 0.2 (N)	1400.00	1400.48	1.000

1. Determined from graphical results. See T. Tussman, K-J Bathe, "A Finite Element Formulation for Nonlinear Incompressible Elastic and Inelastic Analysis", pg. 385, fig. 6.14.

Figure 201.2: Displaced Shape

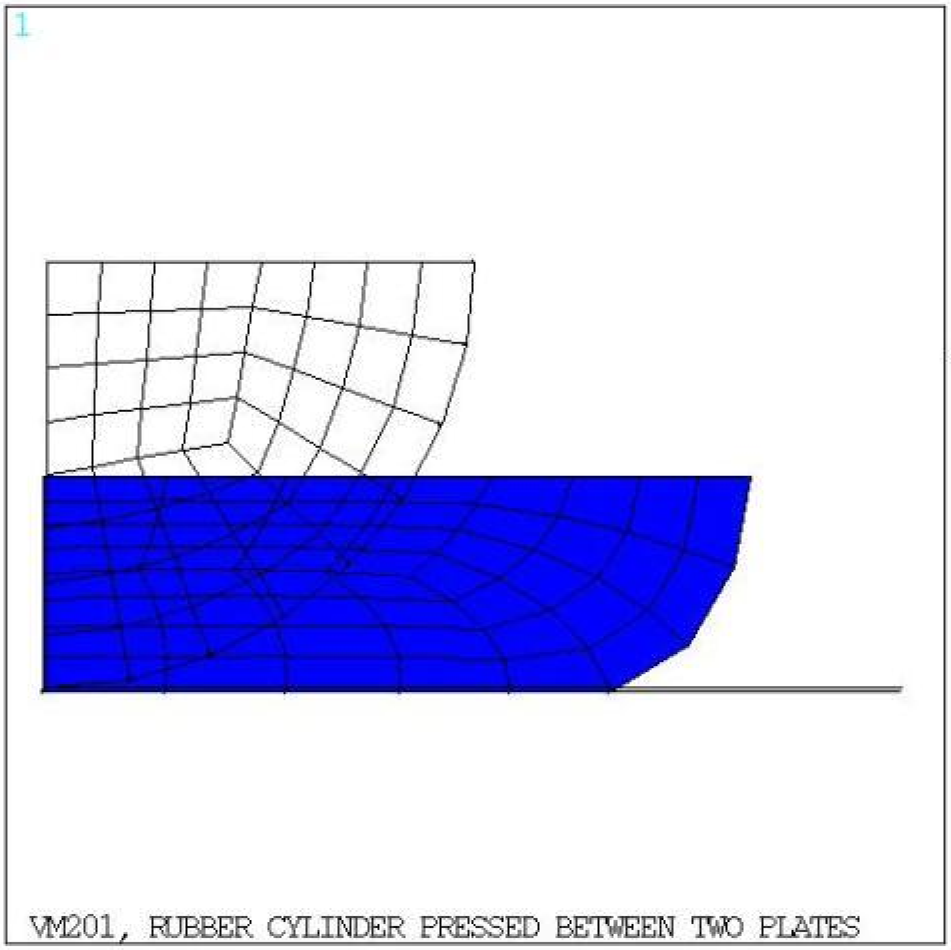
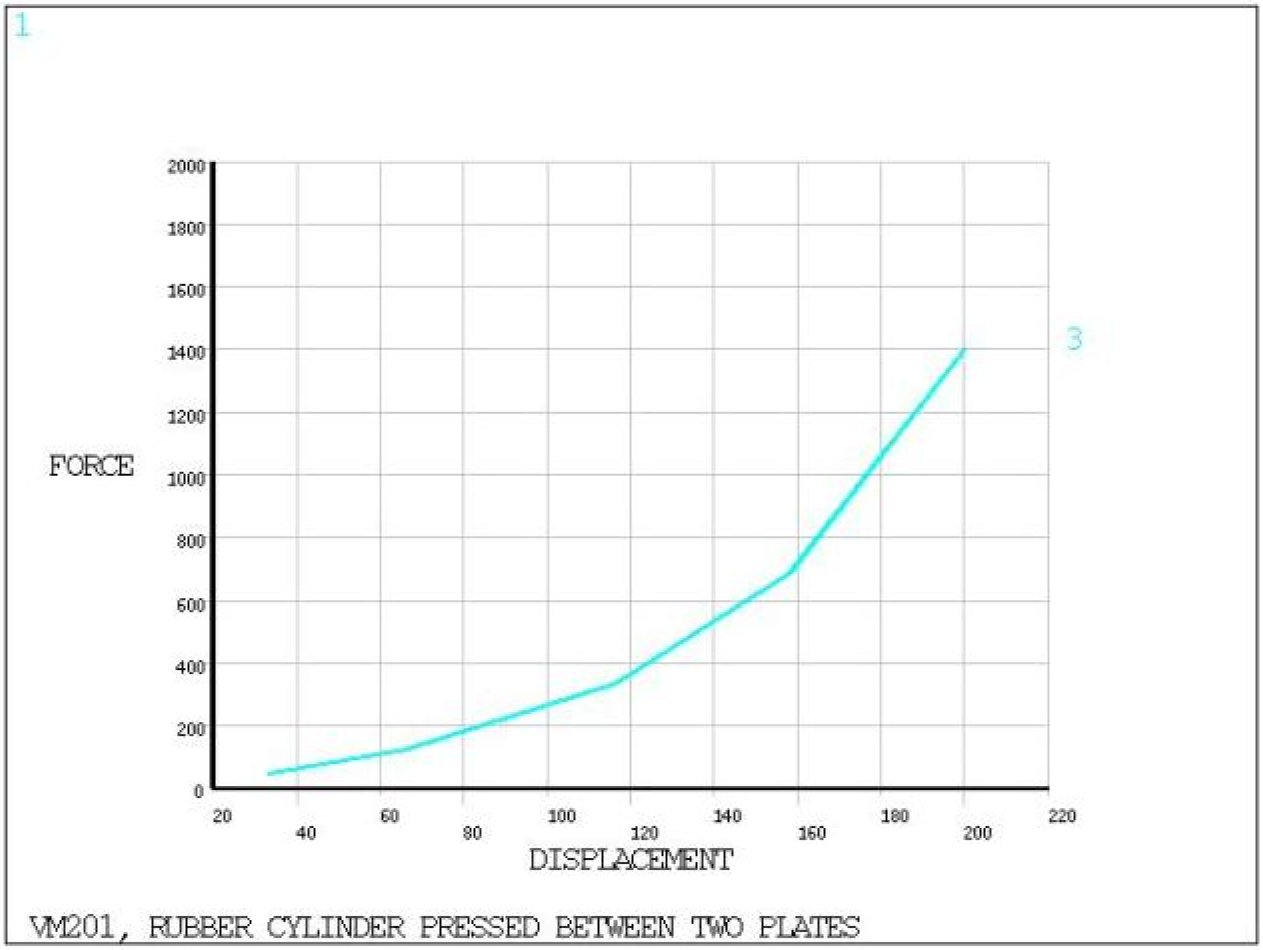


Figure 201.3: Force vs. Displacement



VM202: Transverse Vibrations of a Shear Beam

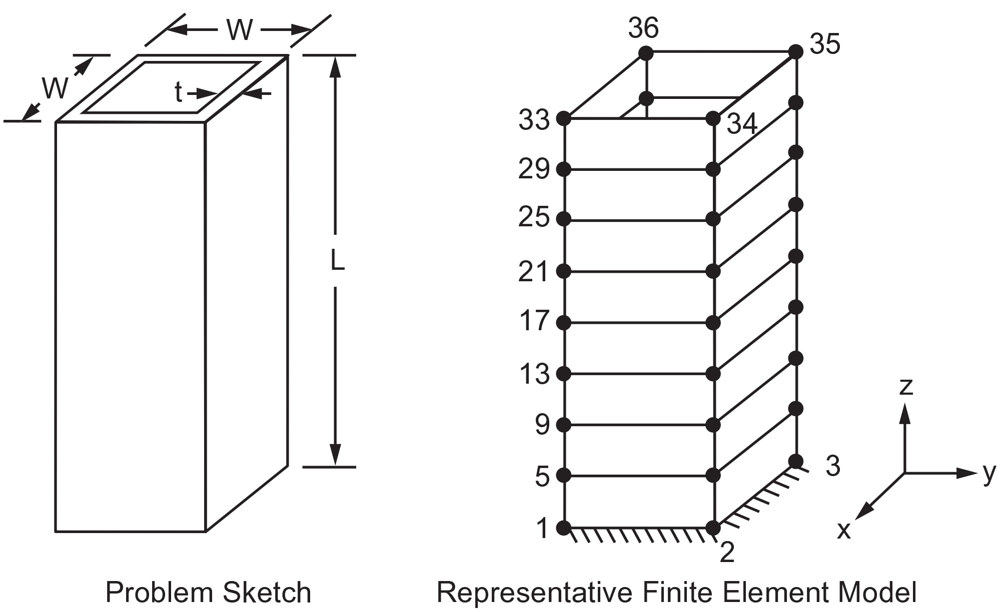
Overview

Reference:	R. D. Blevins, *Formulas for Natural Frequency and Mode Shape*, Van Nostrand Reinhold Co., New York, NY, 1979, pp. 171-176.
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	Shear/Twist Panel Elements (SHELL28)
Input Listing:	vm202.dat

Test Case

A short, thin-walled uniform shear beam clamped at the base vibrates freely. Determine the first two modes of vibrations neglecting all flexural deformations.

Figure 202.1: Shear Beam Problem Sketch



Material Properties	Geometric Properties
E = 200 GPa υ = 0.27 ρ = 7860 Kg/m^3	L = 30 m W = 10 m t = 0.1 m

Analysis Assumptions and Modeling Notes

Flexural deformations were eliminated by requiring all nodes with the same Z coordinate value to be coupled in UX and UY. Since this is a square beam, the frequencies are repeated, one made in the X direction, the other in the Y direction.

Results Comparison

	Target	Mechanical APDL	Ratio
f1, Hz	17.375	18.621	1.072
f2, Hz	52.176	55.146	1.057

Figure 202.2: Mode Shape 1 (f = 18.62 Hz)

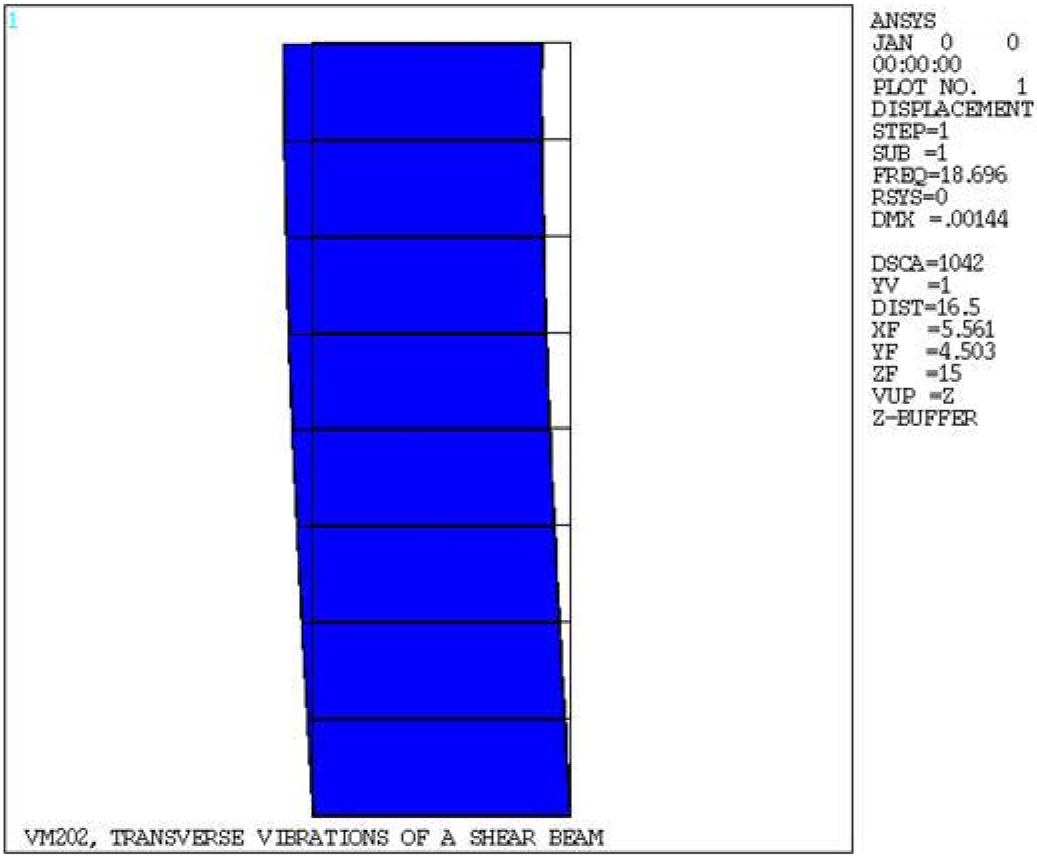
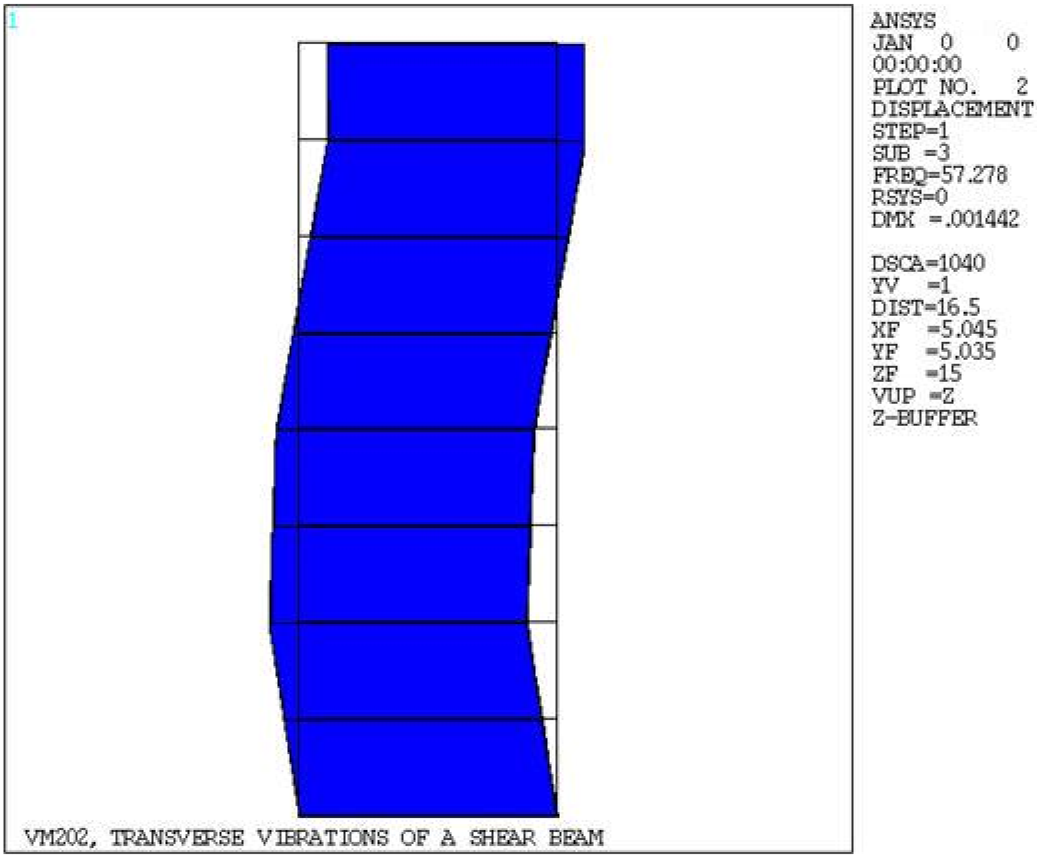


Figure 202.3: Mode Shape 2 (f = 55.15 Hz)



VM203: Dynamic Load Effect on Supported Thick Plate

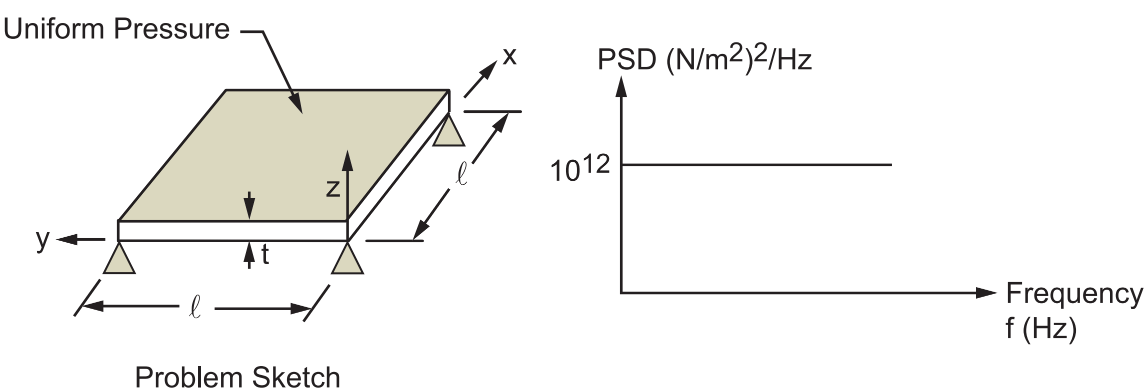
Overview

Reference:	NAFEMS, *Selected Benchmarks for Forced Vibration*, Report prepared by W. S. Atking Engineering Sciences, April 1989, Test 21R.
Analysis Type(s):	Mode-frequency, Spectrum Analysis (**ANTYPE** = 8) Harmonic Analysis (**ANTYPE** = 3)
Element Type(s):	8-Node Finite Strain Shell Elements (SHELL281)
Input Listing:	vm203.dat

Test Case

A simply-supported thick square plate of length ℓ, thickness t, and mass per unit area m is subject to random uniform pressure power spectral density. Determine the peak one-sigma displacement at undamped natural frequency.

Figure 203.1: Thick Square Plate Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 200 \times 10^9$ N/m^2 $\mu = 0.3$ m = 8000 kg/m^3	ℓ = 10 m t = 1.0 m	PSD = (10^6 N/m^2)^2 /Hz Damping δ = 2%

Analysis Assumptions and Modeling Notes

Equivalent nodal forces are obtained from a uniform pressure load by a static run with all UZ degrees of freedom constrained.

Frequency range of 1.0 Hz to 80 Hz was used as an approximation of the white noise PSD forcing function frequency. Equivalent analyses are done with Spectrum and Harmonic (with the ANSYS POST26 random vibration calculation capabilities which used the results of a damped harmonic analysis) analyses, to compare the peak one-sigma standard deviation.

Some of the commands in POST26 followed by harmonic analysis have been undocumented since ANSYS Revision 5.0, but they are compatible to all subsequent ANSYS revisions.

The model is solved using SHELL281 elements.

Results Comparison

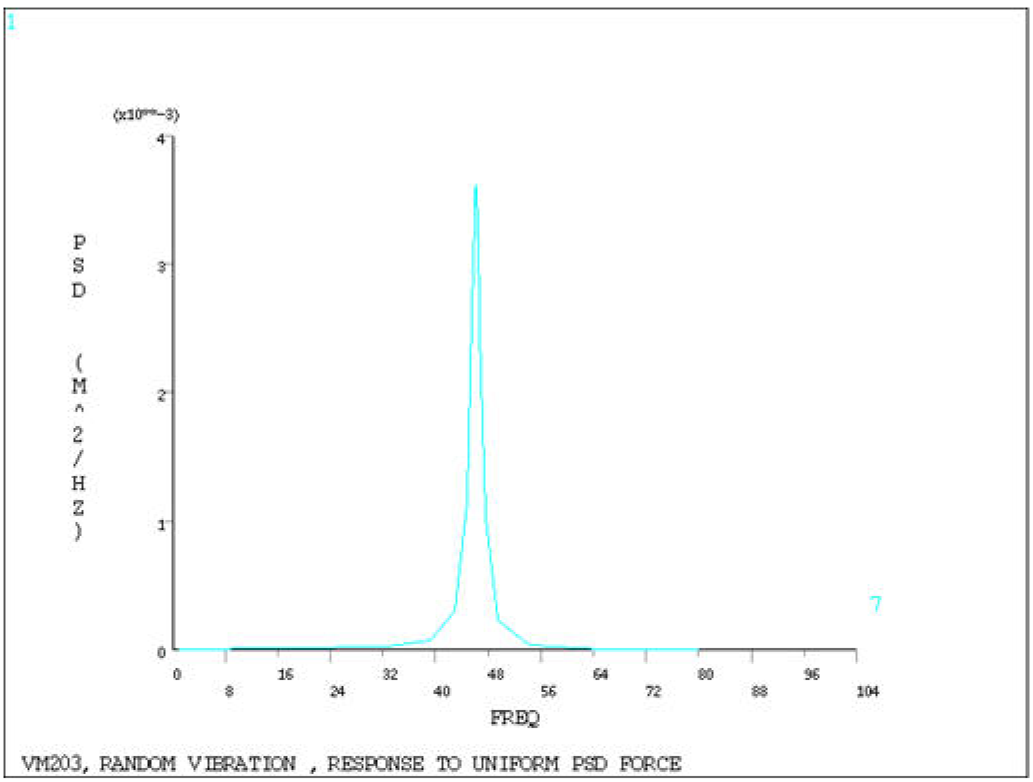
	Target	Mechanical APDL	Ratio
SHELL281			
Frequency f (Hz)	45.9	45.95 [1]	1.001
Peak Deflection PSD (mm^2/Hz)	3402	3595 [2]	1.057

1. From modal analysis solution

2. Peak amplitude ($x10^6$) from Harmonic analysis results using POST26

The peak one-sigma standard deviation from spectrum analysis (102.18 mm) agrees with the value from Harmonic analysis (108.16 mm), (No closed form solution is available from the reference for this entity.)

Figure 203.2: Harmonic Response to Uniform PSD Force



VM204: Solid Model of an Axial Bearing

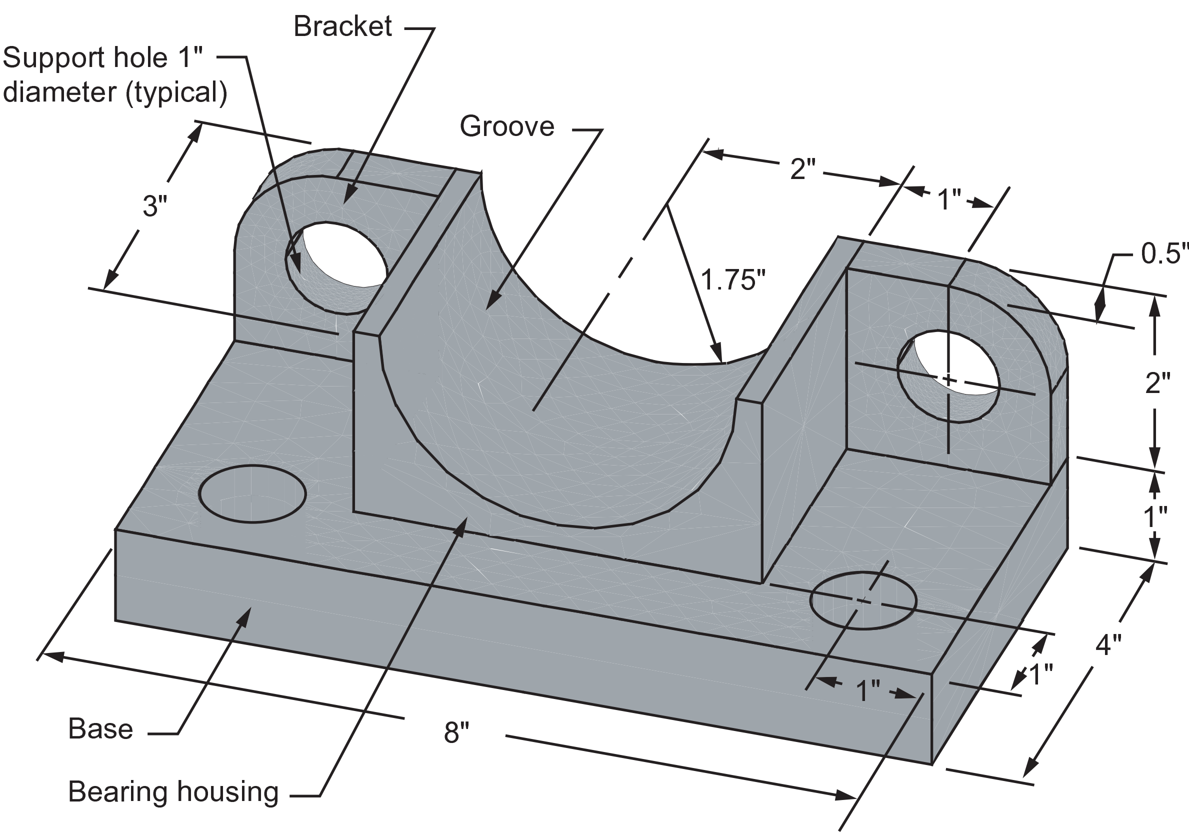
Overview

Reference:	Any basic geometry text
Analysis Type(s):	Solid Modeling Boolean Operations
Element Type(s):	None
Input Listing:	vm204.dat

Test Case

Find the volume of the axial bearing shown below.

Figure 204.1: Axial Bearing Problem Sketch



Solid Model

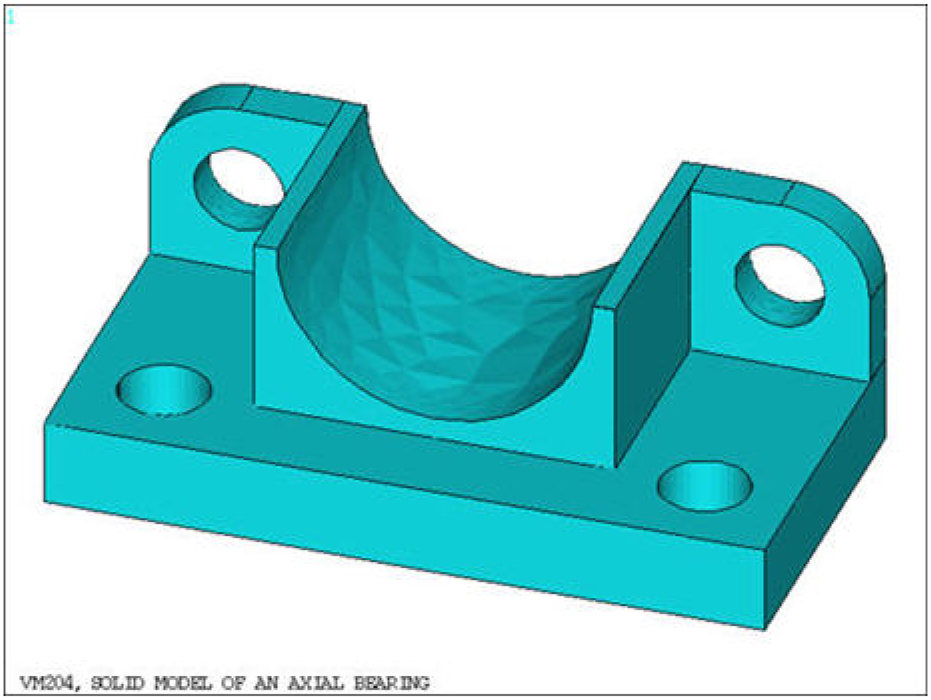
Analysis Assumptions and Modeling Notes

The model is created entirely using only geometric primitives and solid model Boolean operations. A glue operation is used to provide continuity between model entities.

Results Comparison

	Target	Mechanical APDL	Ratio
Volume	42.997	42.995	1.000

Figure 204.2: Solid Model of an Axial Bearing



VM205: Adaptive Analysis of an Elliptic Membrane

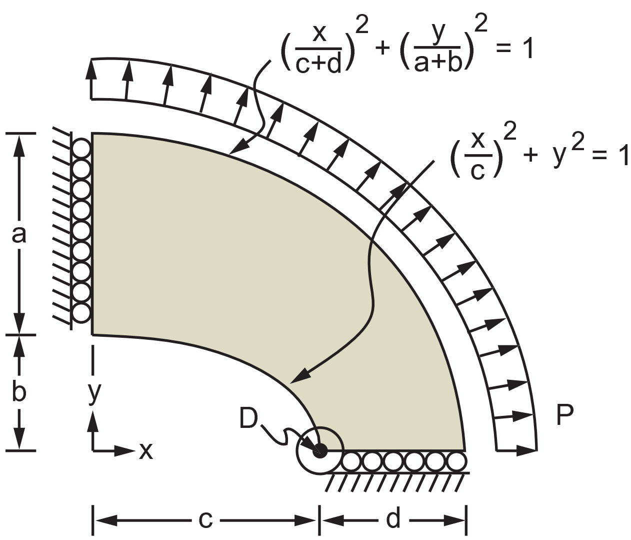
Overview

Reference:	J. Barlow, G. A. O. Davis, "Selected FE Benchmarks in Structural and Thermal Analysis", *NAFEMS Report FEBSTA*, Rev. 1, October 1986, Test No. LE1 (modified).
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4-Node Structural Solid Elements (PLANE182) 2-D 8-Node Structural Solid Elements (PLANE183)
Input Listing:	vm205.dat

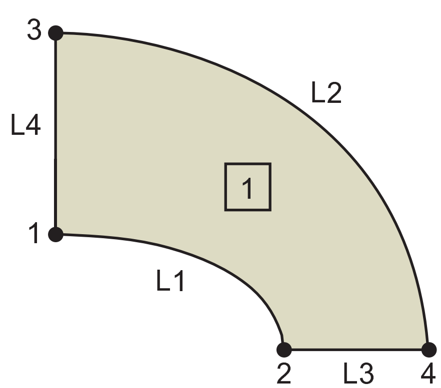
Test Case

An elliptic membrane structure of thickness t is subjected to a uniformly distributed outward pressure P. Determine the tangential edge stress σ_y at target point D.

Figure 205.1: Elliptic Membrane Problem Sketch



Problem Sketch



Area, Line and Keypoint Model

Material Properties	Geometric Properties	Loading
$E = 210 \times 10^3$ MPa $\upsilon = 0.3$	a = 1.75 m b = 1.0 m c = 2.0 m d = 1.25 m t = 0.1 m	At x = 0 UX = 0 At y = 0 UY = 0 Along outer edge P = -10 MPa

Analysis Assumptions and Modeling Notes

The problem is solved first using lower order 2-D structural solid elements (PLANE182) and then higher order 2-D structural solid elements (PLANE183). For both cases, the membrane is modeled with one area and the automatic adaptive meshing procedure is used to refine the mesh in the area of stress concentration (target location at point D).

In the first case, the analysis is performed by running the problem until the SEPC (structural percent error in energy norm) is close to 7.0 percent, whereas in the second case, analysis is performed until the SEPC is close to 5.0 percent. In the second case, the target value of SEPC is set less than the first case since higher order elements are generally more accurate.

POST1 is used to obtain the final value of SEPC and the ***GET** command is used to obtain the tangential stress, σ_y, at the target point D.

Results Comparison

		Target	Mechanical APDL	Ratio
PLANE182[1]	$Stress_y$ (MPa)	92.70	92.48	0.998
PLANE183[1]	$Stress_y$ (MPa)	92.70	91.83	0.991

1. Corresponding to the final mesh with SEPC of 5.5 (for a PLANE182 model) and 0.1 (for a PLANE183 model)

Figure 205.2: Final PLANE182 Mesh (SEPC = 5.5)

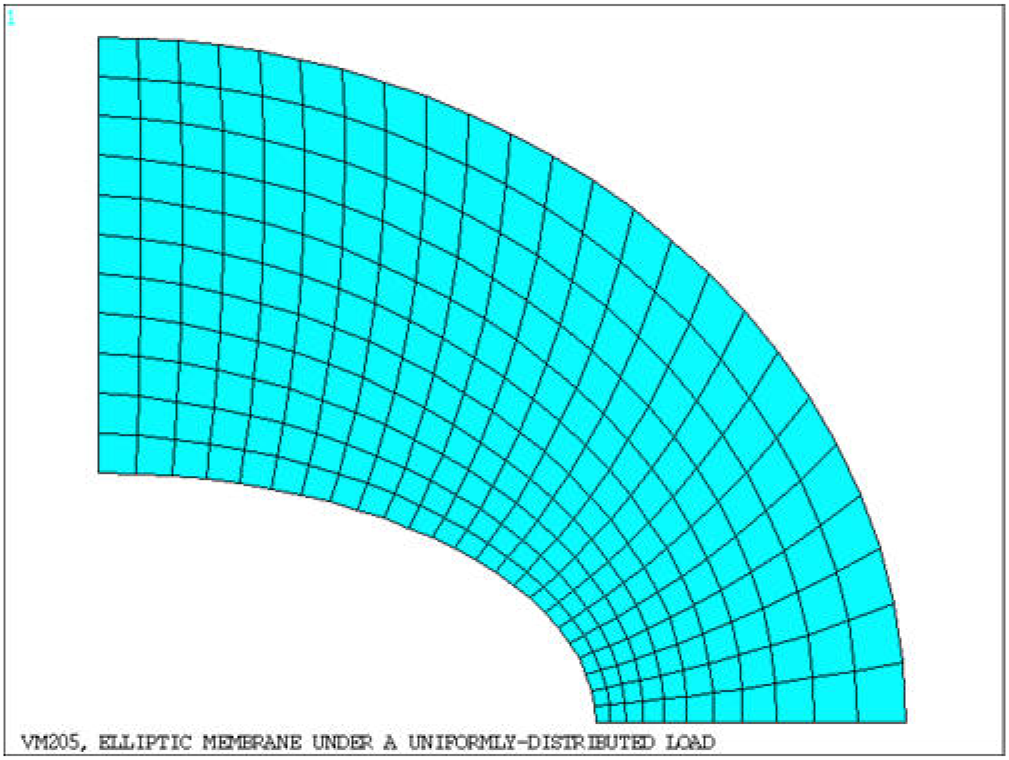
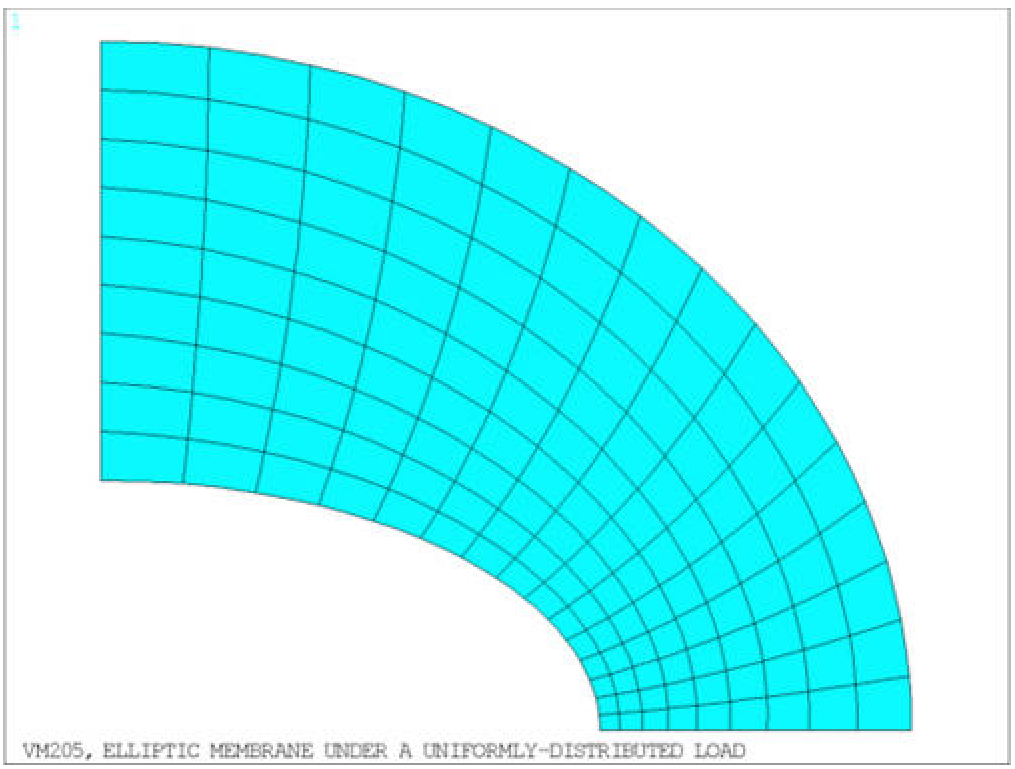


Figure 205.3: Final PLANE183 Mesh (SEPC = 0.1)



VM206: Stranded Coil with Voltage Excitation

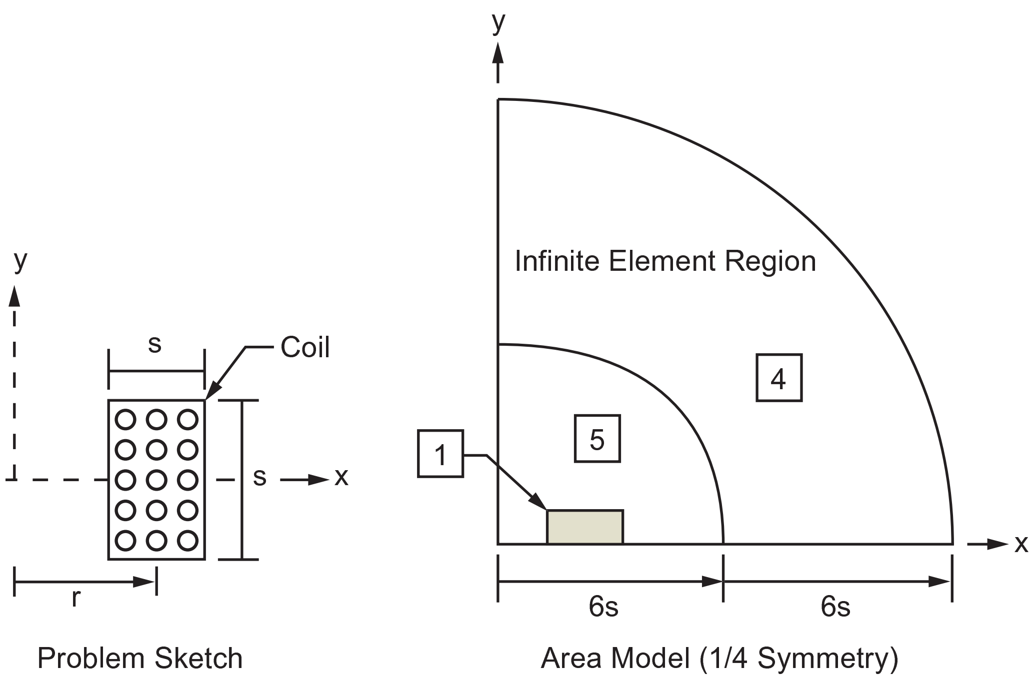
Overview

Reference:	W. B. Boast, *Principles of Electric and Magnetic Fields*, Harper & Brothers, New York, NY, 1948, pg. 247, eq. 12.18.
Analysis Type(s):	Static, Harmonic
Element Type(s):	2-D 8-Node Magnetic Solid Elements (PLANE53) 2-D 8-Node Electromagnetic Solid Elements (PLANE233) 2-D Infinite Solid Elements (INFIN110)
Input Listing:	vm206.dat

Test Case

A stranded coil with 500 turns is modeled in free space. A static analysis with a 12 volt DC excitation is run first to calculate the coil resistance and inductance. A 1/4 symmetry model is constructed. An AC (harmonic) analysis is run to simulate an RL circuit response with an applied excitation of 12 volts at 60 Hz. The complex coil current is calculated.

Figure 206.1: Stranded Coil Problem Sketch



Material Properties	Geometric Properties	Loading
μ_r = 1.0 (coil) μ_r = 1.0 (air) $\rho = 3 \times 10^{-8}$ ohm-m (coil)	n = 500 turns s = 0.02 (coil winding width and depth) m r = (3 x s)/2 m	V_o = 12 volts (static) $V = V_o \cos \omega t$ (harmonic) where: V_o = 12 volts

Material Properties	Geometric Properties	Loading
		ω = 60 Hz

Analysis Assumptions and Modeling Notes

Due to symmetry only 1/4 of the problem domain is required. The open boundary is modeled with infinite elements to accurately represent the decaying field. The infinite element region is set to a depth (6xs) equal to the problem domain (6xs) for optimal performance.

The coil is characterized through the real constant table. A direct voltage load is applied to the coil region. Nodes in the coil region are coupled in the CURR degree of freedom for PLANE53 and VOLT degree of freedom for PLANE233 to solve for a single valued coil current (per turn).

When PLANE53 is used, the coil resistance and inductance are calculated by summing element values in POST1. The real and imaginary current are extracted from the AC solution. From these calculated currents, and the applied voltage, the coil impedance can be calculated. PLANE233 does not support inductance calculations and requires the coil resistance to be part of the input.

Results Comparison

		Target	Mechanical APDL	Ratio
PLANE53				
Static Analysis	Inductance, H	0.01274	0.01275	1.00
	Resistance, Ohm	3.53400	3.53429	1.00
	Coil current, Amps	3.39500	3.39531	1.00
Harmonic Analysis	Real solution, Amps	1.19200	1.19196	1.00
	Imag solution, Amps	-1.62100	-1.62059	1.00
PLANE233				
Static Analysis	Coil current, Amps	3.39500	3.39559	1.00
Harmonic Analysis	Real solution, Amps	1.19200	1.19272	1.00
	Imag solution, Amps	-1.62100	-1.62093	1.00

VM207: Stranded Coil Excited by External Circuit

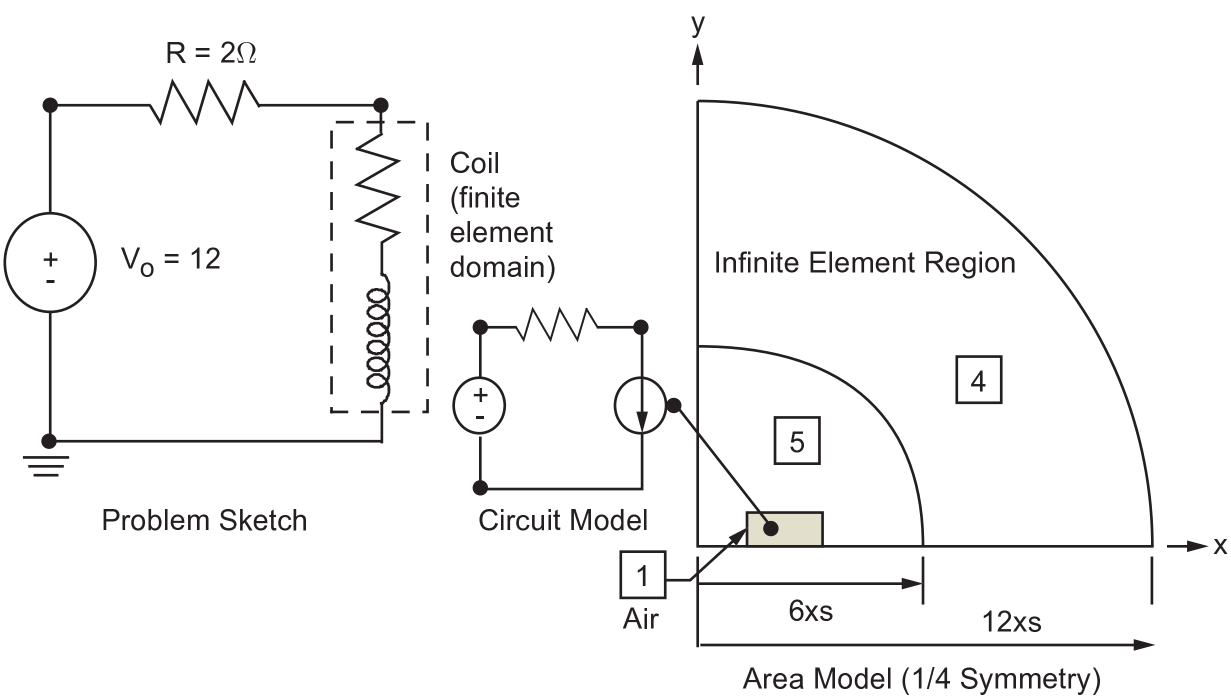
Overview

Reference:	W. B. Boast, *Principles of Electric and Magnetic Fields*, Harper & Brothers, New York, NY, 1948, pg. 247, eq. 12.18.
Analysis Type(s):	Static
Element Type(s):	2-D 8-Node Magnetic Solid Elements (PLANE53) 2-D 8-Node Electromagnetic Solid Elements (PLANE233) 2-D Infinite Solid Elements (INFIN110) Electric Circuit Elements (CIRCU124)
Input Listing:	vm207.dat

Test Case

A stranded coil with 500 turns and a fill factor of 0.9 is connected to an external circuit consisting of an independent voltage source and a 2 ohm resistor. A static analysis is run with a 12 volt DC excitation to determine the coil resistance and inductance. A transient analysis is run to calculate the coil current response to a step 12 volt excitation.

Figure 207.1: Stranded Coil Problem Sketch



Material Properties	Geometric Properties	Loading
$R_{ext} = 2\ \Omega$ $\mu_r = 1.0$ (coil) $\mu_r = 1.0$ (air) $\rho = 3.04878 \times 10^{-8}$ ohm-m (coil)	N = 500 turns S = 0.02 m R = 3(s)/2 m FC = 0.9 Fill factor	V_o = 12 volts (static) $V_o\|_{t=0+}$ = 12 volts (static)

Analysis Assumptions and Modeling Notes

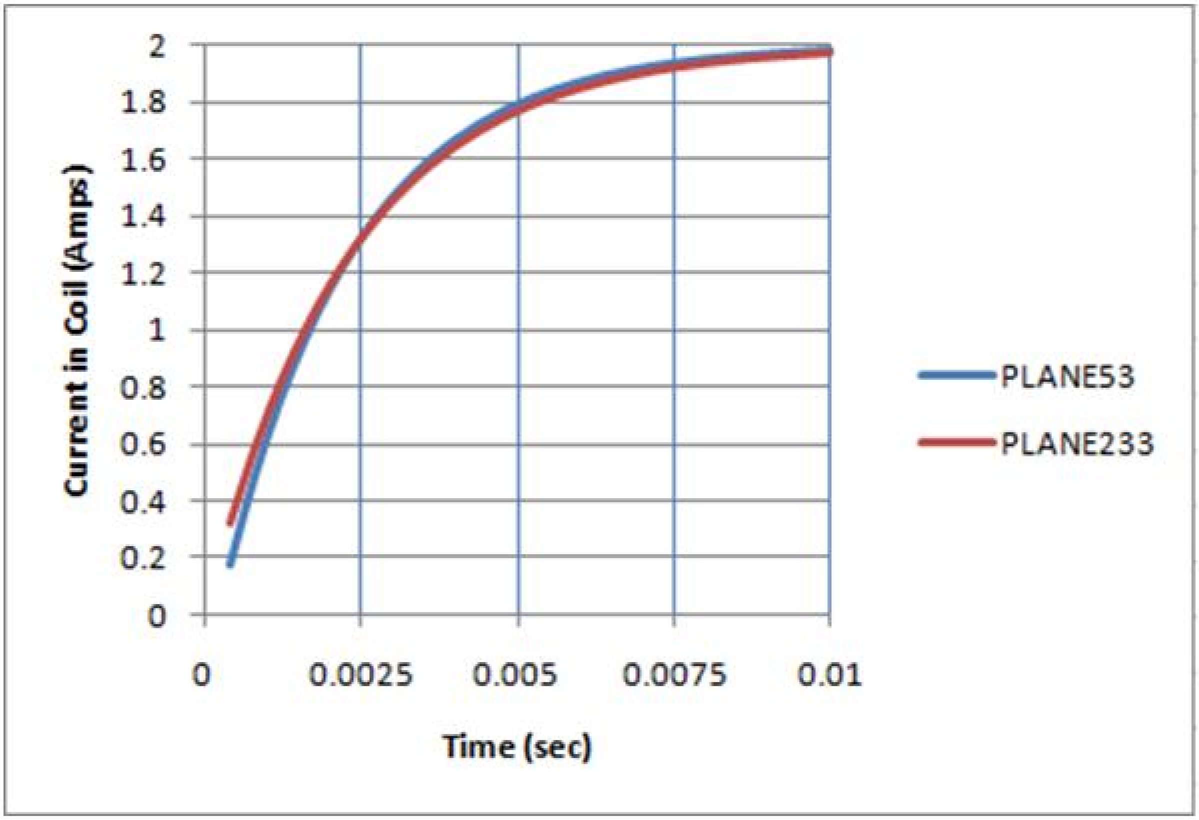
The problem is similar to VM206 except the coil is excited by an external circuit using the general circuit element. In the circuit, the coil is modeled by a stranded coil circuit component that shares a common node with the coil in the finite element model. The finite element model provides to the circuit the necessary coil resistance and inductance to characterize the stranded coil circuit impedance. The nodes in the coil region are coupled in the EMF and CURR degrees of freedom so that a single voltage drop (EMF) and coil current (CURR) are calculated.

A static analysis is run to obtain the coil resistance and inductance so that an analytical solution of the transient response can be calculated and compared to the solution results. A transient solution to a step voltage excitation is run for 0.01 seconds. The calculated coil current is compared to the solution current. The coil current response is plotted versus time.

Results Comparison

		Target	Mechanical APDL	Ratio
PLANE53				
Static Analysis	Inductance, Henry	0.01274	0.01274	1.00
	Resistance, Ohm	3.991	3.99084	1.00
Transient Analysis	Current, Amps	1.985	1.98325	0.999
PLANE233				
Static Analysis	Inductance, Henry	0.01274	0.01274	1.00
Transient Analysis	Current, Amps	1.985	2.00300	1.01

Figure 207.2: Current vs. Time using PLANE53 and PLANE233 Elements



VM208: RL Circuit with Controlled Source

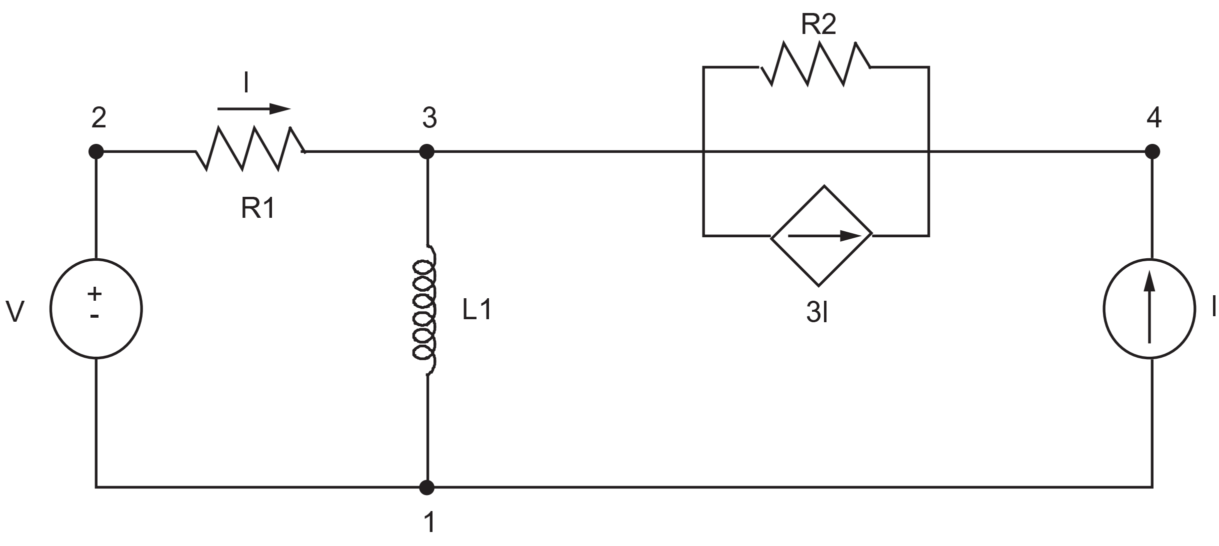
Overview

Reference:	J. O'Malley, *Schaum's Outline of Theory and Problems of Basic Circuit Analysis*, 2nd Edition, McGraw-Hill Book Co., Inc., New York, NY, 1992, Problem 14.23, Figure 14.25.
Analysis Type(s):	Harmonic
Element Type(s):	Electric Circuit Elements (CIRCU124)
Input Listing:	vm208.dat

Test Case

A circuit consists of 2 resistors, an inductor, an independent voltage source, an independent current source, and a current-controlled current source. Determine the voltage at node 4 in the circuit.

Figure 208.1: RL Circuit Problem Sketch



Circuit Values	Loading
$R_1 = 3\ \Omega$ $R_2 = 2\ \Omega$ $L_1 = j4\ \Omega$ AI = -3	V = 15 volts at a phaser angle of 30° I = 5 amps at a phaser angle of -45°

Analysis Assumptions and Modeling Notes

A harmonic analysis is run at a frequency of 1/2 π Hz so that the inductor impedance value can be simply input as 4 ohms. Care must be exercised in assigning the node values to the current controlled current source (CCCS) to correctly account for the sign on the CCCS gain (AI).

Results Comparison

@ Node 4	Target	Mechanical APDL	Ratio
Real Voltage, V	16.44	16.46	1.001
Imag Voltage, V	-1.41	-1.41	1.00

VM209: Static analysis of Double Bellows Air Spring

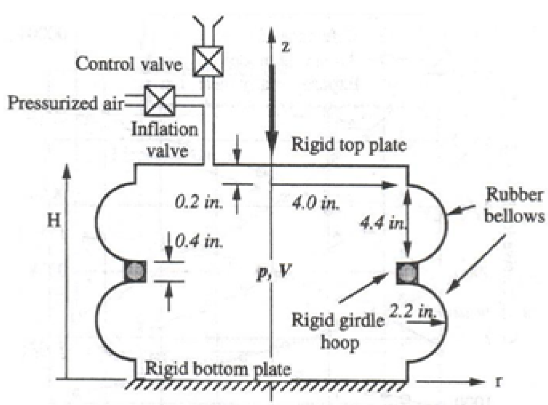
Overview

Reference:	Dale T.Berry, Henry T.Y.Yang, Formulation and Experimental Verification of a Pneumatic Finite Element, International Journal For Numerical Methods in Engineering, Vol.39, pp 1097-1114 (1996)
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-Node Axisymmetric Shell Element (SHELL208) 2-D Hydrostatic Fluid element (HSFLD241) 2-D Smeared Reinforcing Element (REINF263)
Input Listing:	vm209.dat

Test Case

A double bellows-type air spring made of two rubber membranes shaped like toroids (radius Rt, angle of rotation θ degrees) is attached to a rigid plate (height h, radius R) at each end and connected in the middle by a rigid ring (height 2h, radius R). The rubber membrane is reinforced by polyester cords (cross sectional area A) spaced length w apart. The total air spring load with respect to height is measured at pressure loads 20, 40 and 60 PSI.

Figure 209.1: Multiple Species Flow Problem Sketch



Material Properties	Geometric Properties	Loading
E_{rubber} = 1000 psi Nu_{rubber} = 0.49	Rt = 2.2 inches R = 4 inches	T = 20 degree Celsius P = 20, 40,60 psi

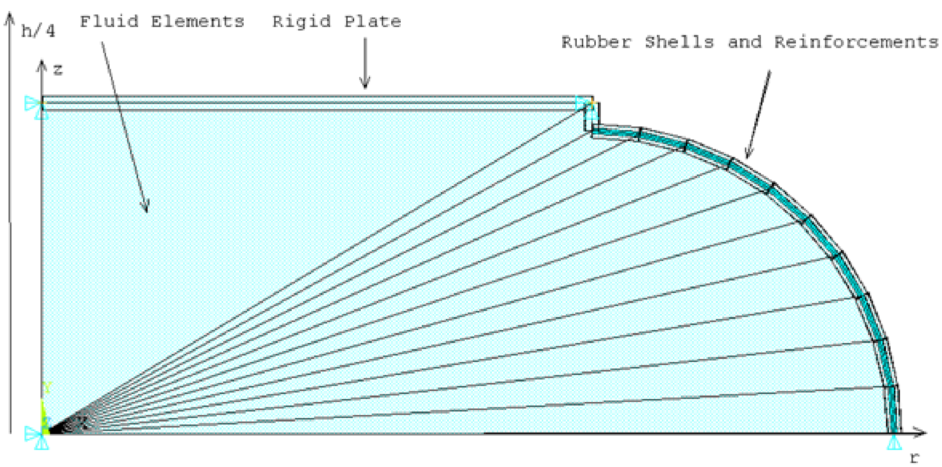
Material Properties	Geometric Properties	Loading
$Density_{gas}$ = 4.4256e-5 lb-sec^2/in^4 $E_{polyester}$ = 40000 psi $Nu_{polyster}$ = 0.37 E_{plate} = 3.0467e7 psi Nu_{plate} = 0.3	θ = 90 h = 0.2 inches A = 1.96e-3 in2 w = 0.05 inches	X = 1.5 inches

Table 209.1: PVDATA points for Fluid material model

PVDATA Points (absolute pressure, volume)		
20 psi	**40 psi**	**60 psi**
(34.7, 238.931)	(34.7, 377.9675418)	(34.7, 517.9960634)
(44.7, 185.4788747)	(44.7, 293.4110447)	(44.7, 402.7732752)
(54.7, 151.5704881)	(54.7, 239.771)	(54.7, 328.6007934)
(74.7, 110.9893668)	(74.7, 175.5752838)	(74.7, 240.622)
(94.7, 87.54916262)	(94.7, 138.4949704)	(84.7, 212.2132633)
(414.7, 19.99253846)	(114.7, 114.345891)	(94.7, 189.8042598)
(1014.7, 8.170795013)	(314.7, 41.67611598)	(104.7, 171.6758682)
	(414.7, 31.62641355)	(164.7, 109.1345683)
	(514.7, 25.48178298)	(214.7, 83.71897252)
	(714.7, 18.35101959)	(264.7, 67.9050374)
	(914.7, 14.3385522)	(314.7, 57.11618494)
	(1014.7, 12.9254693)	(364.7, 49.28561393)
		(414.7, 43.3432925)
		(464.7, 38.67971465)
		(514.7, 34.92221372)
		(564.7, 31.8301105)
		(614.7, 29.24103367)

PVDATA Points (absolute pressure, volume)		
		(664.7, 27.04146743) (714.7, 25.14966196) (764.7, 23.50524833) (814.7, 22.06267755) (864.7, 20.78693852) (914.7, 19.65066514) (964.7, 18.63217933) (1014.7, 17.71406662)

Figure 209.2: Finite Element Model of Problem



Analysis Assumptions and Modeling Notes

Analysis is performed using both GAS and PVDATA options. Smeared reinforcing element REINF263 is used with a base element to provide evenly spaced reinforcing fibers. A one-quarter axisymmetric (HSFLD241 keyopt (3) =1) model is brought to a reference temperature of T degrees Celsius and subjected to a degree of freedom inflation pressure of P applied at the pressure node. Then, the top rigid plate is lowered a distance X. The **CNVTOL** command is used to set convergence values for the nonlinear analysis.

In the attached input file (vm209.dat), we have only solved for pressure 20 PSI. Modify the D command and use the correct material number (PV points) to solve for pressure 40 and 60 PSI (D, 1, HDSP, 40/Material number 5 and D, 1, HDSDP, 60/Material number 6)

Results Comparison

Table 209.2: 20 PSI Applied-Gas

UY (in)	Target Compressive Load (lbs)	Mechanical APDL	Ratio
.25	1231	1226.55	0.996
.50	1692	1609.80	0.951
.75	2230	2050.35	0.919
1.00	2769	2581.33	0.932
1.25	3384	3246.09	0.959
1.5	4230	4109.82	0.972

Table 209.3: 40 PSI Applied-Gas

UY (in)	Target Compressive Load (lbs)	Mechanical APDL	Ratio
.25	2640	2405.88	0.911
.50	3350	3089.12	0.922
.75	4050	3849.41	0.950
1.00	5000	4738.90	0.948
1.25	6000	5825.32	0.971
1.5	7333	7209.64	0.983

Table 209.4: 60 PSI Applied-Gas

UY (in)	Target Compressive Load (lbs)	Mechanical APDL	Ratio
.25	3875	3596.30	0.928
.50	4650	4578.78	0.985
.75	6000	5658.43	0.943
1.00	7200	6906.07	0.959
1.25	8750	8413.20	0.962

Table 209.5: 20 PSI Applied-PVDATA

UY (in)	Target Compressive Load (lbs)	Mechanical APDL	Ratio
.25	1231	1249.79	1.015
.50	1692	1650.75	0.976
.75	2230	2077.76	0.932
1.00	2769	2613.12	0.944
1.25	3384	3263.09	0.964

UY (in)	Target Compressive Load (lbs)	Mechanical APDL	Ratio
1.5	4230	4238.18	1.002

Table 209.6: 40 PSI Applied-PVDATA

UY (in)	Target Compressive Load (lbs)	Mechanical APDL	Ratio
.25	2640	2455.05	0.930
.50	3350	3185.58	0.951
.75	4050	3950.18	0.975
1.00	5000	4742.42	0.948
1.25	6000	5923.76	0.987
1.5	7333	7251.99	0.989

Table 209.7: 60 PSI Applied-PVDATA

UY (in)	Target Compressive Load (lbs)	Mechanical APDL	Ratio
.25	3875	3613.49	0.933
.50	4650	4580.66	0.985
.75	6000	5674.34	0.946
1.00	7200	6922.04	0.961
1.25	8750	8780.85	1.004

Note

Results Comparison chart displacements have been scaled by a factor of 4 due to quarter symmetry.

Figure 209.3: Results Using GAS Option

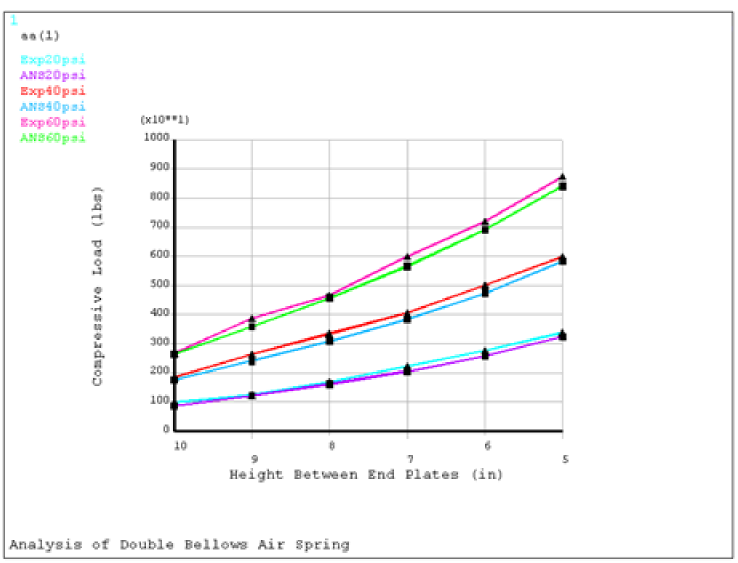
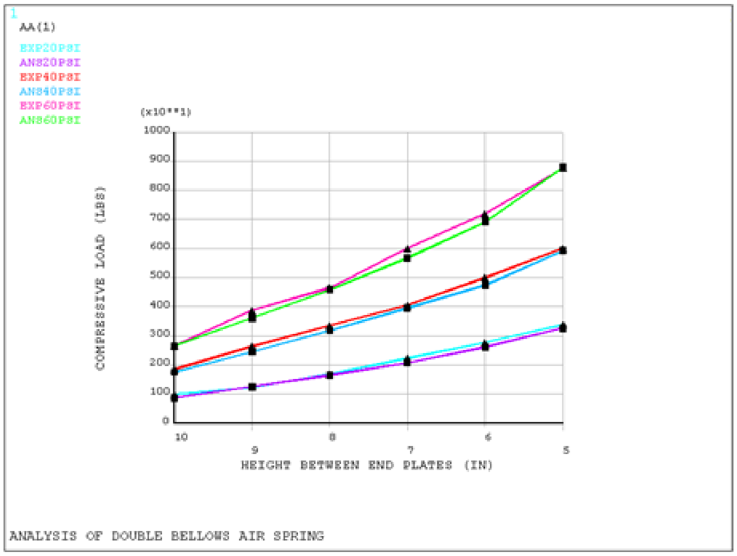


Figure 209.4: Results Using PVDATA Option



VM210: Pyramid Validation of Tetrahedron to Hexahedron

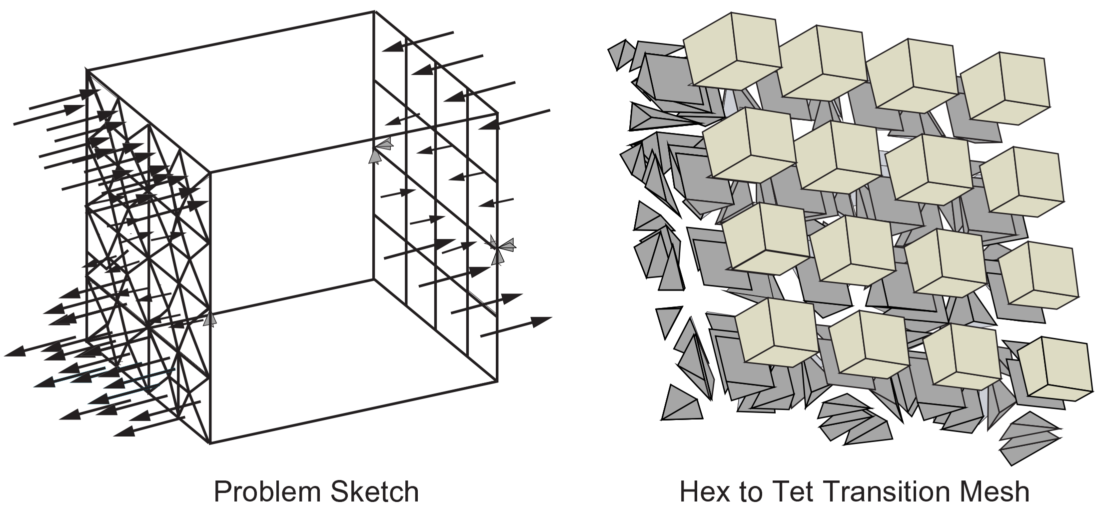
Overview

Reference:	E. P. Popov, *Introduction to Mechanics of Solids*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1998, pp. 182-185.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 20-Node Structural Solid Elements (SOLID95) 3-D 20-Node Structural Solid Elements (SOLID186)
Input Listing:	vm210.dat

Test Case

For an elastic beam subjected to pure bending, validate the use of pyramids in a tetrahedron to hexahedron interface. Find the axial stress at the top, midplane, and bottom surfaces.

Figure 210.1: Tetrahedron to Hexahedron Interface Problem Sketch



Material Properties	Geometric Properties	Loading
E = 30E6 υ = 0.3	W = 31.071 H = 33.917 L = 37.264	at z = 0, L area pressure load sf gradient: (-0.18979 at y = H/2) (0.18979 at y = -H/2)

Analysis Assumptions and Modeling Notes

The problem is solved in two different ways:

- using 3-D solid elements (SOLID95)
- using 3-D solid elements (SOLID186)

The model is generated using the block primitive which is divided into 8 sub-blocks. The pyramid interface is created by meshing the hexahedra first, followed by the tetrahedra. The working plane describes the hex-tet interface region.

Full displacement constraints placed upon three corners in the model midplane does not allow generation of significant reaction forces. A pure bending condition is created by the application of a pressure gradient on the faces of elements lying in the z = 0 and z = L planes. The linear gradient varies from -0.18979 on the bottom to 0.18979 on the top.

$$\sigma_z = (M_z y) / (I_c)$$

where

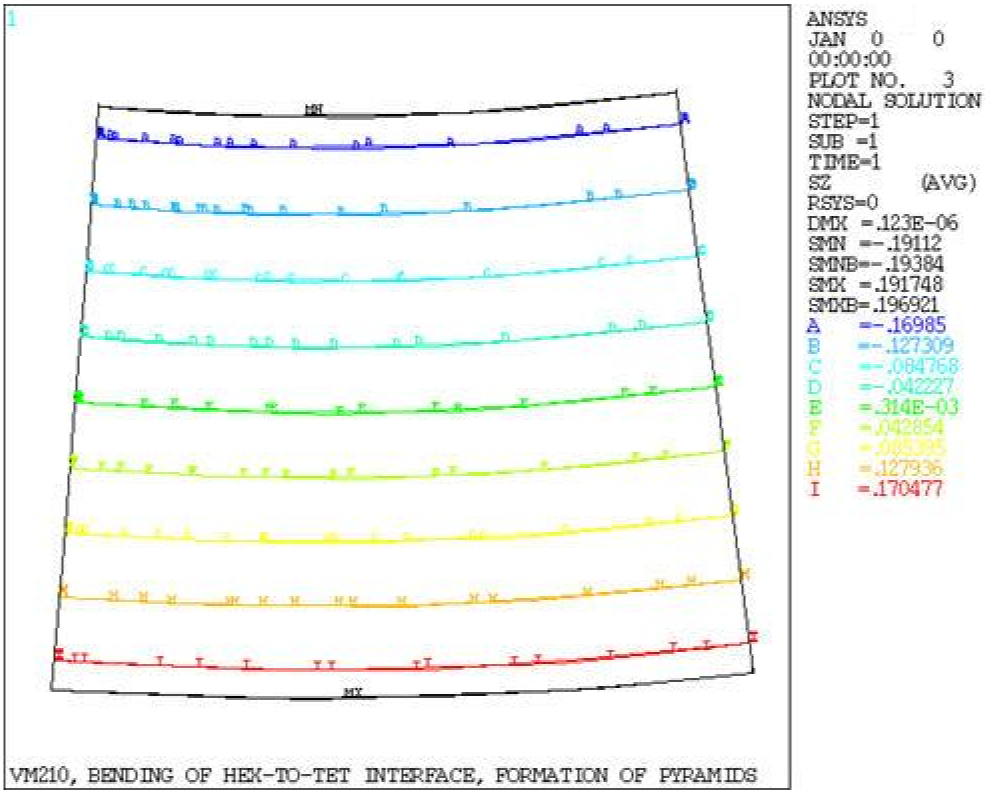
σ_Z = stress in z-direction
M_z = effective moment, z-direction
y = distance from neutral surface
I_c = second moment of area about the horizontal centroidal axis

$I_c = \left(\frac{1}{12}\right)(W H^3)$ for the rectangular ends of the block

Results Comparison

	Target	Mechanical APDL	Ratio
SOLID95			
$Stress_Z$, Top (AVG)	-0.1898	-0.1899	1.001
$Stress_Z$, Neutral Axis (AVG)	0	-0.0001	1.000
$Stress_Z$, Bottom Axis (AVG)	0.1898	0.1898	1.000
SOLID186			
$Stress_Z$, Top (AVG)	-0.1898	-0.1899	1.001
$Stress_Z$, Neutral Axis (AVG)	0	-0.0001	1.000
$Stress_Z$, Bottom Axis (AVG)	0.1898	0.1898	1.000

Figure 210.2: Bending of Hex-to-tet Interface



VM211: Rubber Cylinder Pressed Between Two Plates

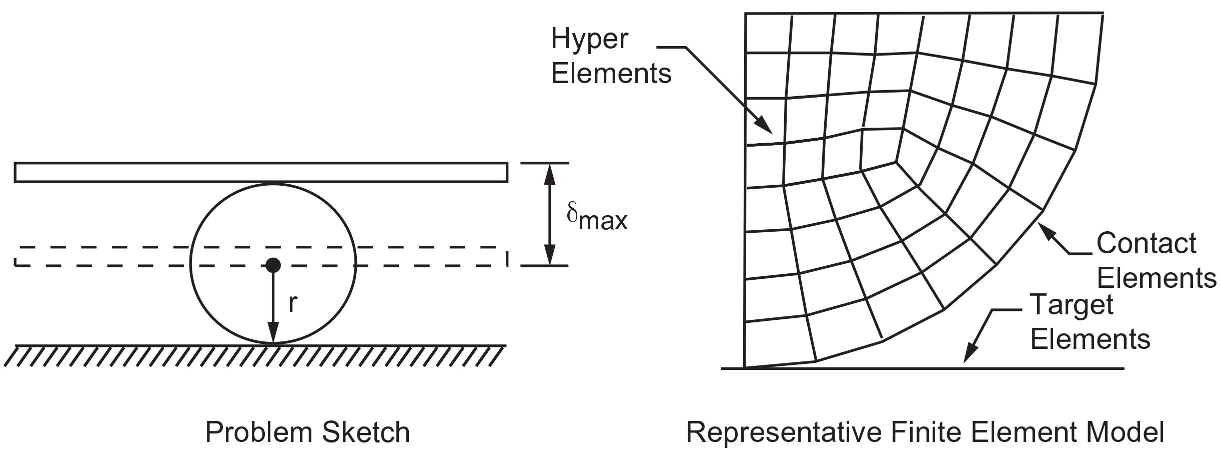
Overview

Reference:	T. Tussman, K-J Bathe, "A Finite Element Formulation for Nonlinear Incompressible Elastic and Inelastic Analysis", *Computers and Structures*, Vol. 26 Nos 1/2, 1987, pp. 357-409.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4-Node Structural Solid Elements (PLANE182) 2-D 8-Node Structural Solid Elements (PLANE183) 3-D 8-Node Structural Solid Elements (SOLID185) 3-D 20-Node Structural Solid or Layered Solid Elements (SOLID186) 2-D 2-Node Surface-to-Surface Contact Elements (CONTA171) 2-D 3-Node Surface-to-Surface Contact Elements (CONTA172) 3-D 4-Node Surface-to-Surface Contact Elements (CONTA173) 3-D 8-Node Surface-to-Surface Contact Elements (CONTA174) 2-D Target Segment Elements (TARGE169) 3-D Target Segment Elements (TARGE170)
Input Listing:	vm211.dat

Test Case

A long rubber cylinder is pressed between two rigid plates using a maximum imposed displacement of δ_{max}. Determine the force-deflection response.

Figure 211.1: Rubber Cylinder Problem Sketch



Material Properties	Geometric Properties	Loading
Mooney-Rivlin Constants: C1 = 0.293 MPa C2 = 0.177 MPa	r = 200 mm	δ_{max} = 200 mm **Real Constant**[1] FKN = 8

1. Applicable to CONTA171, CONTA172, CONTA173, and CONTA174.

Analysis Assumptions and Modeling Notes

This test case solves the problem of VM201 using the 2-D and 3-D rigid target and contact elements. A plane strain solution is assumed based on the geometry of the problem. Due to geometric and loading symmetry, the analysis can be performed using one quarter of the cross section. All nodes on the left edge (X = 0) are constrained, UX = 0. All nodes on the top edge (y = 0) are coupled in UY. An imposed displacement of -0.1 m acts upon the coupled nodes.

This problem is solved in eight different ways. The first four solutions are performed using default contact algorithm and the last four solution are performed using Lagrange multipliers method (KEYOPT(2) = 3) of contact elements.

- The lower order 2-D model used PLANE182 with CONTA171 and TARGE169 elements.
- A higher order 2-D model used PLANE183 with CONTA172 and TARGE169.
- The lower order 3-D model used SOLID185 with CONTA173 and TARGE170.
- The higher order 3-D model used SOLID186 with CONTA174 and TARGE170.
- The lower order 2-D model used PLANE182 with CONTA171 and TARGE169 and solved using Lagrange Multipliers method.
- A higher order 2-D model used PLANE183 with CONTA172 and TARGE169 and solved using Lagrange Multipliers method.
- The lower order 3-D model used SOLID185 with CONTA173 and TARGE170 and solved using Lagrange Multipliers method.
- The higher order 3-D model used SOLID186 with CONTA174 and TARGE170 and solved using Lagrange Multipliers method.

Results Comparison

		Target[1]	Mechanical APDL	Ratio
PLANE182	Force at Displacement = 0.1 (N)	250.00	250.72	1.003
	Force at Displacement = 0.2 (N)	1400.00	1397.36	0.998
PLANE183	Force at Displacement = 0.1 (N)	250.00	251.91	1.008
	Force at Displacement = 0.2 (N)	1400.00	1398.95	0.999
SOLID185	Force at Displacement = 0.1 (N)	250.00	249.60	0.998
	Force at Displacement = 0.2 (N)	1400.00	1389.18	0.992
SOLID186	Force at Displacement = 0.1 (N)	250.00	255.11	1.020
	Force at Displacement = 0.2 (N)	1400.00	1411.80	1.008
With KEYOPT (2) = 3 of CONTA171				
PLANE182	Force at Displacement = 0.1 (N)	250.00	252.57	1.010
	Force at Displacement = 0.2 (N)	1400.00	1406.84	1.005
With KEYOPT (2) = 3 of CONTA172				
PLANE183	Force at Displacement = 0.1 (N)	250.00	256.10	1.024

		Target[1]	Mechanical APDL	Ratio
	Force at Displacement = 0.2 (N)	1400.00	1415.80	1.011
With KEYOPT (2) = 3 of CONTA173				
SOLID185	Force at Displacement = 0.1 (N)	250.00	251.46	1.006
	Force at Displacement = 0.2 (N)	1400.00	1400.48	1.000
With KEYOPT (2) = 3 of CONTA174				
SOLID186	Force at Displacement = 0.1 (N)	250.00	255.55	1.022
	Force at Displacement = 0.2 (N)	1400.00	1416.39	1.012

1. Determined from graphical results. See T. Tussman, K-J Bathe, "A Finite Element Formulation for Nonlinear Incompressible Elastic and Inelastic Analysis", pg. 385, fig. 6.14.

Figure 211.2: Displaced Shape

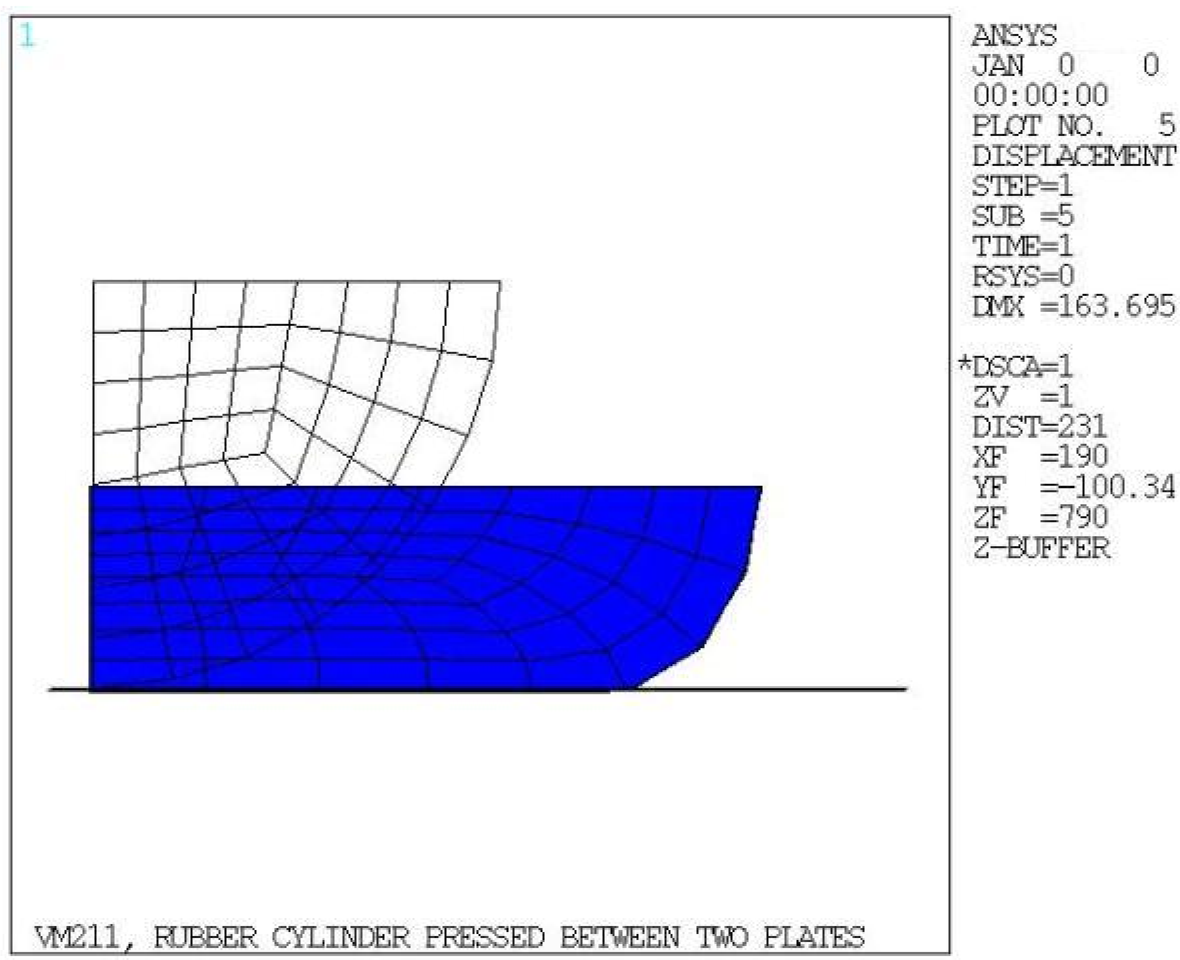
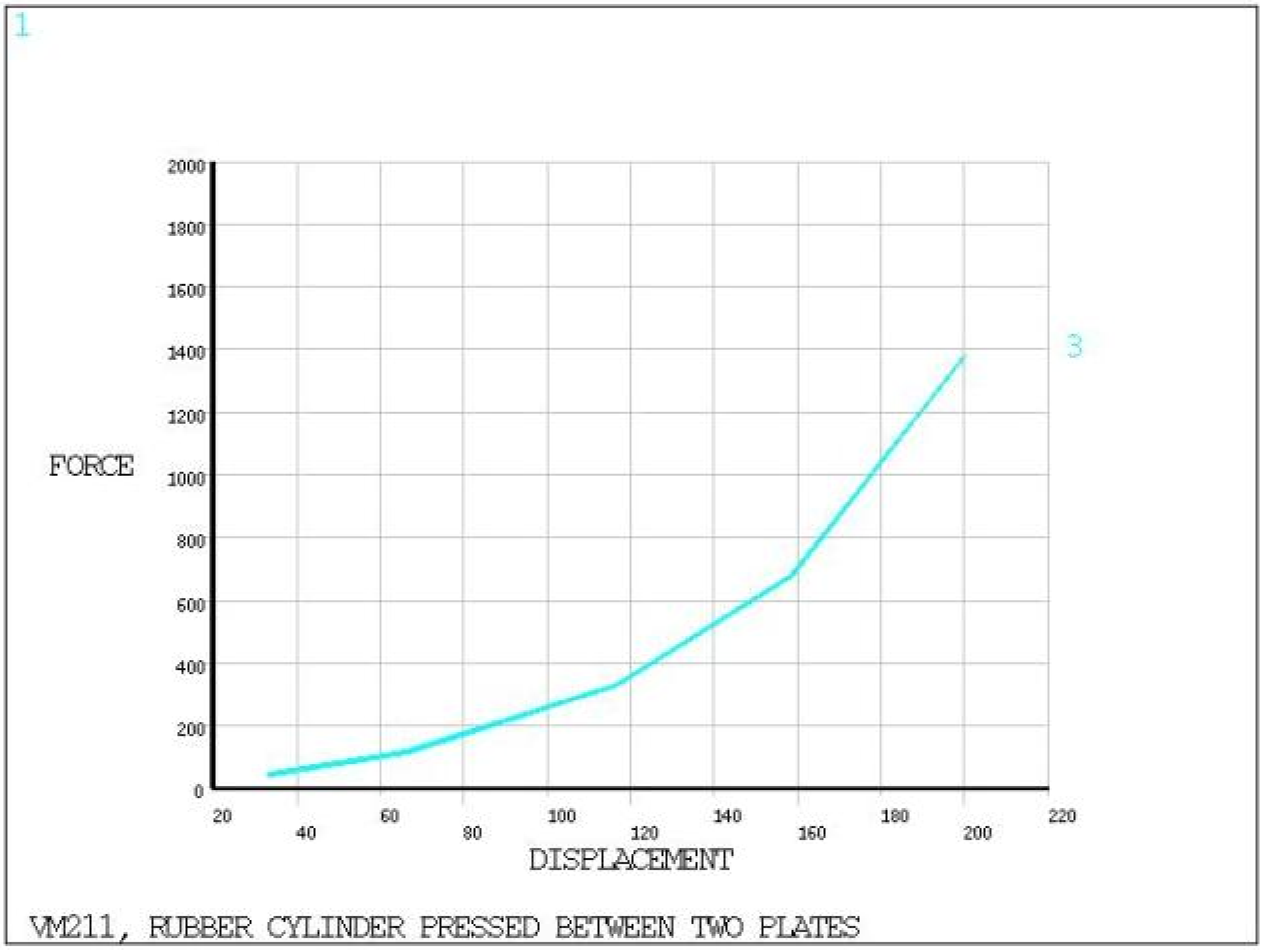


Figure 211.3: Force vs. Displacement



VM212: DDAM Analysis of Foundation System (2-DOF System)

Overview

Reference:	O'Hara, G.J., Cunniff, P. F., "Interim Design Values for Shock Design of Shipboard Equipment", *NRL Memorandum Report 1396*, 1963, p. 10
Analysis Type(s):	Modal Analysis (**ANTYPE** = 2) Spectrum Analysis (**ANTYPE** = 8)
Element Type(s):	Structural Mass (MASS21) Spring-Damper Combination Element (COMBIN40) 3-D 2-Node Beam (BEAM188)
Input Listing:	vm212.dat

Test Case

A simple equipment-foundation system is modeled using a spring-damper element (COMBIN40) representing the foundation, a beam element (BEAM188) representing the equipment, and a mass element (MASS21) representing the equipment mass, as shown in Figure 212.1: Schematic Representation of 2-DOF System (Foundation System) (p. 578).

Shock loading is applied at the fixed base of the foundation system along the athwartship direction. The shock spectrum is based on the ship type, mounting location, direction of shock, and type of design (elastic or elastic-plastic). DDAM analysis is performed on this system to determine natural frequency, deflection, and shock design value.

Figure 212.1: Schematic Representation of 2-DOF System (Foundation System)

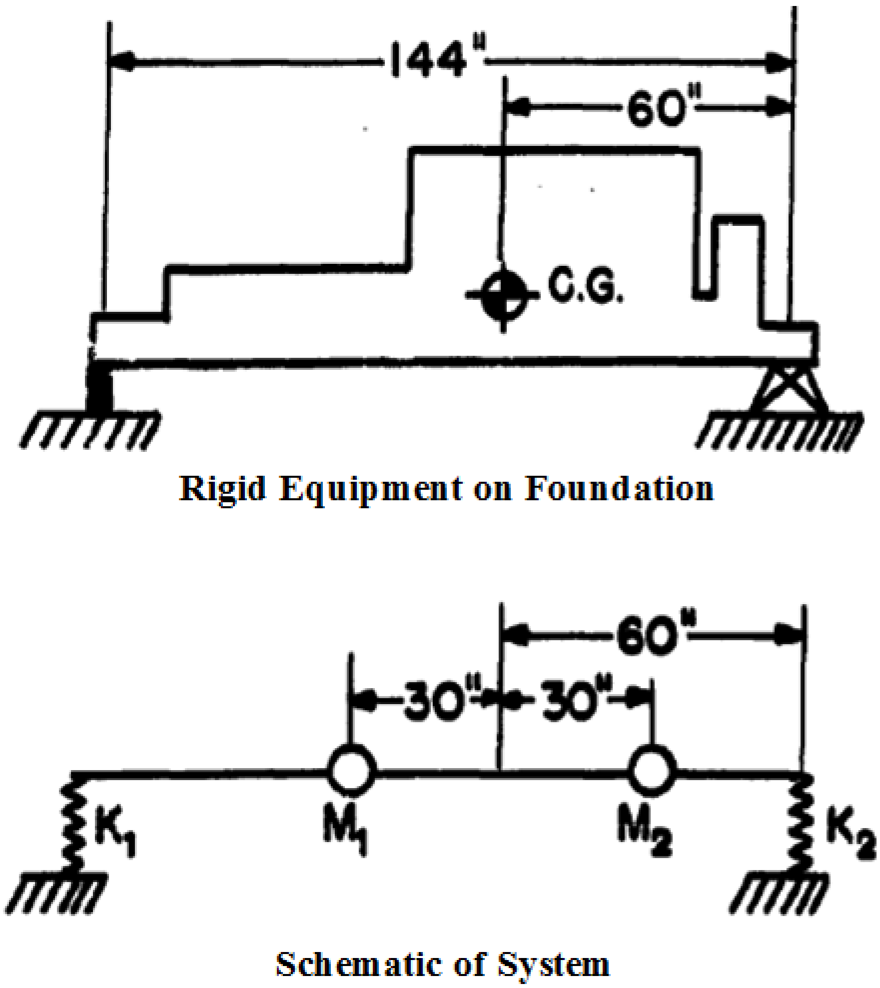
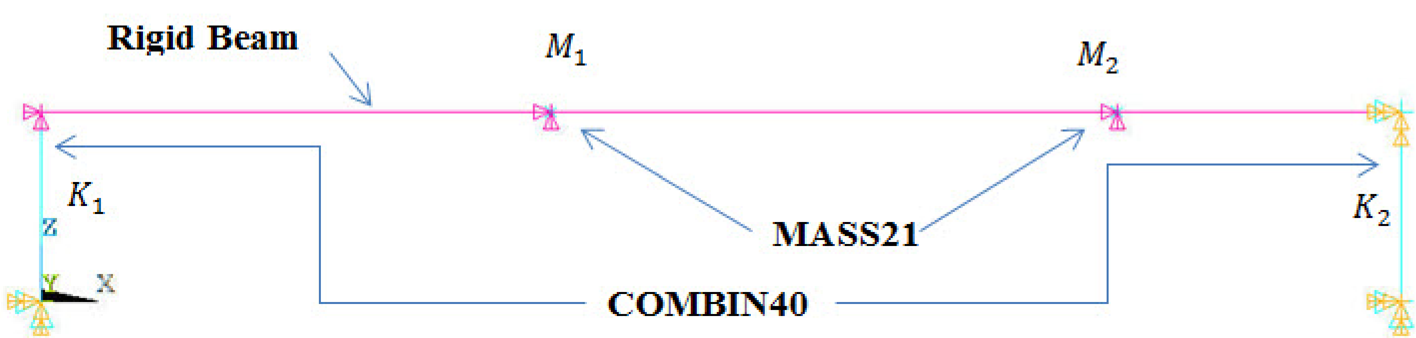


Figure 212.2: Finite Element Representation of 2-DOF System (Foundation System)



Material Properties	Geometric Properties	Loading
Equipment weight, W = 20,000 lb Mass, M_1 (and M_2) = 10,000 lb	Length = 144 in Beam with arbitratry section Area = 100 in^2	Acceleration spectrum computation constants (ADDAM) AF = 0.4

Material Properties	Geometric Properties	Loading
Spring constant, K_1 = 1.3×10^6 lb/in Sprint constant, K_2 = 3.9×10^6 lb/in Foundation material, E = 1.0 psi	Moment of inertia along Y and Z = 833 $in \cdot lb \cdot sec^2$ Thickness along Y and Z = 10 in	AA = 10.0 AB = 37.5 AC = 12.0 AD = 6.0 Velocity spectrum computation constants (VDDAM) VF = 0.2 VA = 30.0 VB = 12.0 VC = 6.0

Analysis Assumptions and Modeling Notes

The equipment is assumed to be rigid. As only unidirectional motion is being considered, the rigid equipment is divided into two equal masses located about the center of gravity such that $\sum_i M_i d_i^2 = I_g$ where I_g is the moment of inertia of the equipment at the center of gravity and d_i is the distance to the mass from the center of gravity.

The fixed support condition is applied at the base of the foundation system. At node 40, only UZ and ROTY DOF are being considered, while other DOFs are constrained.

Results Comparison

	Target	Mechanical APDL	Ratio
f_1, Hz	46.300	46.333	1.001
f_2, Hz	114.000	114.036	1.000
Mode #1			
Node = 20, UZ, Deflection, in	0.1629	0.1629	1.000
Node = 30, UZ, Deflection, in	0.1099	0.1099	1.000
Mode Coefficient	0.1931	0.1931	0.999
Participation Factor	7.0659	7.0659	1.001
Shock Design Value, D_1, in/sec^2	2316.000	2316.000	1.000
Mode #2			
Node = 20, UZ, Deflection, in	-0.1099	0.1099	1.000
Node = 30, UZ, Deflection, in	0.1629	-0.1629	1.000

	Target	Mechanical APDL	Ratio
Mode Coefficient	0.0218	-0.0218	1.000
Participation Factor	1.3730	-1.3735	1.000
Shock Design Value, D_2, in/sec^2	8133.000	8132.8713	1.000

VM213: Differential Inductance of a Transformer

Overview

Reference:	M. Gyimesi, D. Ostergaard, "Inductance Computation by Incremental Finite Element Analysis", *IEEE Transactions on Magnetics*, vol. 35, no. 3, 1998, pp. 1119-1122.
Analysis Type(s):	Nonlinear Magnetic Static Analysis (**ANTYPE** = 0) Linear Perturbation Magnetic Static Analysis
Element Type(s):	3-D 20-Node Electromagnetic Solid Element (SOLID236)
Input Listing:	vm213.dat

Test Case

A transformer with a nonlinear iron core is wound with two separate coils. Coil 1 is excited by a current of 0.2 A, while coil 2 is excited by a current of 0.025 A. Calculate the differential self-inductance of both coil 1 and 2, as well as the differential mutual inductance between the two coils.

Figure 213.1: Schematic Drawing of a Transformer

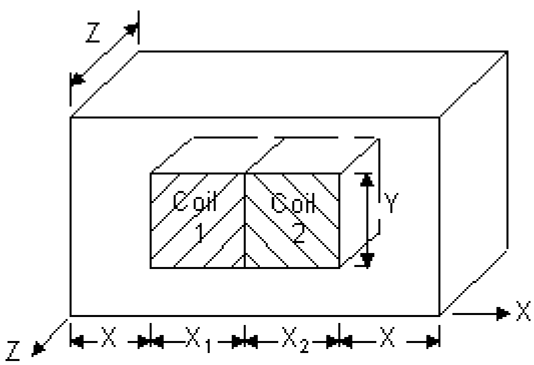
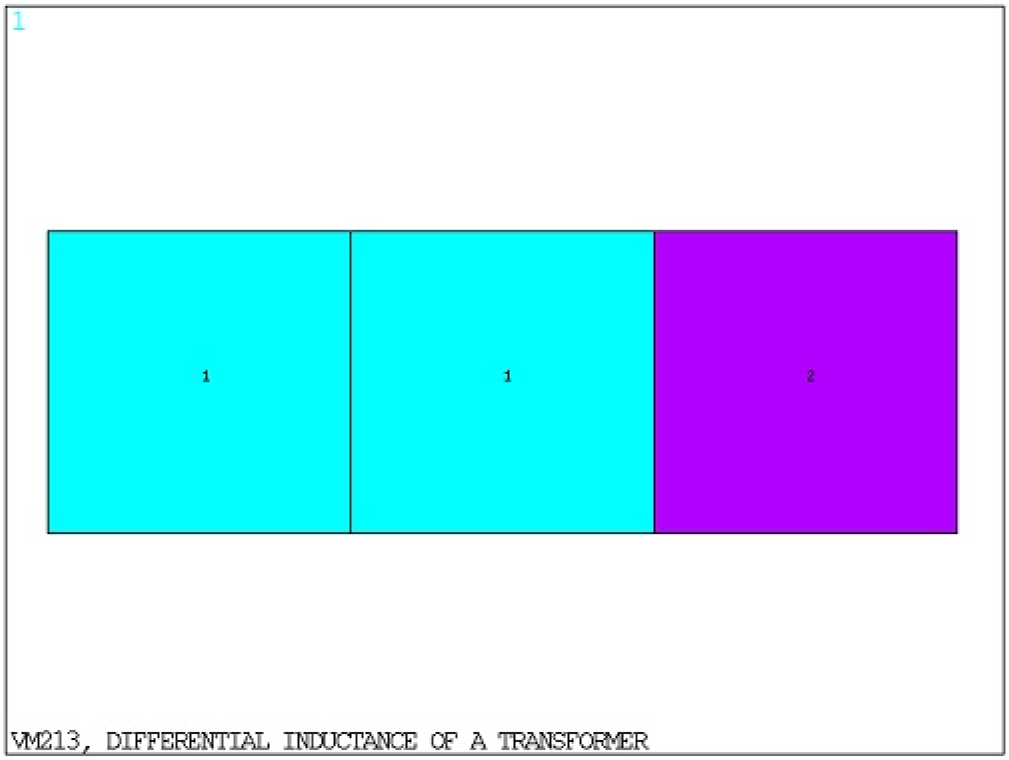


Figure 213.2: Finite Element Model



Material Properties	Geometric Properties	Loading
$B = B_s \sqrt{\frac{H}{H_s}}$ where B_s = 2T H_s = 100 A/m	$X = X_1 = X_2 = Y = Z$ = 0.015m Number of turns in coil 1, N_1 = 10 Number of turns in coil 2, N_2 = 20	Applied current in coil 1, I_1 = 0.2 A Applied current in coil 2, I_2 = 0.025 A

Analysis Assumptions and Modeling Notes

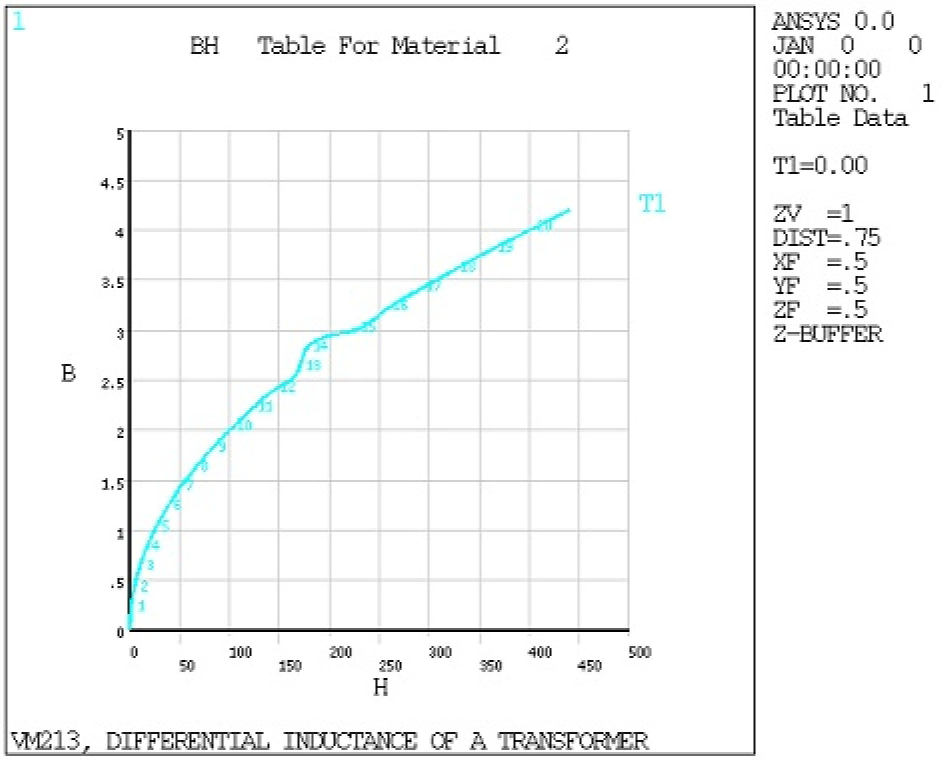
The half-symmetry model of the transformer consists of three blocks, which represent coil 1, coil 2, and the nonlinear iron core. The blocks are meshed using edge-based electromagnetic elements (SOLID236). A nonlinear magnetic static analysis is performed first to determine the operating point (I1, I2). The nonlinear analysis is followed by a linear perturbation magnetic static analysis with three load steps (I1, I0), (I0,I2), and (I1, I2), to determine the coil differential inductance with respect to an operating point (I1,I2). The differential inductance matrix is derived from the incremental energy of the system at these solution points. The incremental energy is calculated using the IENE element record.

Results Comparison

		Target	Mechanical APDL	Ratio
Inductance	Self-Coil 1	0.4000	0.4002	1.001
	Self-Coil 2	1.6000	1.6008	1.000
	Mutual	0.8000	0.8004	1.001

		Target	Mechanical APDL	Ratio
Energy (J)	Energy	0.0166	0.0167	1.005
	Co-energy	0.0333	0.0333	1.000
Flux (W)	Coil 1	0.2000	0.2000	1.000
	Coil 2	0.4000	0.4000	1.000

Figure 213.3: Harmonic Analysis of a Coaxial Cable



VM214: Rotating Rod in a Uniform Magnetic Field

Overview

Reference:	Any basic electromagnetics textbook
Analysis Type(s):	Electromagnetic Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 20-Node Electromagnetic Solid Elements (SOLID236)
Input Listing:	vm214.dat

Test Case

A conducting rod of length L (along the X-axis) and radius R is rotated about the Z-axis in a uniform magnetic field B_z with angular velocity Ω_z. Determine the induced voltage difference V between the ends of the rod.

Figure 214.1: Rotating Rod Surrounded by an Air Box

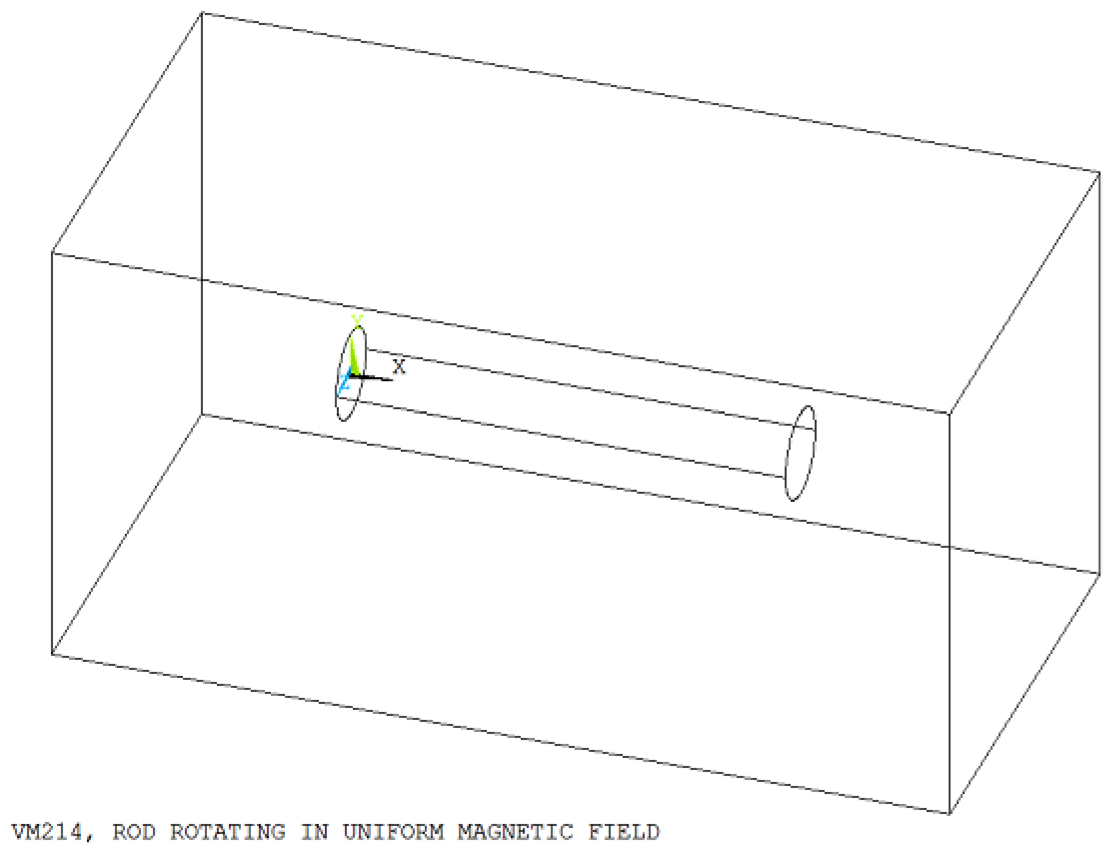


Figure 214.2: Finite Element Mesh of a Rod

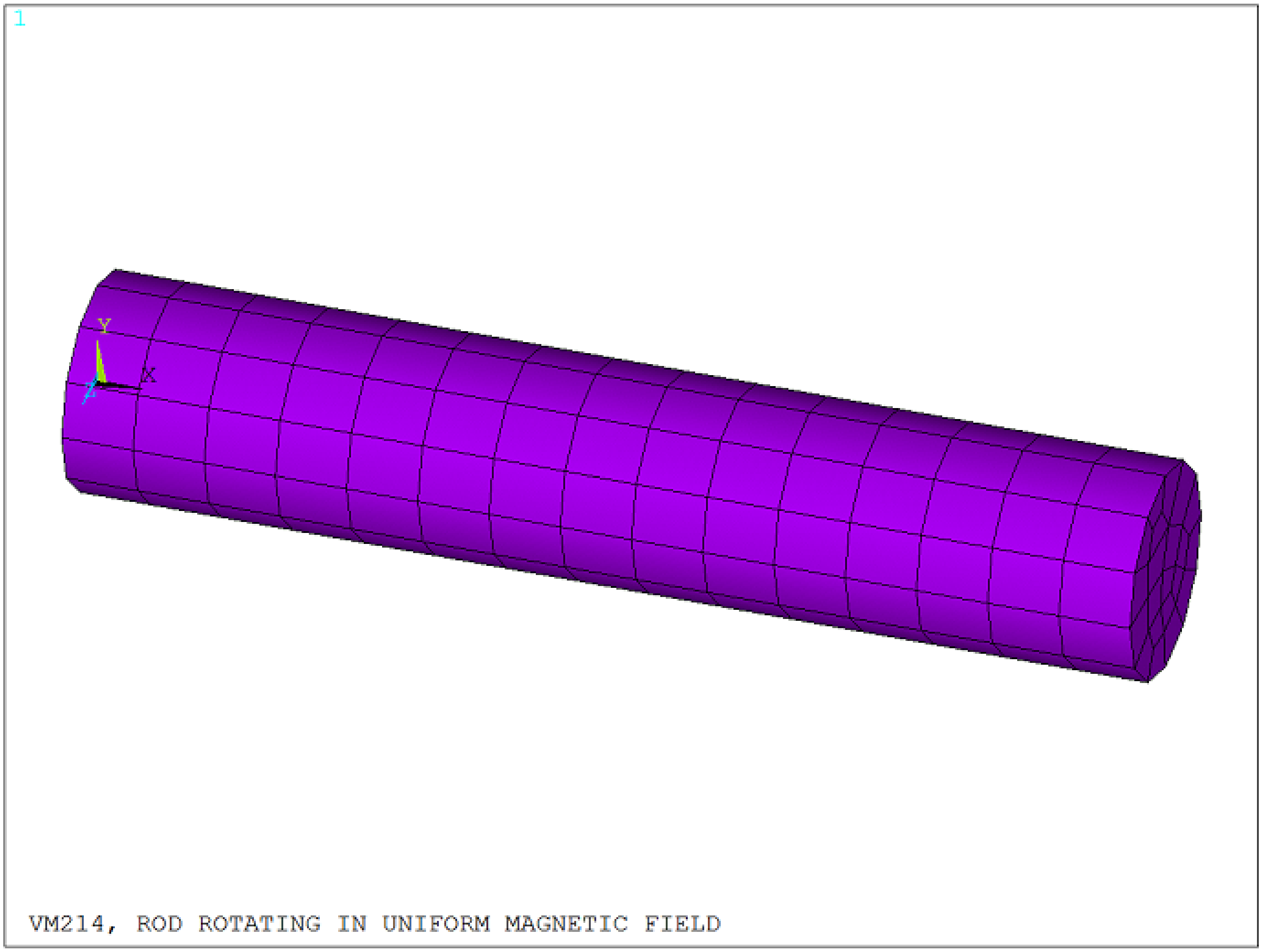
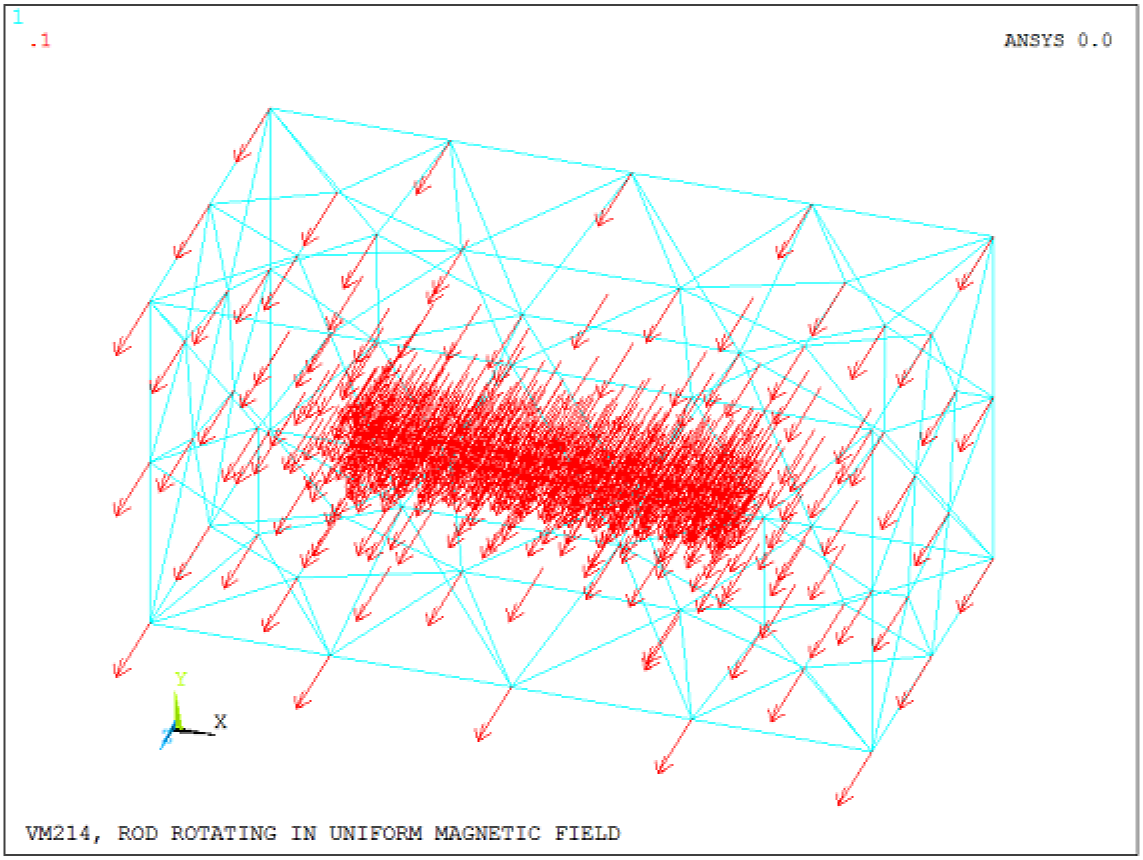


Figure 214.3: Uniform Magnetic Field



Material Properties	Geometric Properties	Loading
Relative magnetic permeability, μ =1 Electrical resistivity, ρ = 1 Ohm-m	Length, L = 0.06 m Radius, R = L/10 = 0.006 m	Magnetic field, B_z = 0.1 T Angular velocity, Ω_z = 60 Hz or 377 rad/s

Analysis Assumptions and Modeling Notes

The model consists of a conducting rod surrounded by an open air box, as shown in Figure 214.1: Rotating Rod Surrounded by an Air Box (p. 585). The rod is meshed with brick-shaped electromagnetic (KEYOPT(1) = 1) elements (SOLID236), and the surrounding air box with tetrahedron-shaped magnetic (KEYOPT(1) = 0) elements (SOLID236). Angular velocity Ω_z is specified using the **BF**,,VELO load to take into account the velocity effects in the conducting rod. The uniform magnetic field B_z is defined using the **DFLX** command. One end of the rod is electrically ground (**D**,,VOLT,0).

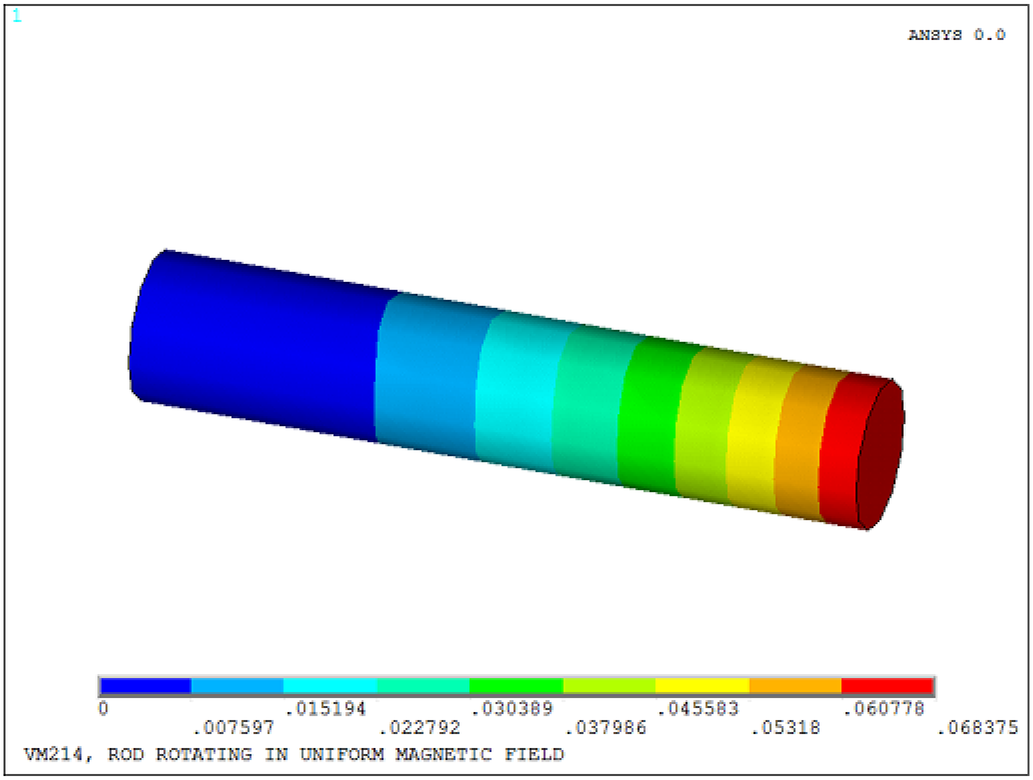
A linear static electromagnetic analysis is performed to determine the voltage distribution in the rod. The calculated voltage at the free end of the rod agrees with the analytical solution for the induced EMF:

$$V = \frac{1}{2}\Omega_z B_z L^2$$

Results Comparison

	Target	Mechanical APDL	Ratio
Voltage	0.06786	0.06770	0.998

Figure 214.4: Electric Potential Distribution in the Rod



VM215: Thermal-Electric Hemispherical Shell with Hole

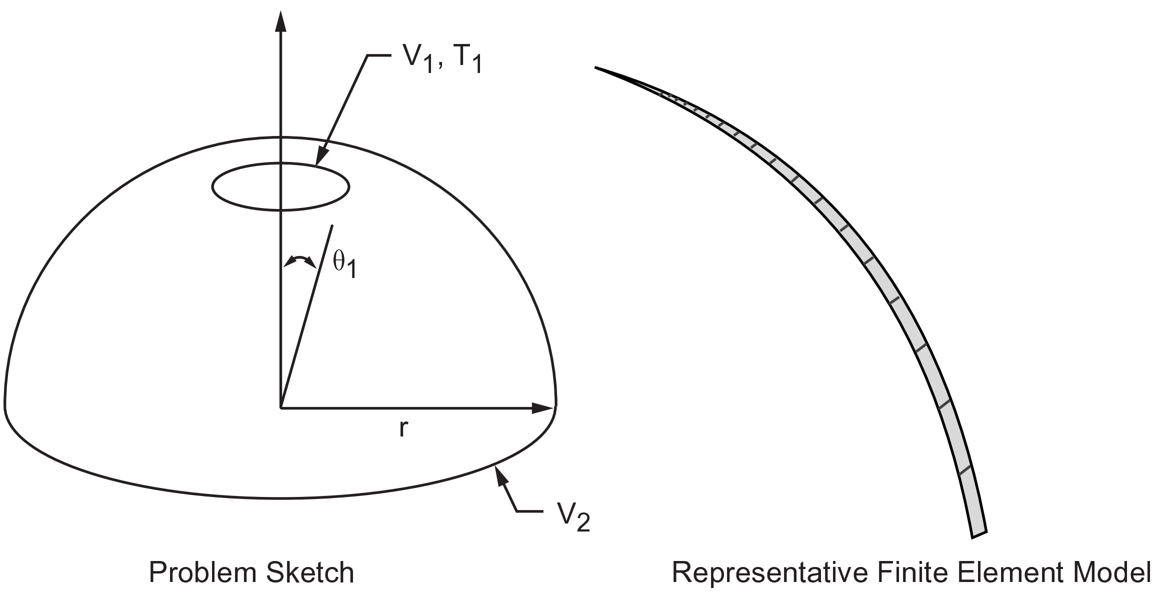
Overview

Reference:	Any standard electrical engineering text
Analysis Type(s):	Coupled Thermal-Electric Shell
Element Type(s):	Thermal-Electric Shell Elements (SHELL157)
Input Listing:	vm215.dat

Test Case

A conducting hemisphere of radius, r, has a hole subtending an angle Θ_1. The edge of the hole is electrically and thermally grounded. A voltage, V_2, is applied at the equator. A Φ degree sector in the azimuthal plane is analyzed.

Figure 215.1: Hemispherical Shell Problem Sketch



Material Properties	Geometric Properties	Loading
ρ = 7 ohm-m K = 3 W/m-K	t = 0.2 m r = 10 m Θ_1 = 10° Φ = 3°	V_1 = 0 volts V_2 = 100 volts T_1 = 0°C

Analysis Assumptions and Modeling Notes

A hemispherical shell with a hole is analyzed. The symmetry of the model is utilized and only a 3 degree sector in the azimuthal direction is analyzed.

The electric current (I) in the sphere is given by:

$$I = \frac{V}{R} = \frac{(V_2 - V_1)}{R}$$

Where resistance R is given by:

$$R = \rho \int \frac{dL}{A}$$

$$= \rho \int \frac{r d\theta}{2\pi r t \cos\theta} \left(\frac{2\pi}{\phi} \right) \text{with } \phi \text{ in radians}$$

$$= \left(\frac{pr}{2\pi r t} \right) \left(\frac{2\pi}{\phi} \right) \int_{\theta=0}^{\theta - 90 - \theta_1} \frac{d\theta}{\cos\theta}$$

$$= \left(\frac{pr}{2\pi r t} \right) \left(\frac{360^\circ}{3^\circ} \right) \frac{1}{2} \ln \left[\frac{1 + \sin(90 - \theta_1)}{1 - \sin(90 - \theta_1)} \right]$$

The total heat flow is due to Joule Heating and is given by $Q = I (V_2 - V_1)$

Results Comparison

SHELL157	Target	Mechanical APDL	Ratio
I (Amps) Node 21	0.06140	0.06143	1.000
Q (Watts) Node 21	6.14058	6.14291	1.000

VM216: Lateral Buckling of a Right Angle Frame

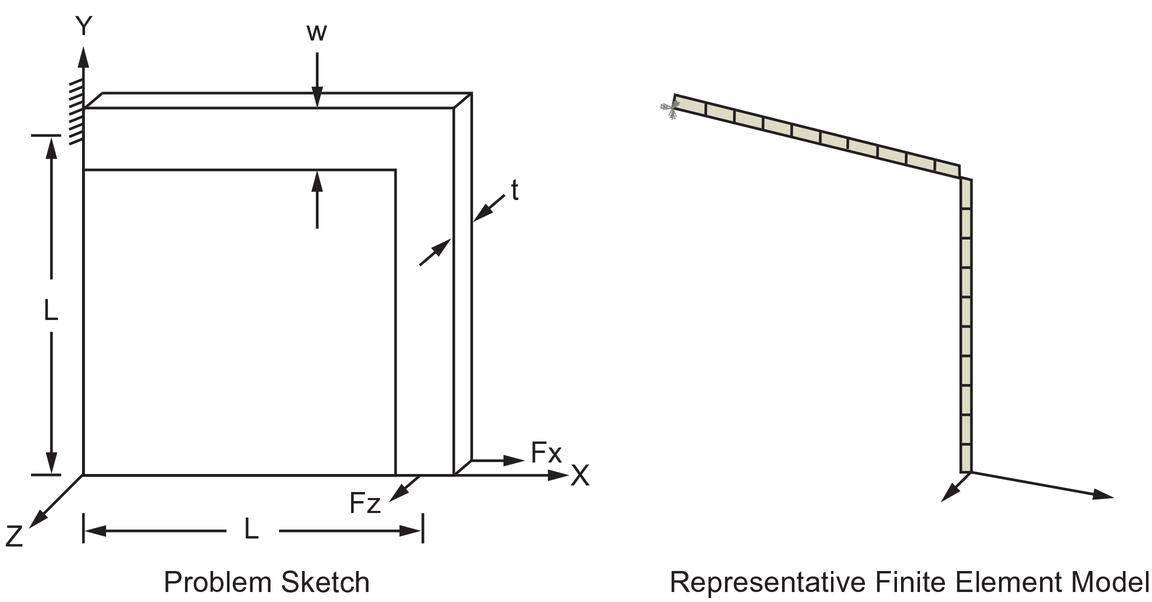
Overview

Reference:	J. C. Simo, L. Vu-Quoc, "Three-Dimensional Finite-Strain Rod Model, Part II", *Computer Methods in Applied Mechanical Engineering*, Vol. 58, 1986, pp. 79-116.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Linear Finite Strain Beam Elements (BEAM188) 3-D Quadratic Finite Strain Beam Elements (BEAM189)
Input Listing:	vm216.dat

Test Case

A 0.6in thick plate that is 30in wide is fashioned into a cantilever right angle frame, and is subjected to an in-plane fixed end load (Fx). The frame is driven to buckling mode by a perturbation load (Fz) applied at the free end, normal to the plane of the frame. This perturbation is removed close to the buckling load. Determine the critical load.

Figure 216.1: Right Angle Frame Problem Sketch



Material Properties	Geometric Properties	Loading
Ex = 71240 psi Nuxy = 0.31	Izz = 0.54 in Iyy = 1350 in^4 t = 0.6 in w = 30 in L = 240 in	Fz = 1 x 10^{-3} lb Fx = 1.485 lb

Analysis Assumptions and Modeling Notes

A first analysis is performed using BEAM188 elements. A second analysis is also performed using BEAM189 elements.

Results Comparison

Critical Load	Target	Mechanical APDL	Ratio
BEAM188	1.09	1.045	0.959
BEAM189	1.09	1.045	0.959

Figure 216.2: Displacement Tip vs. Applied End Force (Fx) using BEAM188 elements

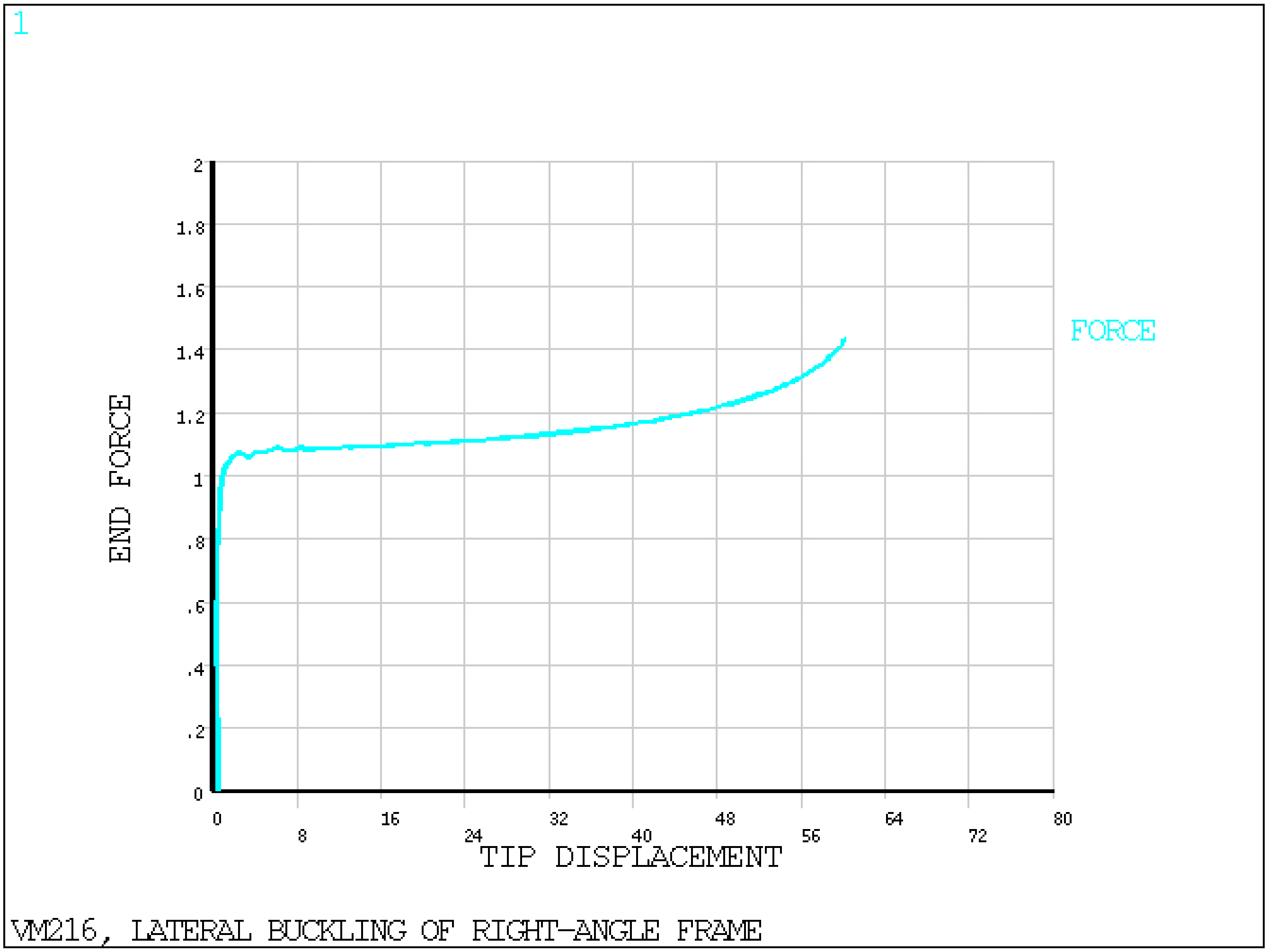
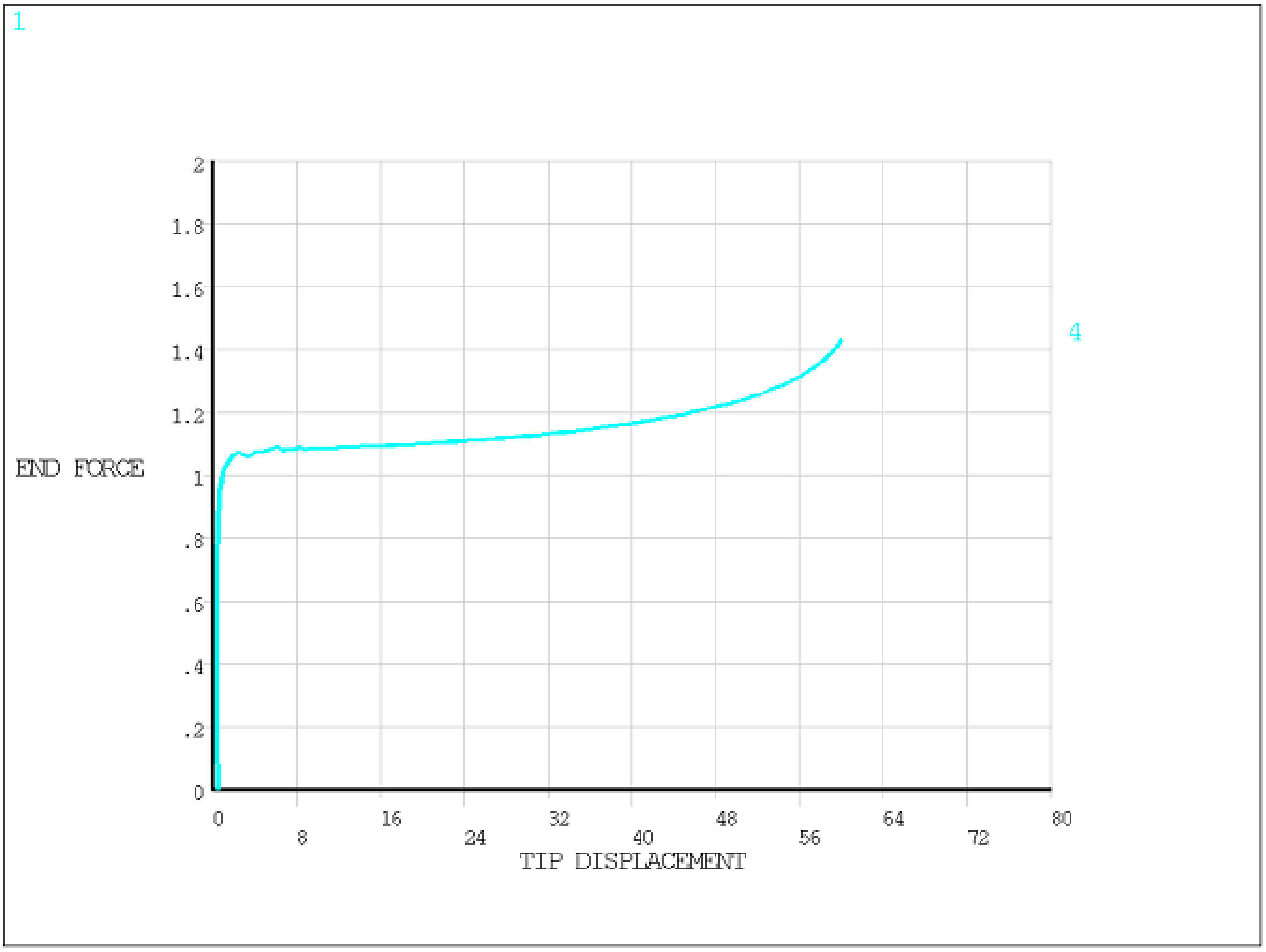


Figure 216.3: Displacement Tip vs. Applied End Force (Fx) using BEAM189 elements



VM217: Portal Frame Under Symmetric Loading

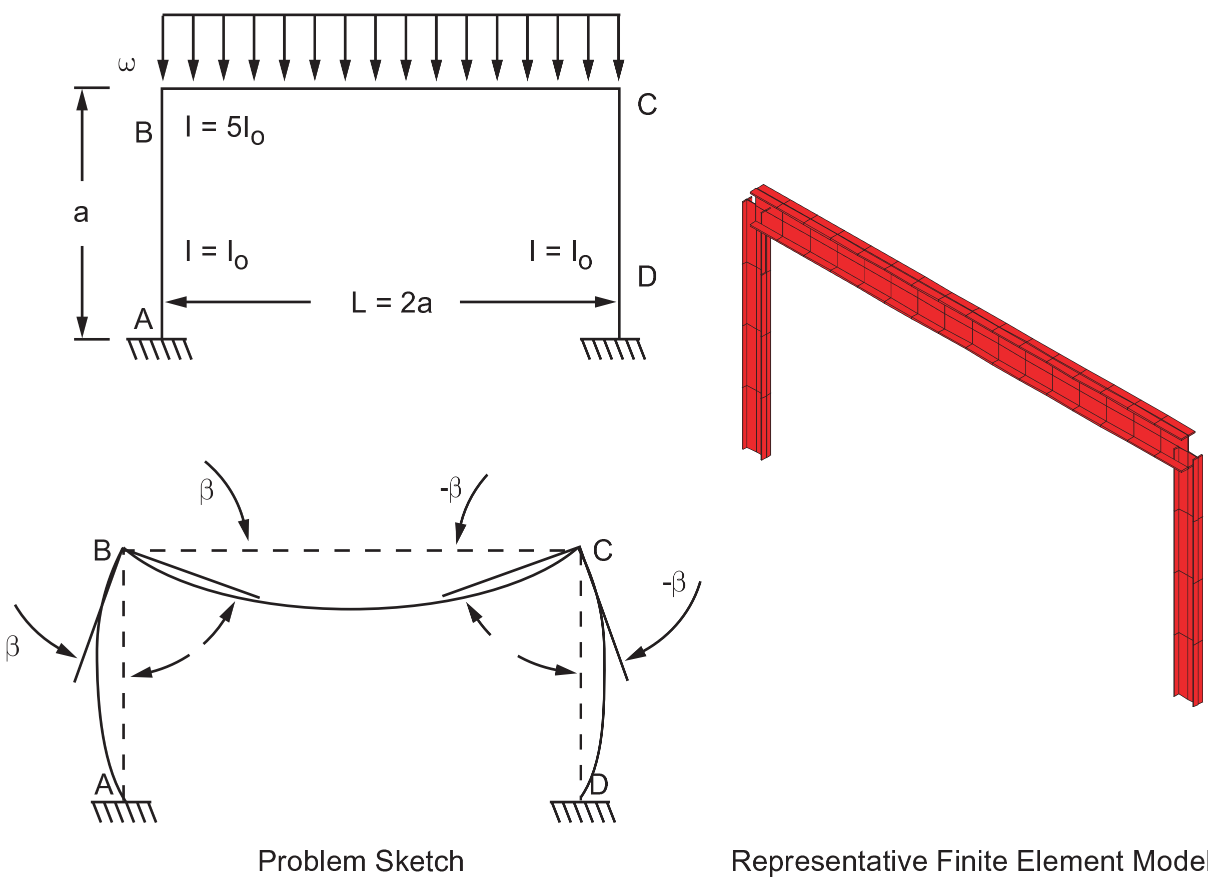
Overview

Reference:	N. J. Hoff, *The Analysis of Structures*, John Wiley and Sons, Inc., New York, NY, 1956, pp. 115-119.
Analysis Type(s):	Static Structural (**ANTYPE** = 0)
Element Type(s):	3-D Linear Finite Strain Beam Elements (BEAM188) 3-D Quadratic Finite Strain Beam Elements (BEAM189)
Input Listing:	vm217.dat

Test Case

A rigid rectangular frame is subjected to a uniform distributed load ω across the span. Determine the maximum rotation, and maximum bending moment. The moment of inertia for the span, I_{span} is five times the moment of inertia for the columns, I_{col}.

Figure 217.1: Portal Frame Problem Sketch



Material Properties	Loading	Geometric Properties	I-Beam Section Data
Ex = 30 x 10^6 psi	ω = -500 lb/in	a = 400 in L = 800 in	W1 = W2 = 16.655 in

Material Properties	Loading	Geometric Properties	I-Beam Section Data
Nuxy = 0.3		I_{span} = 5 I_{col} I_{col} = 20300 in^4	W3 = 36.74 in t1 = t2 = 1.68 in t3 = 0.945 in

Analysis Assumptions and Modeling Notes

All the members of the frame are modeled using an I-Beam cross section. The cross section for the columns is chosen to be a W36 x 300 I-Beam Section. The dimensions used in the horizontal span are scaled by a factor of 1.49535 to produce a moment of inertia that is five times the moment of inertia in the columns. The columns are modeled with BEAM188, while the span is modeled with BEAM189 elements. The theoretical maximum rotation is β =(1/27) (w(a^3)/E(I_{col})), and the theoretical maximum bend moment is M_{max} = (19/54)(w(a^2)).

Results Comparison

	Target	Mechanical APDL	Ratio
Max. Rotation	0.195E-2	0.213E-2	1.093
Max. Bend Moment in lb	0.281E8	0.287E8	1.019

Figure 217.2: I-Section

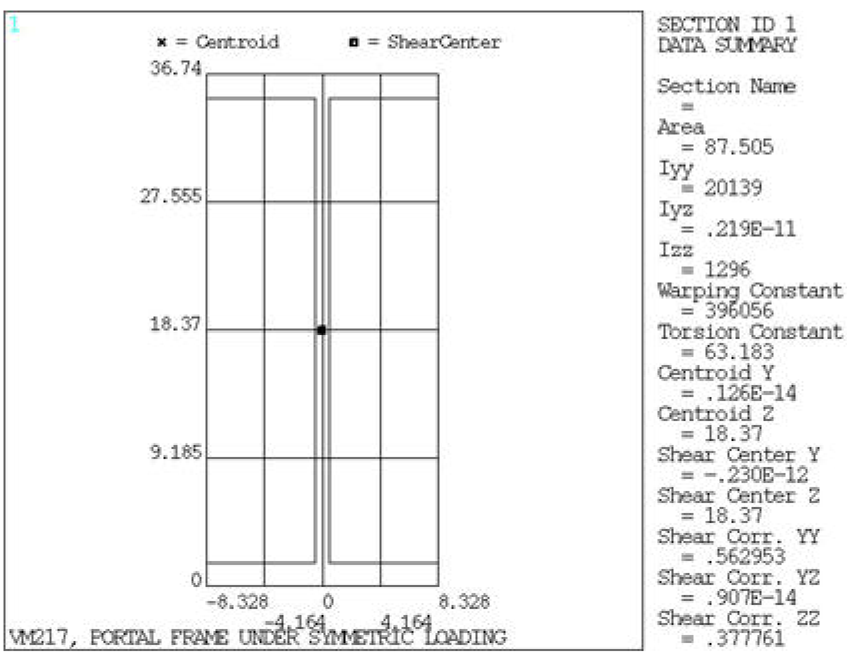


Figure 217.3: I-Section Under Symmetric Loading

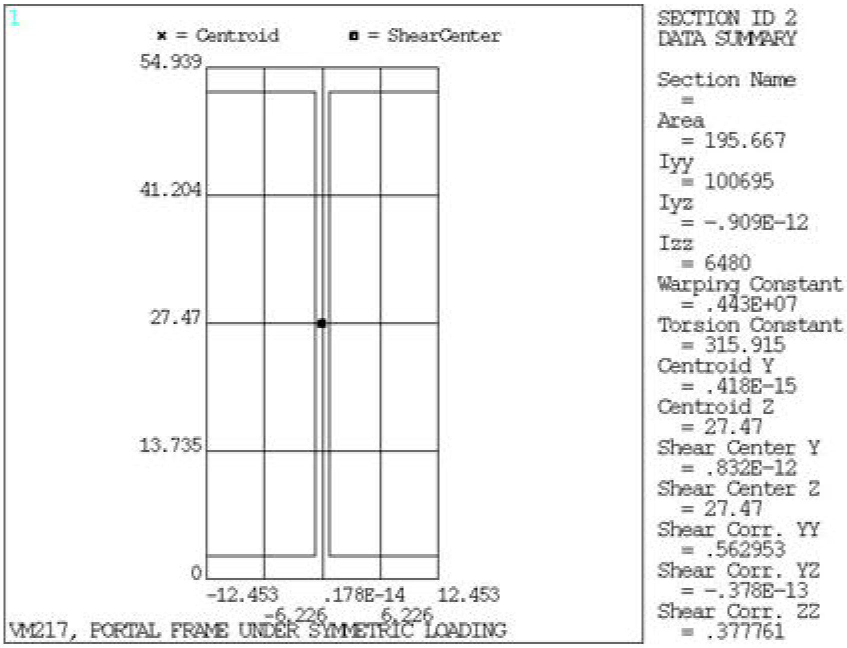


Figure 217.4: Moment Diagram

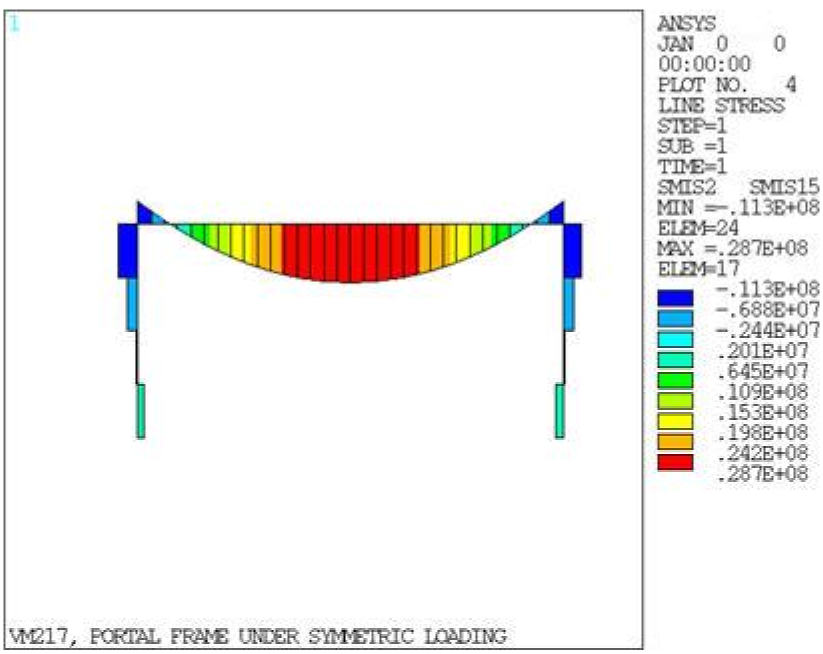
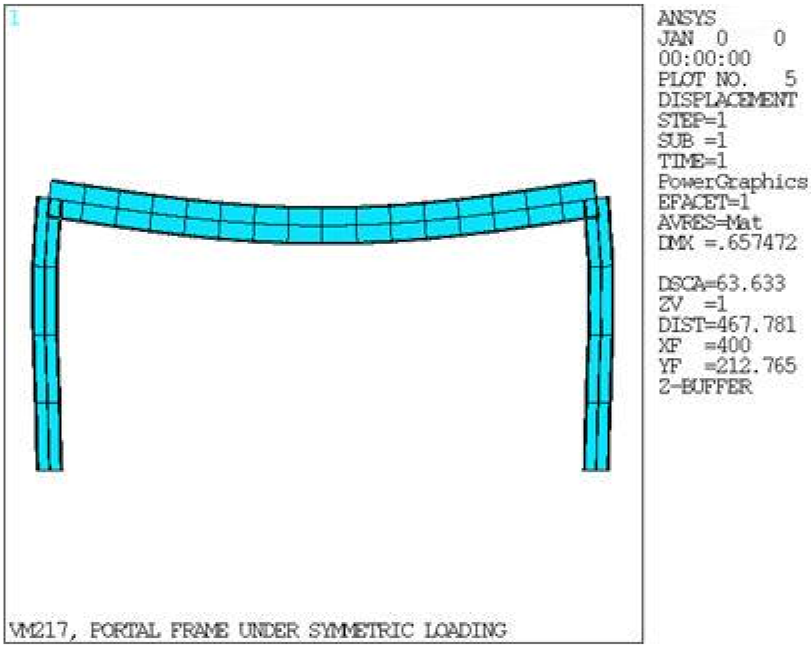


Figure 217.5: Displaced Shape (front view)



VM218: Hyperelastic Circular Plate

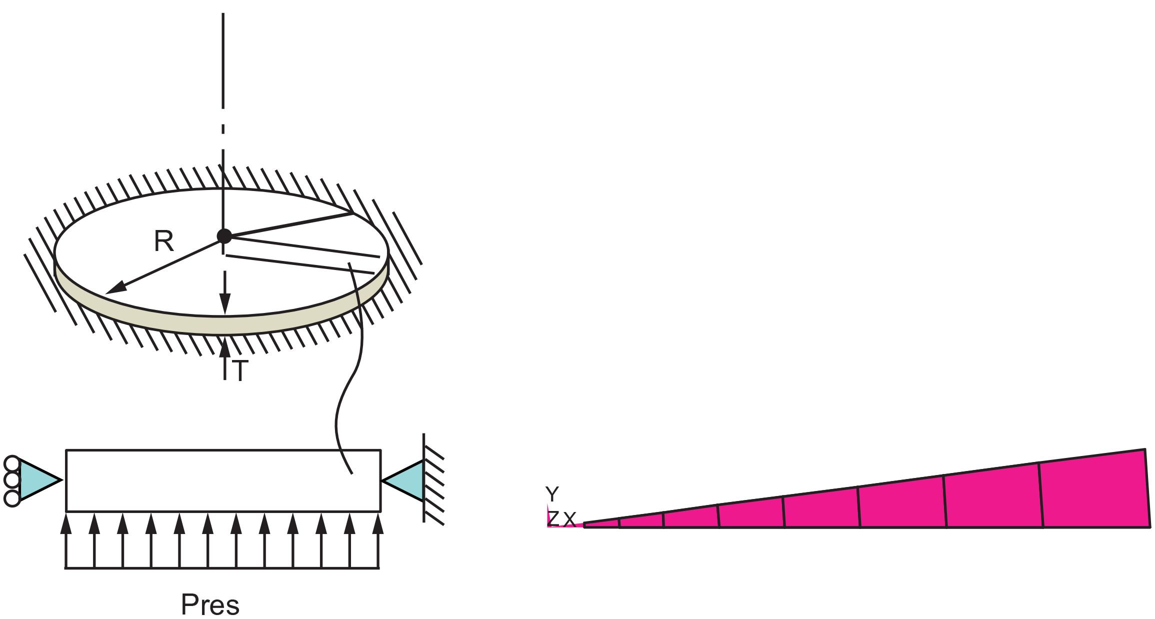
Overview

Reference:	J. T. Oden, *Finite Elements of Nonlinear Continua*, McGraw-Hill Book Co., Inc., New York, NY, 1972, pp. 318-321.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	4-Node Finite Strain Shell Elements (SHELL181) 2-Node Finite Strain Axisymmetric Shell Elements (SHELL208) 8-Node Finite Strain Shell Elements (SHELL281)
Input Listing:	vm218.dat

Test Case

A flat circular membrane made of a rubber material is subjected to uniform water pressure. The edges of the membrane are fixed. Determine the response as pressure is increased to 50 psi.

Figure 218.1: Hyperelastic Circular Plate Project Sketch



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
C_1 = 80 psi C_2 = 20 psi	R = 7.5 in T = 0.5 in	Pres = 50.0 psi

Analysis Assumptions and Modeling Notes

The full circular plate is reduced to a 7.5° sector for analysis. The midplane of the outer edge of the circle is considered to be fixed. A pressure of 50 psi is applied to the bottom surface of the shell sector. The SHELL181 and SHELL281 models are solved using standard formulation using reduced integration.

Four different analyses are performed using SHELL181, SHELL208, SHELL209, and SHELL281 elements, respectively.

Results Comparison

Pressure	Target	Mechanical APDL	Ratio
SHELL181			
4.0	2.250	2.292	1.019
24.0	6.200	5.715	0.922
38.0	10.900	10.092	0.926
SHELL208			
4.0	2.250	2.301	1.023
24.0	6.200	5.730	0.924
38.0	10.900	10.079	0.925
SHELL209			
4.0	2.250	2.288	1.017
24.0	6.200	5.704	0.920
38.0	10.900	10.118	0.928
SHELL281			
4.0	2.250	2.291	1.018
24.0	6.200	5.716	0.922
38.0	10.900	10.180	0.934

Figure 218.2: Results Plot 1 - UZ vs. Thickness

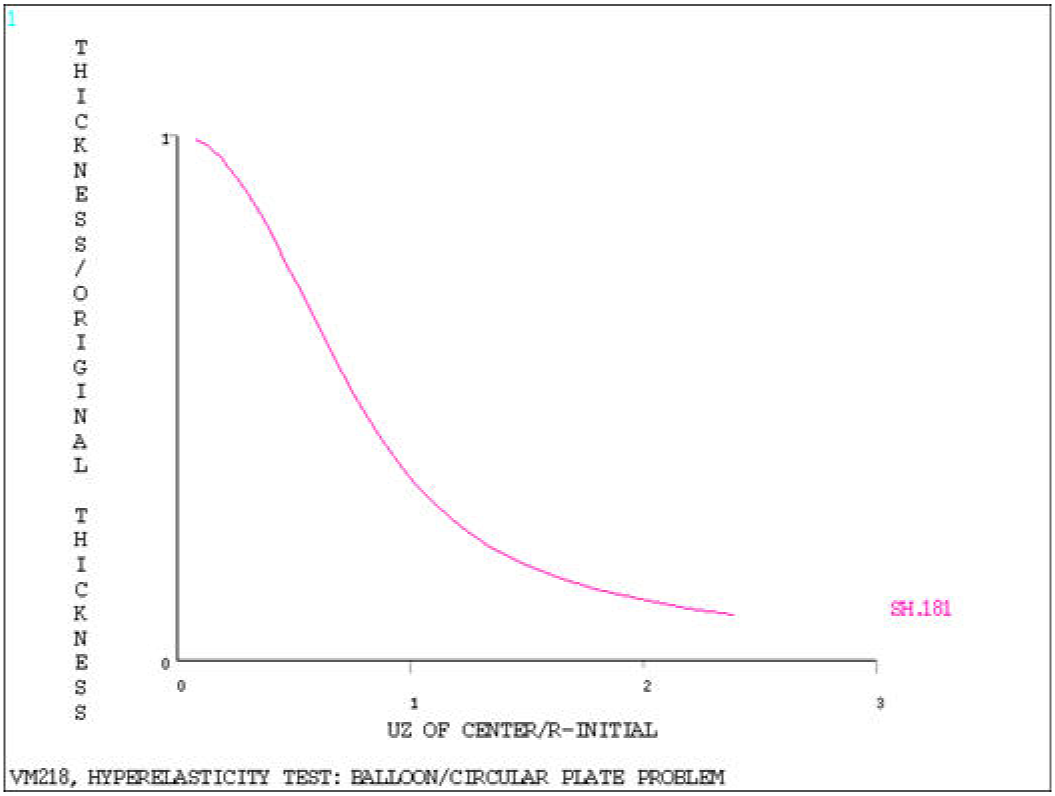


Figure 218.3: Results Plot 2 - UZ vs. Pressure

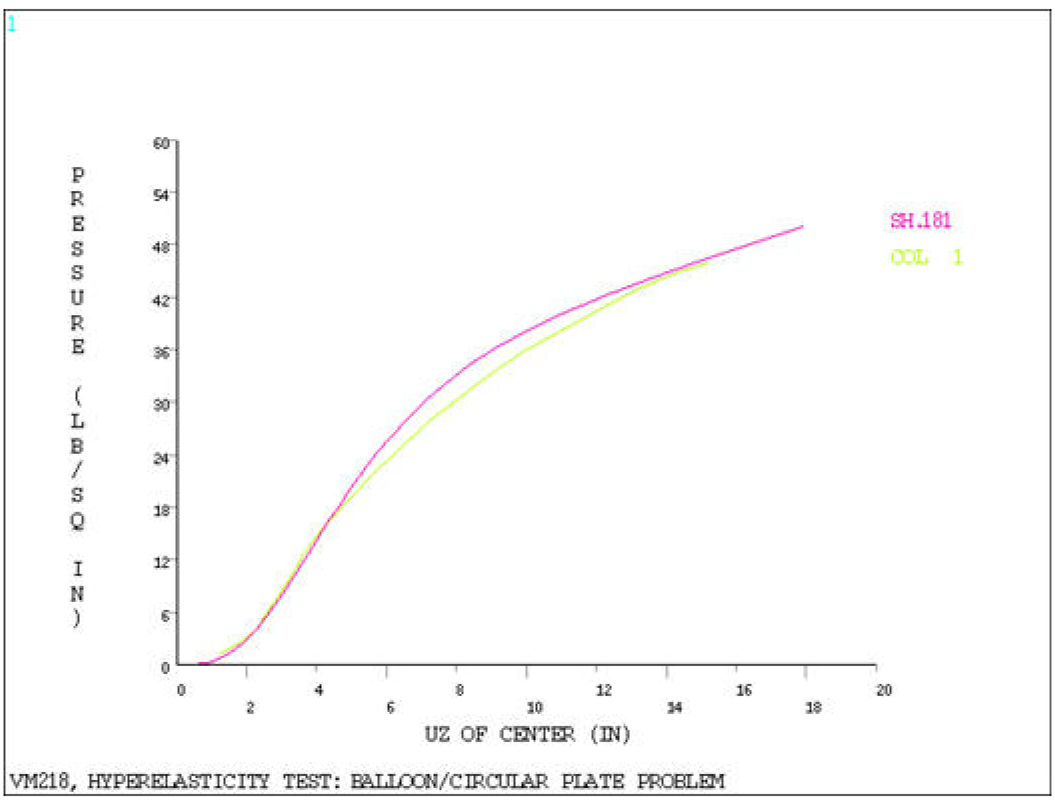
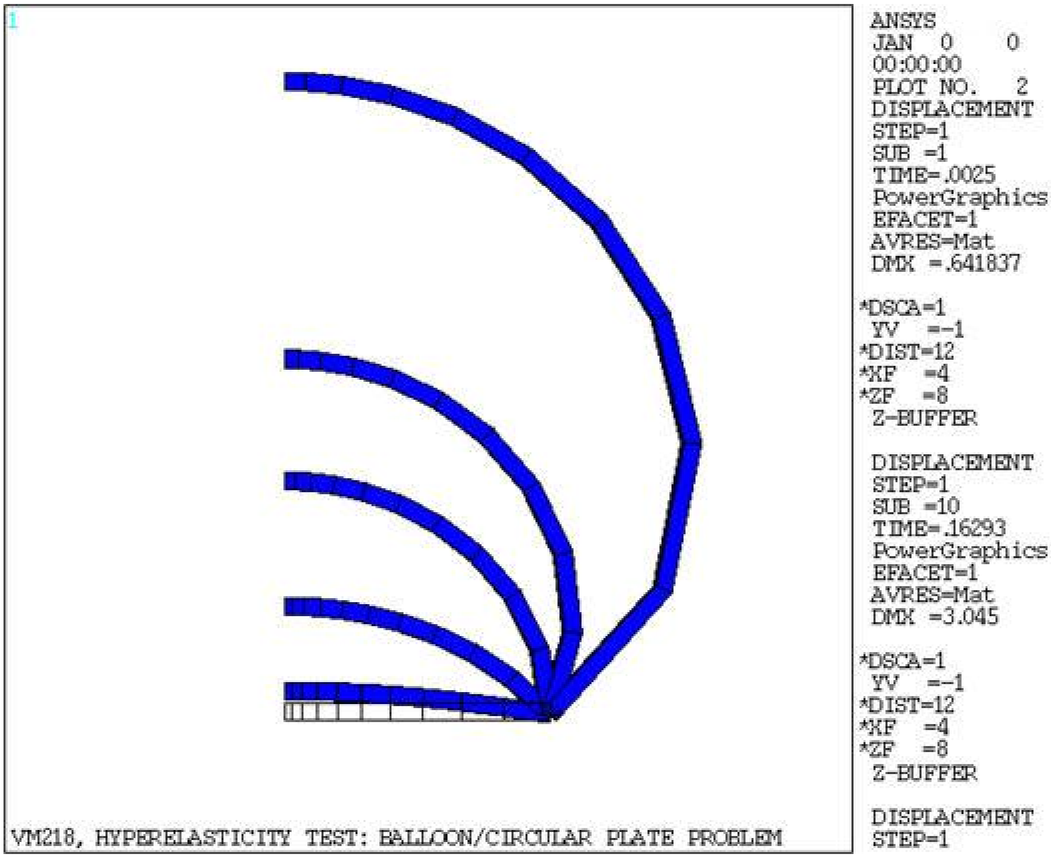


Figure 218.4: Results Plot 3 - Displaced Shape



VM219: Frequency Response of a Prestressed Beam using APDL MATH Commands

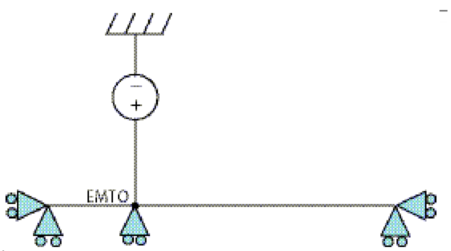
Overview

Reference:	R. D. Blevins, Formulas for Natural Frequency and Mode Shape, Van Nostrand Reinhold Co., pg. 144, equation 8-20.
Analysis Type(s):	Modal (**ANTYPE**=2)
Element Type(s):	2-D Elastic Beam Elements (BEAM188) Electromechanical Transducer Elements (TRANS126)
Input Listing:	vm219.dat

Test Case

A beam is in series with an electromechanical transducer. With a voltage applied to the beam, determine the prestressed natural frequencies of the beam.

Figure 219.1: Element Plot



Material Properties	Geometric Properties	Loading
Ex = 169E3 μN/μm^2 DENS = 2332E-18 kg/μm^3 Beam Stiff = 112666.667 μN/μm Gap Stiff = 20.022 μN/μm	L = 150μm W = 4 μm H = 2 μm Initial Gap = 1 μm Gap = 0.999 μm	Volt = 150.162V

Analysis Assumptions and Modeling Notes

The beam is created using BEAM188 elements which are used in series with one TRANS126 element. The node that connects the transducer and beam is free to move in the X-direction, while the end node of the beam and the ground node of the transducer are constrained in both the X and Y directions. It should also be noted that the transducer gap stiffness is much less than the beam stiffness and will not have any effect on the frequency solution. **WRFULL** command is used to write the assembled global matrices onto a .FULL file. ***EIGEN** command is then used to perform the modal analysis with unsymmetric matrices imported from .FULL file.

Results Comparison

	Target	Mechanical APDL	Ratio
Frequency (mode 1)	351699.332	351609.996	1.000
Frequency (mode 2)	1381162.303	1379724.174	1.001
Frequency (mode 3)	3096816.034	3089542.986	1.002

VM220: Eddy Current Loss in Thick Steel Plate

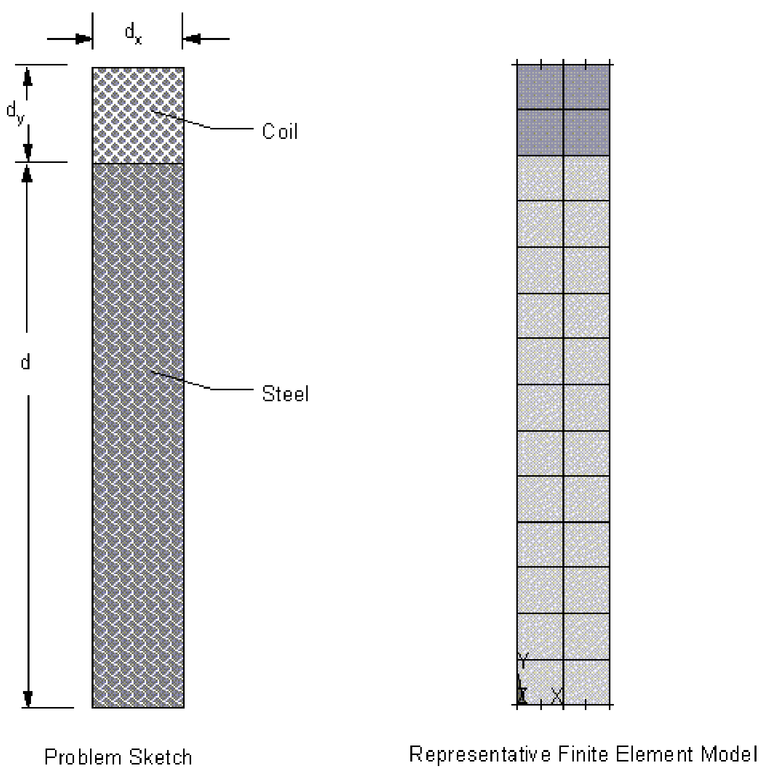
Overview

Reference:	K. K. Lim, P. Hammond, "Universal Loss Chart for the Calculation of Eddy-Current Losses in Thick Steel Plates", *Proc. IEE*, Vol. 117 No. 4, April 1970, pg. 861.
Analysis Type(s):	2-D Harmonic Analysis (**ANTYPE** = 3)
Element Type(s):	2-D 8-Node Magnetic Solid Elements (PLANE53)
Input Listing:	vm220.dat

Test Case

A 5 mm thick semi-infinite steel plate is subject to a tangential field created by a coil, H = 2644.1 A/m at a frequency of 50 Hz. The material conductivity, σ is 5 x 10^6 S/m. The B-H curve is defined by the equation B = H/(a+b |H|), where a = 156, b = 0.59. η, a geometry constant, is given to be 10.016. Compute the eddy current loss.

Figure 220.1: Thick Steel Plate Problem Sketch and Finite Element Model



Material Properties	Geometric Properties	Loading
$\mu = 4 \pi * 10^7$ H/m $\sigma = 5.0 \times 10^6$ S/m	d = 2.5 mm (half thickness of plate) d_x = d/6 (plate width) d_y = d/6 (coil height)	H = 2644.1 A/m (imposed H-field) f = 50 Hz

Material Properties	Geometric Properties	Loading
	η = 10.016	

Analysis Assumptions and Modeling Notes

A nonlinear harmonic analysis is performed with PLANE53. The command macro POWERH is used to calculate the power loss in the plate.

Verification was performed by comparing the ANSYS results to those obtained through the use of the universal loss chart shown in the reference. The values of h_o and η are required to use the universal loss chart η, which is given to be 10.016 in this case.

The equation for h_o is H / ξ = a/b.

The universal loss chart (Lim Fig. 6), h_o vs. P_n, can now be used to extract P_n. By using the curve that is given for the value η, and h_o located at the x-axis, P_n is the corresponding value on the y-axis. The value found for P_n (1.2 W/m) is used to calculate the average losses, $P = P_n(H^2 / \sigma d)$. The loss was calculated to be 671.16 W/m^2.

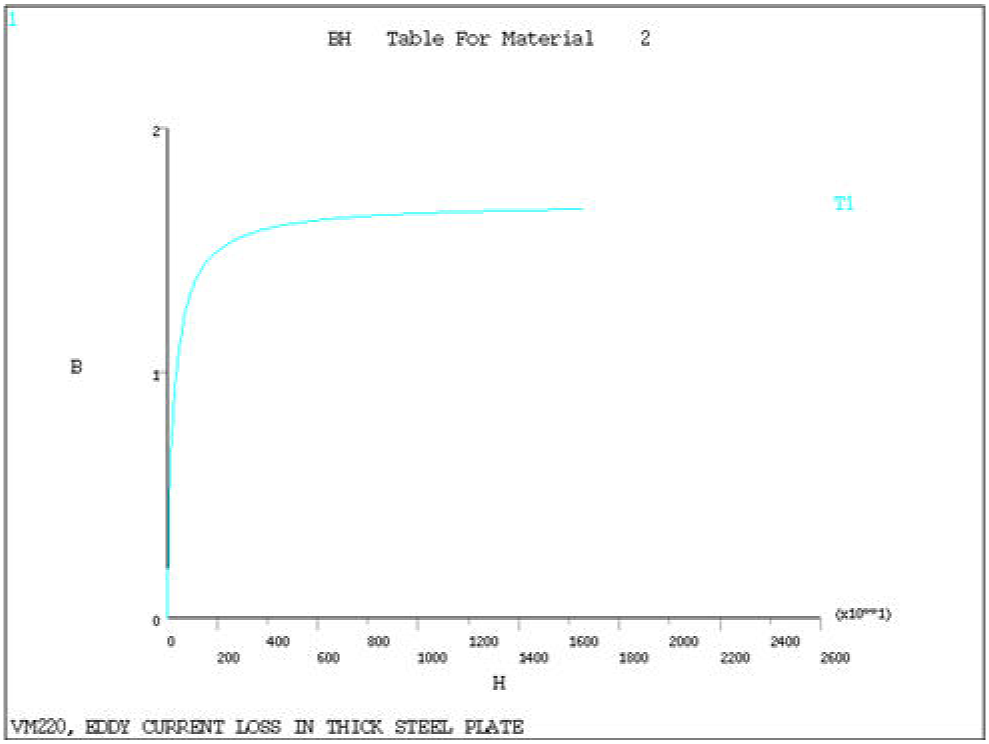
Note that this result is for the half plate thickness. The full plate loss is twice the half plate, or 1342.3 W/m^2.

Results Comparison

Eddy Current Loss	Target	Mechanical APDL	Ratio
PLANE53 (w/m^2)	1342.323[1]	1339.862	0.998

1. Results based on graphical data

Figure 220.2: B-H Curve



VM221: Simulation of Shape Memory Alloy Effect

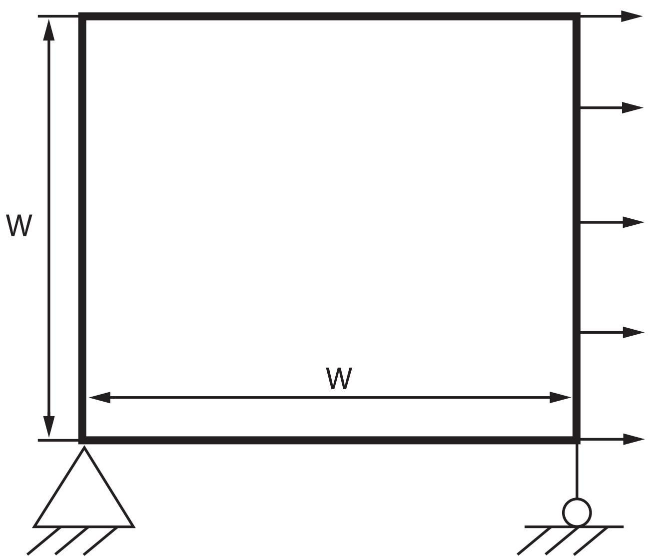
Overview

Reference:	A. Souza, et al. "*Three-dimensional model for solids undergoing stress-induced phase transformation*". *Eur. J. Mech. A/Solids*. 1998, 17: 789-806.
Analysis Type(s):	Static (**ANTYPE**, 0)
Element Type(s):	3-D Structural Solid Elements (SOLID185)
Input Listing:	vm221.dat

Test Case

A block is composed of shape memory alloy material. The block, which has an initial temperature of 253.15K, is loaded up to 70 MPA to obtain detwinned martensitic structure, and then unloaded until it is stress free to obtain a martensitic structure in which residual strain remains. The temperature is then increased to 259.15K to recover residual strain and regain the austenitic structure. The final stress and strain is obtained and compared against the reference solution.

Figure 221.1: Uniaxial Loading Problem Sketch



Material Properties	Geometric Properties	Loading
Material properties for Austenite phase: E=70,000 MPa μ=0.33 Material properties for Martensite phase: Em=70,000MPa	W=5m	1. Apply pressure on X direction to 70MPA. 2. Remove pressure in X direction. 3. Increase temperature to T=259.15K.

Material Properties	Geometric Properties	Loading
Parameters for phase transformation: h=500 MPa R=45 MPa β=7.5MPa.K^{-1} T_0=253.15K m=0		

Analysis Assumptions and Modeling Notes

The problem is solved using 3-D SOLID185 elements. The shape memory material is defined using **TB**,SMA. The block is subjected to 70MPa uniaxial tension, then loading is removed. Finally, temperature is increased to recover residual strain. The final stress and strain state is acquired by ***GET** in POST1.

Results Comparison

	Target	Mechanical APDL	Ratio
S_X	0.0	0.0	-
EPEL_X	0.0	0.0	-
EPPL_X	0.0	0.0	-

VM222: Warping Torsion Bar

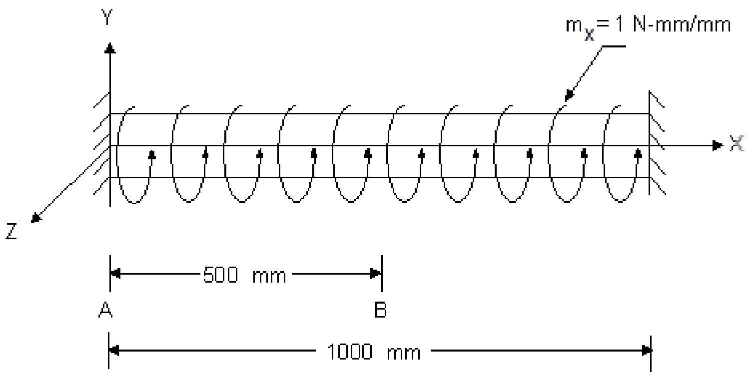
Overview

Reference:	C-N Chen, "The Warping Torsion Bar Model of the Differential Quadrature Method", *Computers and Structures*, Vol. 66 No. 2-3, 1998, pp. 249-257.
Analysis Type(s):	Static Structural (**ANTYPE** = 0)
Element Type(s):	3-D Linear Finite Strain Beam Elements (BEAM188) 3-D Quadratic Finite Strain Beam Elements (BEAM189)
Input Listing:	vm222.dat

Test Case

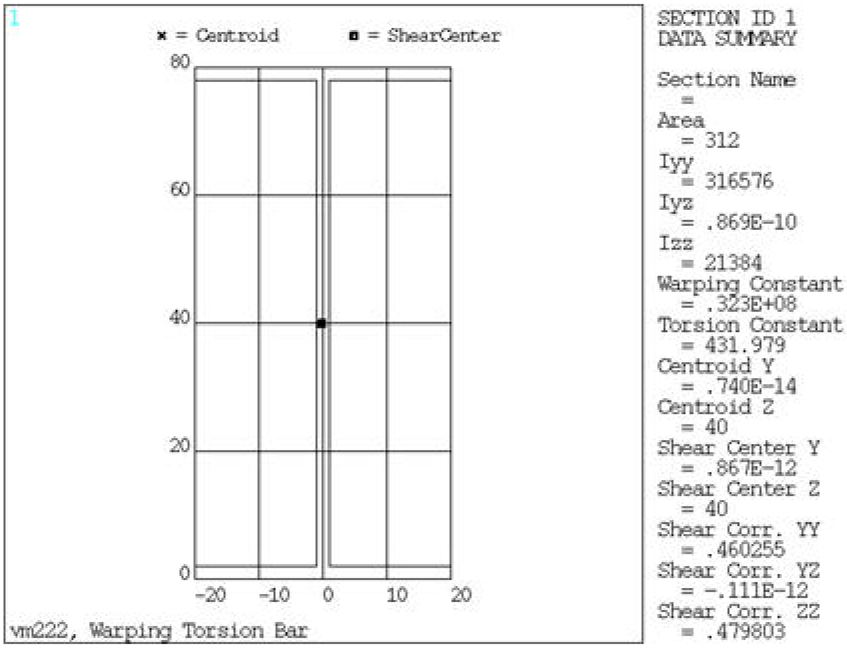
A cantilever I-beam is fixed at both ends and a uniform moment, M_x, is applied along its length.

Figure 222.1: Warping Torsion Bar Problem Sketch



Material Properties	**Geometric Properties**	**Loading**
Warping rigidity (EC_W) = 7.031467e12 Nmm^4 and GJ=3.515734e7 Nmm^2 Warping constant (C_W) =0.323e8 and J=431.979 (E=217396.3331684 N/mm^2 and G=81386.6878 N/mm^2) Poisson's Ratio = (E/(2*G))-1 = 0.33557673	b=40mm h=80mm t=2mm L=1000mm	Mo- ment = 1Nmm/mm

Figure 222.2: I-Beam Section Plot



Analysis Assumptions and Modeling Notes

Given that:

EC_w = 7.031467E12 Nmm^4(warping rigidity)

Iyy = 316576 mm^4 for this beam cross section

and

GJ = 3.515734E7 Nmm^2

C_w = 0.323E8 mm^6 (warping constant)

J = 431.979 mm^4 (torsion constant)

E = 217396.333 N/mm^2 (Young's modulus)

Therefore υ = E/2G-1 = 0.33557673 (Poisson's ratio)

Uniformly distributed moments are converted to a moment load on each element.

mload1 and mload2 are the loads on the beam ends.

The warping DOF results are compared to the reference at the midspan.

Results Comparison

MX Twist in X-Direction	Target	Mechanical APDL	Ratio
BEAM188	0.3293E-03	0.3326E-03	1.010
BEAM189	0.3293E-03	0.3330E-03	1.011

Figure 222.3: Warping Torsion Bar Plot

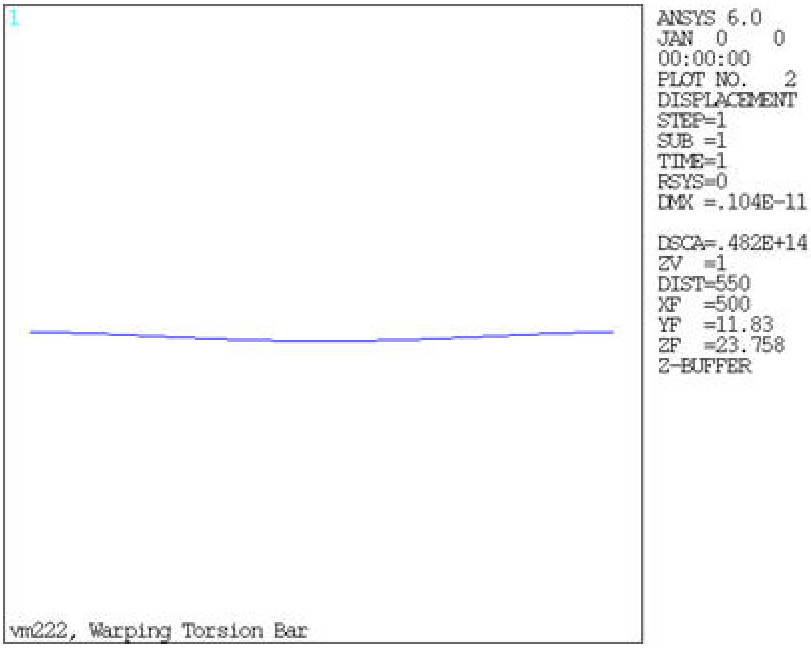
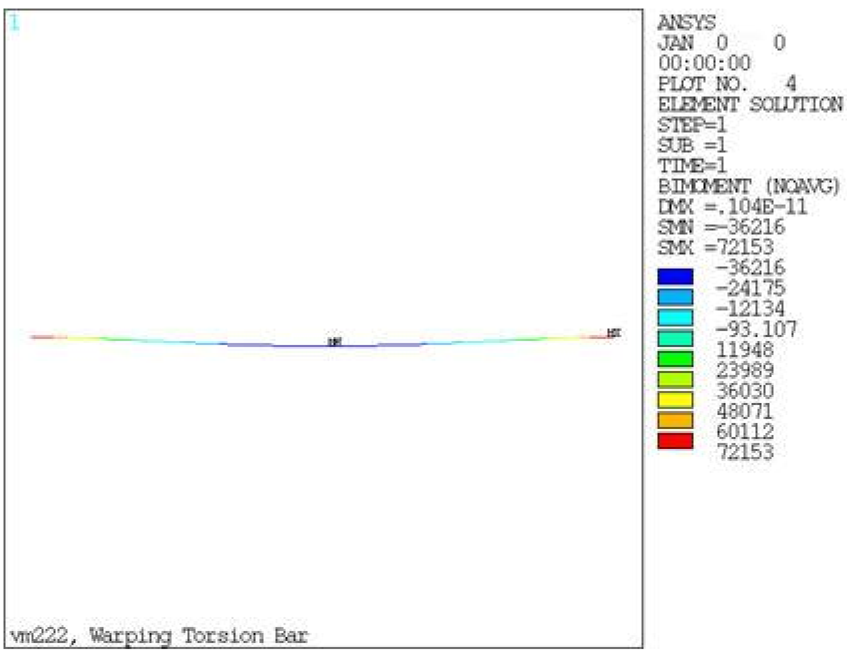


Figure 222.4: Warping Torsion Bar Plot



VM223: Electro-Thermal Microactuator Analysis

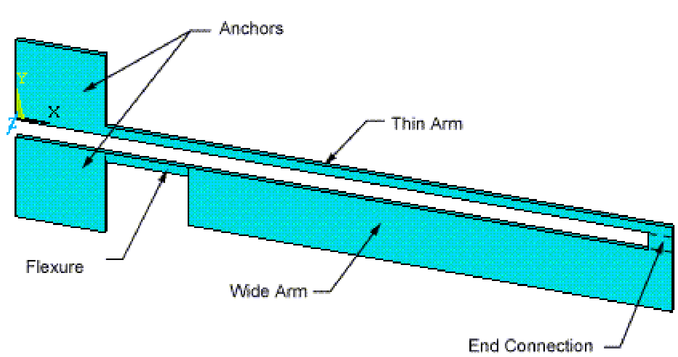
Overview

Reference:	Mankame and Ananthasuresh "Comprehensive thermal modeling and characterization of an electro-thermal-compliant microactuator", Journal of Micromech. Microeng. 11, 2001, pg. 252-262.
Analysis Type(s):	Static
Element Type(s):	3-D 10-Node Coupled-Field Solid (SOLID227) KEYOPT(1) =111
Input Listing:	vm223.dat

Test Case

The actuator silicon structure is comprised of a thin arm connected to a wide arm, flexure, and two anchors as shown in the figure below. In addition to providing mechanical support, the anchors also serve as electrical and thermal connections. The actuator operates on the principle of differential thermal expansion between the thin and wide arms. When a voltage difference is applied to the anchors, current flows through the arms producing Joule heating. Because of the width difference, the thin arm of the microactuator has a higher electrical resistance than the wide arm, and therefore it heats up more than the wide arm. The non-uniform Joule heating produces a non-uniform thermal expansion, and actuator tip deflection.

Figure 223.1: Electro-Thermal Microactuator Sketch



Material Properties	Geometric Properties	Loading
Young's modulus: 169.0 (Gpa) Poisson ratio: 0.3 Electrical resistivity: 4.2e-4 (Ohm m @ T = 300K) Coefficient of linear expansion [alpha, μmm^{1} K^{1}] and thermal conductivity [k, W,	Microactuator dimensions (m): d1 = 40e-6 d2 = 255e-6 d3 = 40e-6 d4 = 330 e-6 d5 = 1900e-6 d6 = 90e-6 d7 = 75e-6	Applied voltage drop of 15.0 V

Material Properties	Geometric Properties	Loading
m1, K1] with temperature [T, K]: alpha k T 2.568 146.4 300 3.212 98.3 400 3.594 73.2 500 3.831 57.5 600 3.987 49.2 700 4.099 41.8 800 4.185 37.6 900 4.258 34.5 1000 4.323 31.4 1100 4.384 28.2 1200 4.442 27.2 1300 4.500 26.1 1400 4.556 25.1 1500	d8 = 352e-6 d9 = 352e-6 d11 = 20e-6	

Analysis Assumptions and Modeling Notes

A 3-D static structural-thermoelectric analysis is performed to determine the tip deflection and temperature distribution in the microactuator when a 15 volt difference is applied to the anchors. Radiative and convective surface heat transfers are also taken into account, which is important for accurate modeling of the actuator.

Results Comparison

	Target	Mechanical APDL	Ratio
Tip Transverse Displacement UY	0.2700E-04	0.2779E-04	1.029

Figure 223.2: Displacement Magnitude Plot

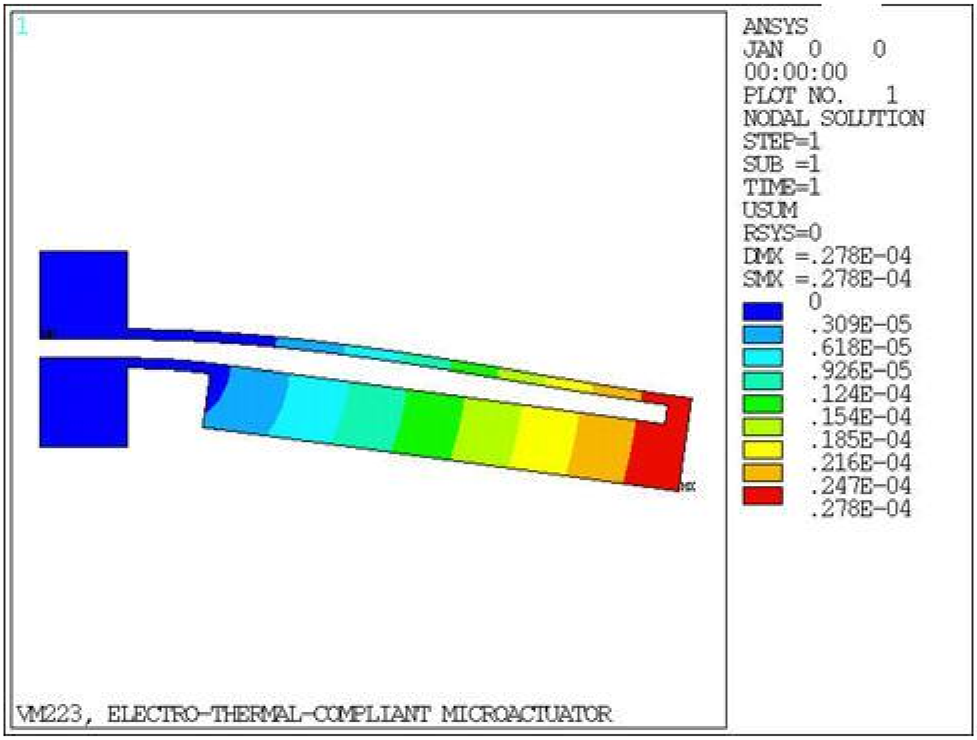
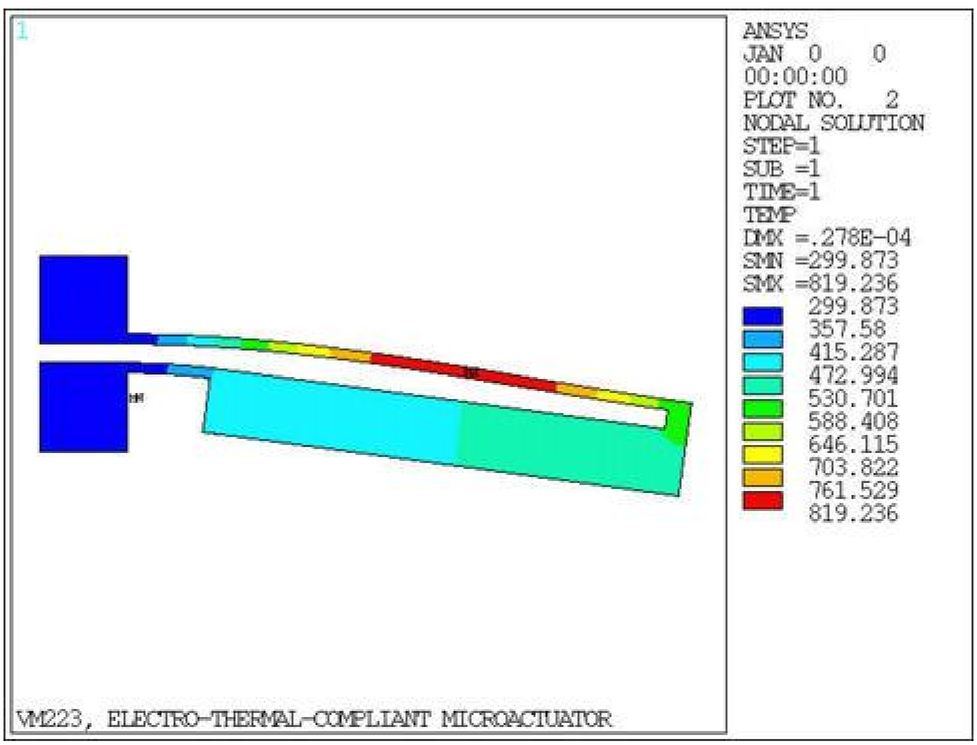


Figure 223.3: Temperature Plot



VM224: Implicit Creep under Biaxial Load

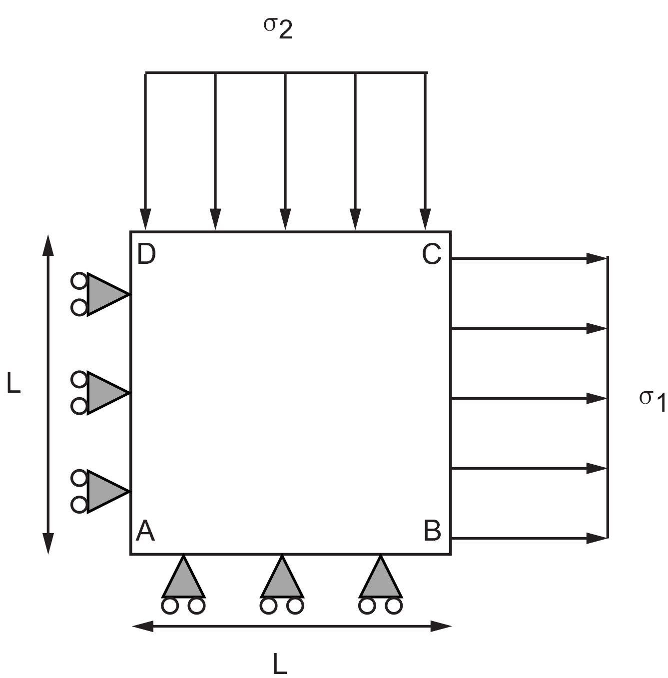
Overview

Reference:	A. A. Becker, T. H. Hyde, *Fundamental Test of Creep Behavior*, 2nd Edition, NAFEMS, Ref.: R0027, Test 10a.
Analysis Type(s):	2-D Plane Stress - Biaxial (Negative) Load
Element Type(s):	2-D 4-Node Structural Solid Elements (PLANE182) 2-D 8-Node Structural Solid Elements (PLANE183)
Input Listing:	vm224.dat

Test Case

A specimen under plane stress conditions is constrained on the left and bottom edges. It is biaxially loaded with tensile stress σ_1 on the right edge and compressive stress σ_2 on the top edge. Determine the creep strain after 1000 hours.

Figure 224.1: Implicit Creep Under Biaxial Load Problem Sketch



Problem Sketch

Material Properties	Geometric Properties	Loading
$E = 200 \times 10^3$ N/mm^2 $\nu = 0.3$ **Creep Law** $\varepsilon = A\ \sigma^n t^m$	L = 100 mm	$\sigma_1 = 200$ N/mm^2 $\sigma_2 = -200$ N/mm^2 Total creep time 1000 hours

Material Properties	Geometric Properties	Loading
A = 3.125 x 10^{-14} per hour n = 5 m = 0.5		

Analysis Assumptions and Modeling Notes

For a 2-D plane stress condition a biaxial load is applied as follows:

$$\sigma_{xx} = \sigma_0$$

$$\sigma_{yy} = \alpha\sigma_0$$

In this case the effective stress is given by the following equation, where α = -1

$$\sigma_{eff} = \sigma_0 (\alpha^2 - \alpha + 1)^{\frac{1}{2}}$$

And the creep strains may be obtained as follows:

$$\varepsilon^c_{xx} = A(\sigma_0)^n \left[\frac{1}{2}(2 - \alpha)(\alpha^2 - \alpha + 1)^{\frac{(n-1)}{2}} \right] t^m$$

$$\varepsilon^c_{yy} = A(\sigma_0)^n \left[\frac{1}{2}(2\alpha - 1)(\alpha^2 - \alpha + 1)^{\frac{(n-1)}{2}} \right] t^m$$

$$\varepsilon^c_{zz} = A(\sigma_0)^n \left[\frac{1}{2}(\alpha + 1)(\alpha^2 - \alpha + 1)^{\frac{(n-1)}{2}} \right] t^m$$

This gives the following reference solution:

$$\varepsilon^c_{xx} = 0.135t^{0.5}$$

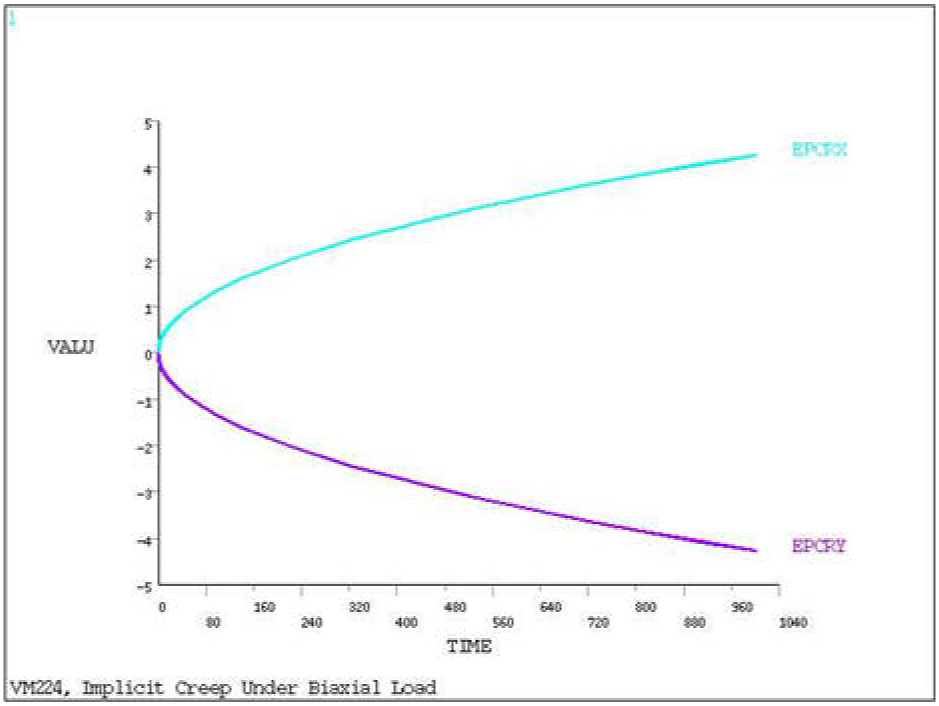
$$\varepsilon^c_{yy} = -0.135t^m$$

$$\varepsilon^c_{zz} = 0$$

Results Comparison

@ Time = 1000	Target	Mechanical APDL	Ratio
PLANE182 2-D 4-Node Structural Solid			
ecrxx	4.2691	4.2690	1.000
ecryy	-4.2691	-4.2690	1.000
PLANE183 2-D 8-Node Structural Solid			
ecrxx	4.2691	4.2687	1.000
ecryy	-4.2691	-4.2687	1.000

Figure 224.2: Creep Strain



VM225: Rectangular Cross-Section Bar with Preload

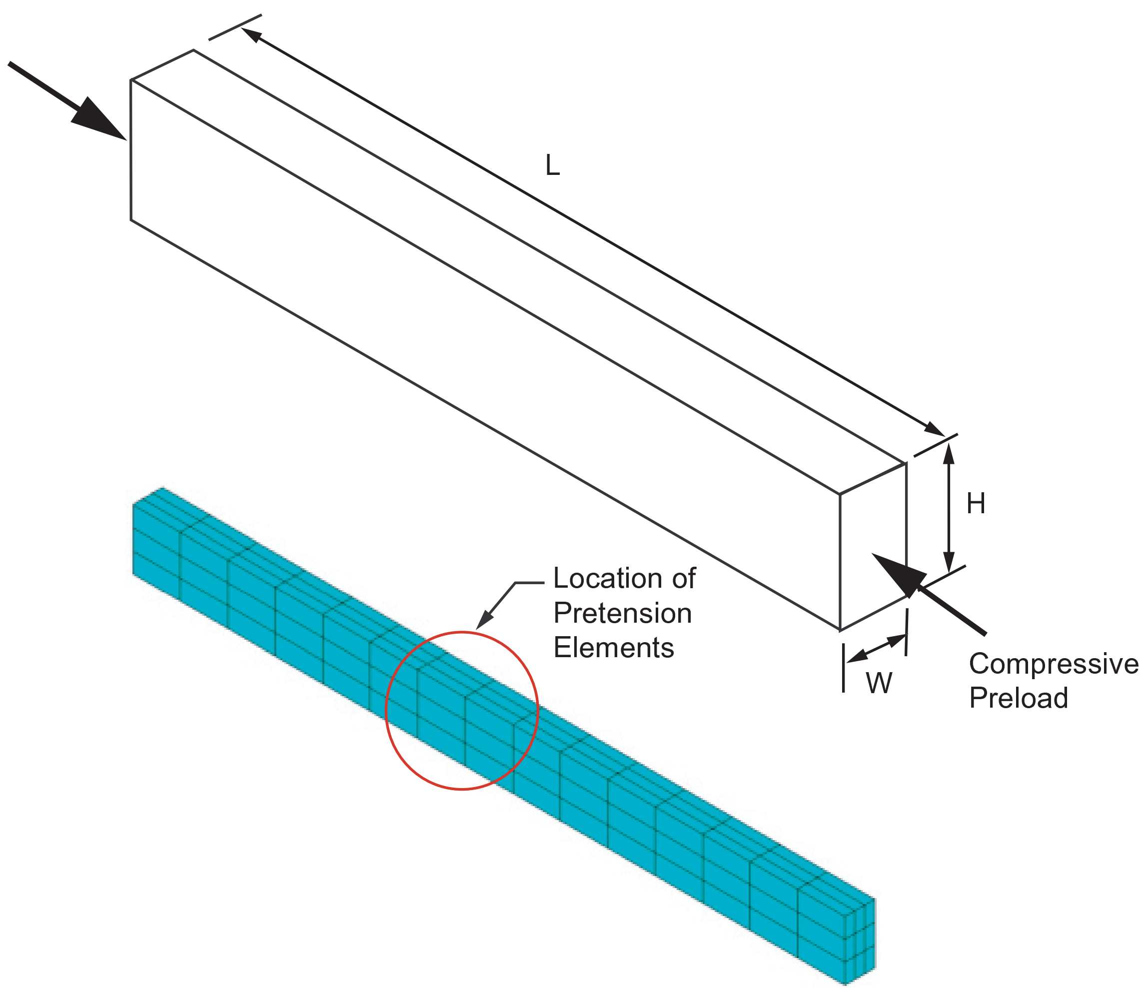
Overview

Reference:	Engineering Statics Text
Analysis Type(s):	Static, Preloading Analysis
Element Type(s):	3-D Structural Solid Elements (SOLID45) Pretension Elements (PRETS179) 3-D Structural Solid Elements (SOLID185)
Input Listing:	vm225.dat

Test Case

A compressive preload is applied to a rectangular cross-section bar. Determine the resulting stress and displacement.

Figure 225.1: Finite Element Model



Material Properties	Geometric Properties	Loading
E = 30,000,000 psi ν = 0.3	L = 12 in W = 1 in H = 2 in	F = 500 lbf

Analysis Assumptions and Modeling Notes

The problem is solved in two different ways:

- using 3-D solid elements (SOLID95)
- using 3-D solid elements (SOLID186)

Due to symmetry, only one-quarter of the bar is modeled. The preload is applied using the PRETS179 2-D/3-D Pretension Element and the **SLOAD** command.

Results Comparison

	Target	Mechanical APDL	Ratio
SOLID45			
Stress SigX (psi)	250.0	250.0	1.0
Displacement (UX)	0.00010	0.00010	1.0
SOLID185			
Stress SigX (psi)	250.0	250.0	1.0
Displacement (UX)	0.00010	0.00010	1.0

VM226: Fourier Series Analysis of a Diode Rectified Circuit

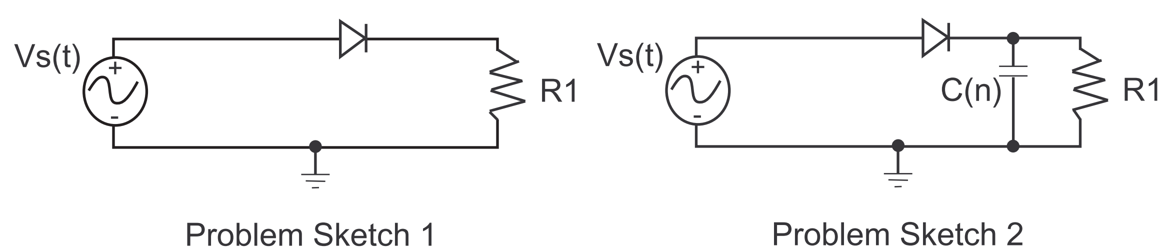
Overview

Reference:	A. S. Sedra, K. C. Smith, *Microelectronic Circuits*, 4th Edition, Oxford University Press, 1977.
Analysis Type(s):	Transient
Element Type(s):	Electric Circuit Elements (CIRCU124) Diode Elements (CIRCU125)
Input Listing:	vm226.dat

Test Case

Compute the Fourier series coefficients of the output voltages from the following two circuits, the first with no capacitance, second with a capacitance of 1E-6F, third with a capacitance of 10E-6F, and finally with a capacitance of 1E-3F.

Figure 226.1: Diode Rectified Circuit Problem Sketch



Geometric Properties	Loading
R1 = 2500 Ohm C1 = 1E-6 F C2 = 10E-6 F	Vs = 135 sin (60 * pi * t) V

Analysis Assumptions and Modeling Notes

These circuits make use of CIRCU125 diode elements, which have parameters that are set up to produce ideal characteristics. The circuit in Problem Sketch 1 is modeled to be a simple half-wave rectifier with three elements:

- a voltage source
- an ideal diode
- a single load resistor

In this case computing the Fourier series coefficients is a minor task. However, in Problem Sketch 2, a capacitor is introduced into the circuit which causes a combination, sinusoidal-exponential output waveform, and hence making the Fourier series calculation much more complex.

Definition:

$$V_{LOAD}(t) = \frac{a0}{2} + \sum_{n>0} \left(an\cos\left(\frac{2n\pi}{T}t\right) + bn\sin\left(\frac{2n\pi}{T}t\right)\right)$$

Problem Sketch One: Resistor, Diode and Voltage Source

We have: Vs(t) = Vsl*SIN(ωt)

where:

Vsl = 135 Volts
ω = 2πf and f = (1)/T = 60 Hz

Fourier coefficients:

$$-a_0 = \frac{2}{T}\int_0^{T/2} Vs(t)dt = \frac{2 * Vs1}{\pi}$$

$$-a_n = \frac{2}{T}\int_0^{T/2} Vs(t)\cos(n\omega t)\,dt$$

So we have:

$$\begin{cases} n>1,\ a_n = \dfrac{Vs1}{\omega T}\left[\dfrac{1}{n+1}(1-\cos((n+1)\pi)) - \dfrac{1}{n-1}(1-\cos((n-1)\pi)\right] \\ a_1 = 0 \end{cases}$$

That is to say:

$$\begin{cases} p \ge 0,\ \ a_{2p} = \dfrac{-2Vs1}{\pi((2p)^2 - 1)} \\ p \ge 0,\ \ a_{2p+1} = 0 \end{cases}$$

$$b_n = \frac{2}{T}\int_0^{T/2} Vs(t)\sin(n\omega t)dt$$

So we have:

$$\begin{cases} n>1,\ b_n = \dfrac{Vs1}{\omega T}\left[\dfrac{-1}{n+1}\sin\left((n+1)\dfrac{\omega T}{2}\right) + \dfrac{1}{n-1}\sin\left((n-1)\dfrac{\omega T}{2}\right)\right] \\ b_1 = \dfrac{Vs1}{2} \end{cases}$$

That is to say:

$$\begin{cases} b_1 = \dfrac{Vs1}{2} \\ n>1,\ b_0 = 0 \end{cases}$$

Figure 226.2: Output Voltage with No Capacitance

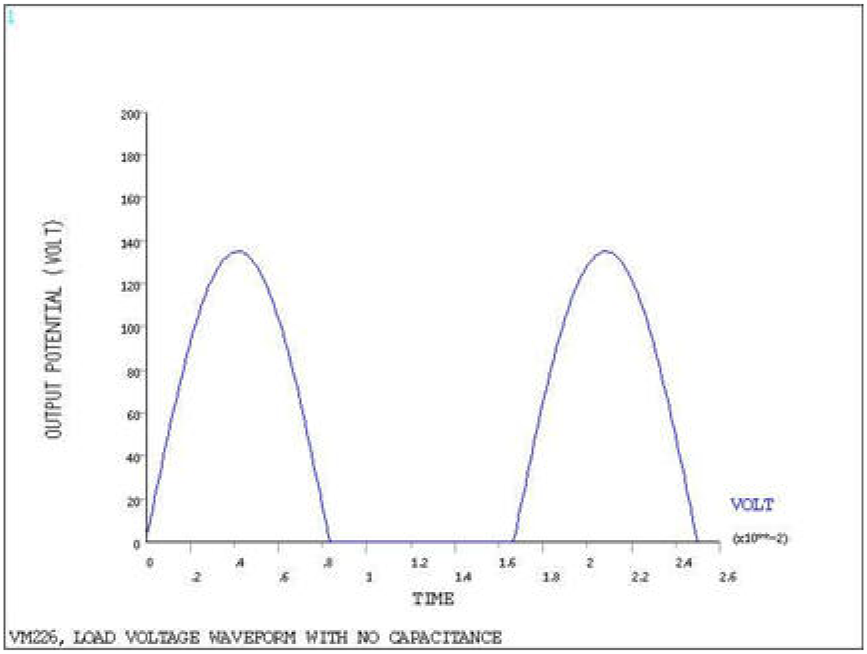


Figure 226.3: Plot of Fourier Series Without Capacitance

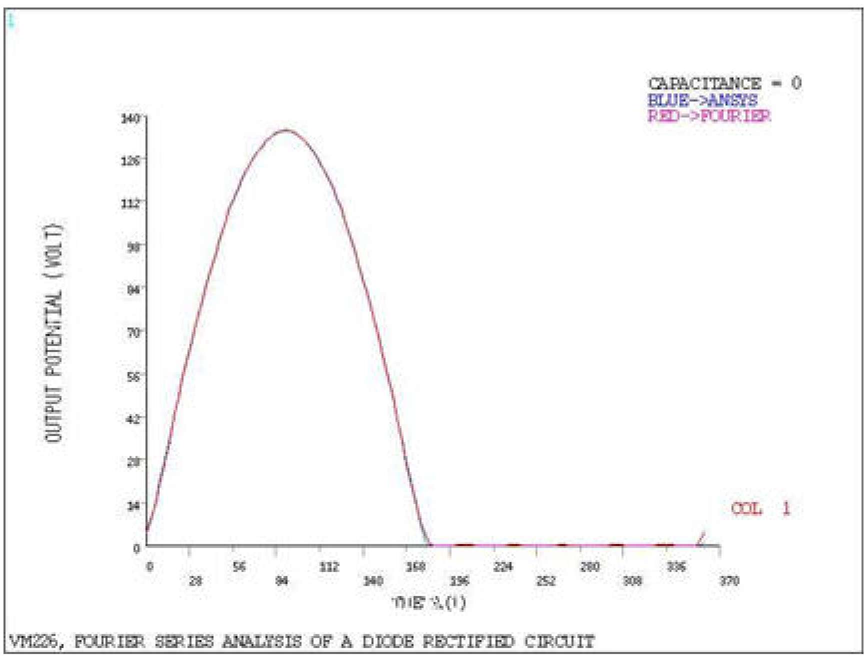
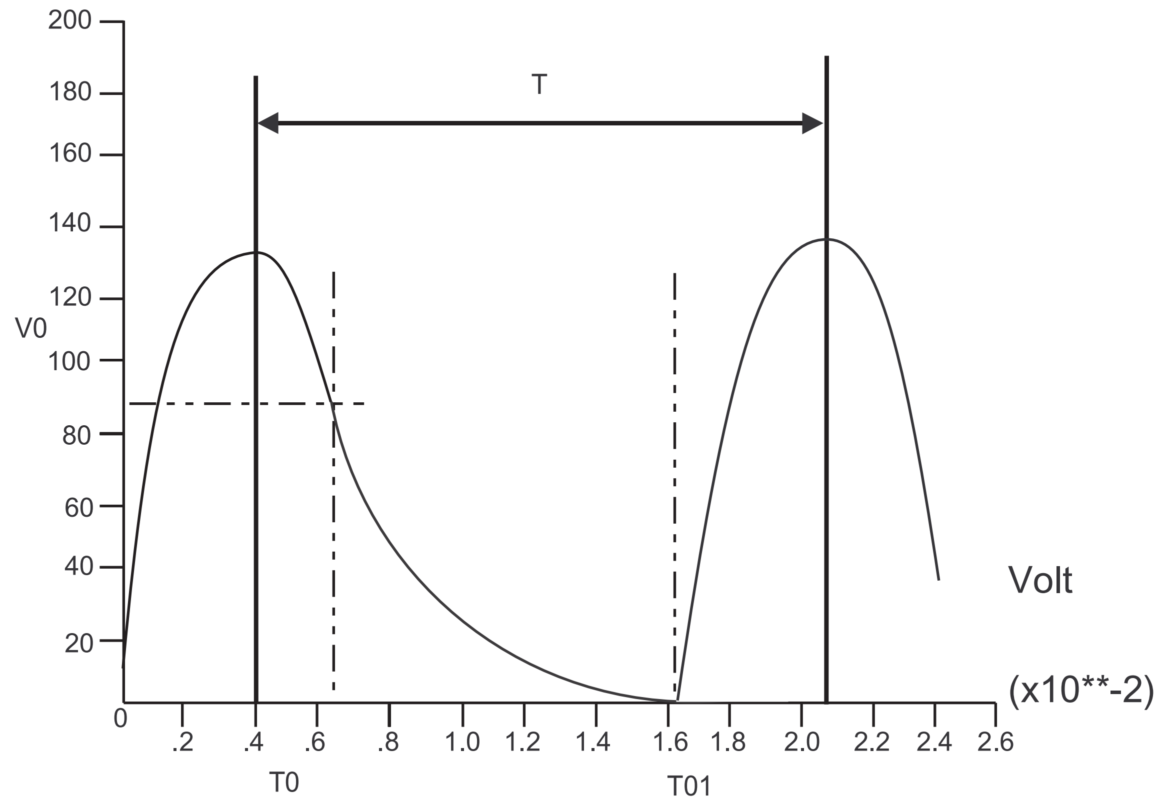


Figure 226.4: Resistor, Capacitor, Diode and Voltage Source



To compute the Fourier coefficients, take a periodic signal such that the first time (TO) will be the first maximum of Vs(t) and the end time (TO1) will be the second maximum of Vs(t).

We have:

Vsl = 135 Volts
$\omega = 2\pi f$ and f = (1)/T = 60 Hz
τ = RC
0 < t < T0: Vs(t) = Vsl*COS(ω.t)
T0 < t < T01: Vs(t) = V0*EXP (-(t-T0)/τ)
T01 < t < T: Vs(t) = Vsl*COS(ω.t)

How to Find T0 and T01

For T0 we have:

$$\begin{cases} \dfrac{dVs(t)}{dt}(t < T0) = \dfrac{dVs(t)}{dt}(t > T0) \\ -\omega Vs1\sin(\omega t) = -\dfrac{V0}{\tau}\exp(-\dfrac{t-T0}{\tau}) = -\dfrac{Vs1\cos(\omega t)}{\tau} \\ t = \dfrac{1}{\omega}\arctan(\dfrac{1}{\omega\tau}) \end{cases}$$

Due to the discontinuity of the function, T01 must be found using a Newton's Method algorithm which can be done using Mechanical APDL. The code that performs this operation can be found in the input listing.

T01 verifies this equation:

$$Vs1\cos(\omega t) = Vo\exp(-\frac{t - T0}{\tau})$$

Compute only the first three Fourier coefficients: a_0, a_1 and b_1.

First Fourier Coefficient:

$$a_0 = \frac{2}{T}\int_0^T Vs(t)\,dt$$

$$a_0 = \frac{Vs1}{\pi}(\sin(\omega T0) - \sin(\omega T01)) + \frac{2V0\tau}{T}\left(1 - \exp\left(-\frac{T01 - T0}{\tau}\right)\right)$$

Second Fourier Coefficient:

$$a_1 = \frac{2}{T}\int_0^T Vs(t)\cos(\omega t)\,dt$$

$$a_1 = \frac{2}{T}\left(\int_0^{T0} Vs1 * \cos^2(\omega t)\,dt + \int_{To1}^{T} Vs1 * \cos^2(\omega t)\,dt\right) + A1$$

$$a_1 = \frac{2Vs1}{T}\left(\frac{T0 + T - T01}{2} + \frac{1}{4\omega}(\sin(2\omega T0) - \sin(2\omega T01))\right) + A1$$

$$A1 = \frac{2V0}{T}\int_{T0}^{T01} \exp\left(-\frac{t - T0}{\tau}\right)\cos(\omega t)\,dt$$

$$A1 = \frac{2V0\tau}{T(1 + \omega^2\tau^2)}\left[\cos(\omega T0) + \omega\tau\sin(\omega T01) - (\cos(\omega T01) - \omega\tau\sin(\omega T01))\exp\left(-\frac{T01 - T0}{\tau}\right)\right]$$

Third Fourier Coefficient:

$$b_1 = \frac{2}{T}\int_0^T Vs(t)\sin(\omega t)\,dt$$

$$b_1 = \frac{2}{T}\left(\int_0^{T0} Vs1\cos(\omega t)\sin(\omega t)\,dt + \int_{T0}^{T01} Vs1\cos(\omega t)\sin(\omega t)\,dt\right) + B1$$

$$b_1 = \frac{Vs1}{2\pi}\left(\sin^2(\omega T0) - \sin^2(\omega T01)\right) + B1$$

$$B1 = \frac{2V0}{T}\int_{T0}^{T01} \exp\left(-\frac{t - T0}{\tau}\right)\sin(\omega t)\,dt$$

$$B1 = \frac{2V0\tau}{T(1+\omega^2\tau^2)}\left[\sin(\omega T0) + \omega\tau\cos(\omega T0) - (\sin(\omega T01) + \omega\tau\cos(\omega T01))\exp\left(-\frac{T01 - T0}{\tau}\right)\right]$$

Figure 226.5: VLOAD with Capacitance of 1E-6F

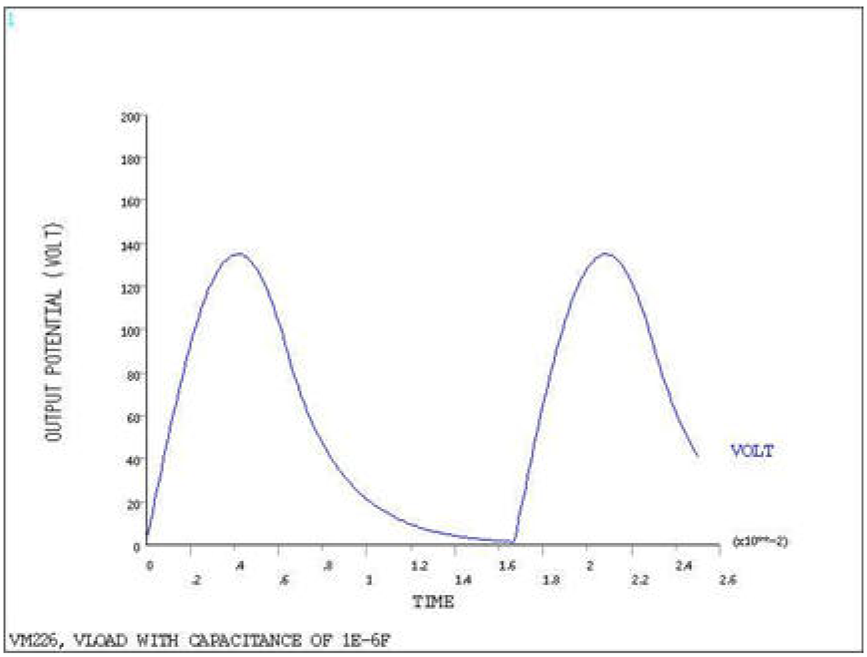


Figure 226.6: Plot of Fourier Series With Capacitance

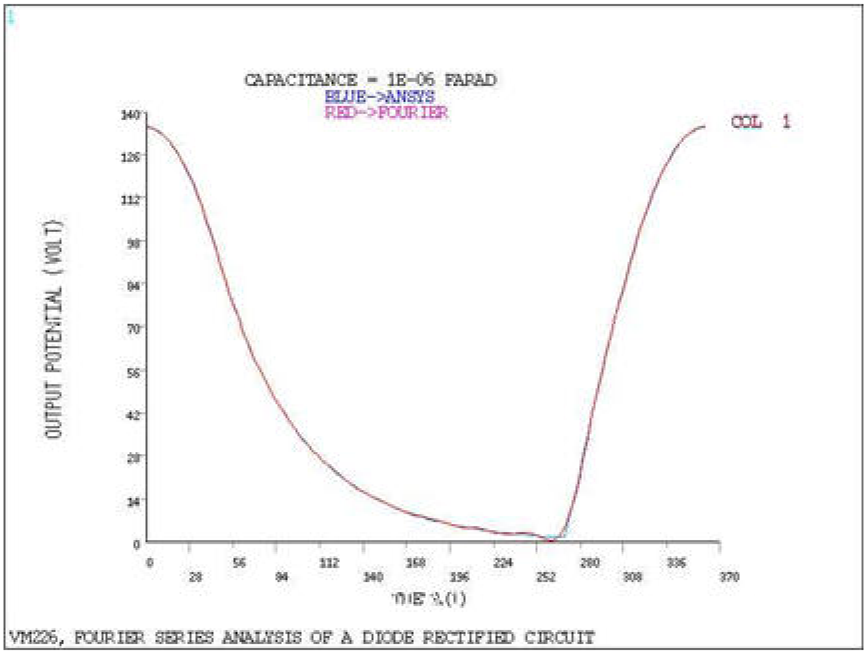
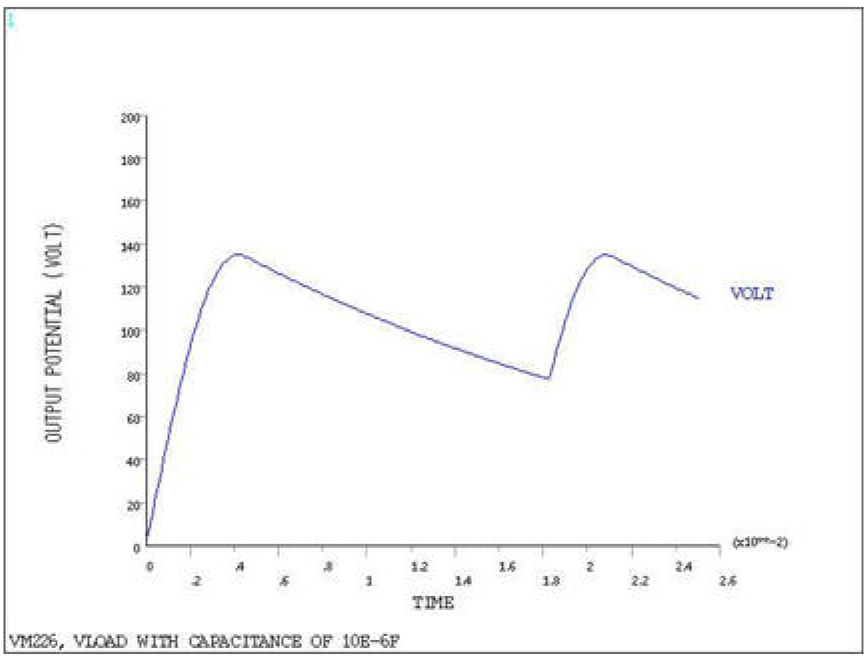


Figure 226.7: VLOAD With Capacitance of 10E-6F



Results Comparison

		Target	Mechanical APDL	Ratio
Tau = 0	A0/2	42.9834	42.9718	0.9997
	A1	0.0151	0.0000	0
	B1	67.492	67.5000	1.0001

		Target	Mechanical APDL	Ratio
Tau = 0.0025	A0/2	50.6891	50.7897	1.0020
	A1	61.7639	61.7634	1.0001
	B1	10.1966	10.3401	1.0141
Tau = 0.025	A0/2	105.4266	105.4741	1.0005
	A1	13.8831	13.8684	0.9989
	B1	16.4729	16.4932	1.0012

VM227: Radiation Between Finite Coaxial Cylinders

Overview

Reference:	M. Modest, *Radiative Heat Transfer*, McGraw-Hill Book Co., Inc., New York, NY, 1992, p. 791, View Factor Evaluations 44, 45.
Analysis Type(s):	Steady State Radiosity
Element Type(s):	2-D 8-Node Thermal Solid Elements (PLANE77)
Input Listing:	vm227.dat

Test Case

This test is designed to show a quick calculation of the end effects which are present in the radiation solution of two finite concentric cylinders. Concentric cylinders of length L, with radii r_1 and r_2, are created, and the radiosity method is used to determine radiation view factors upon the facing surfaces.

Figure 227.1: Problem sketch of finite co-axial cylinder

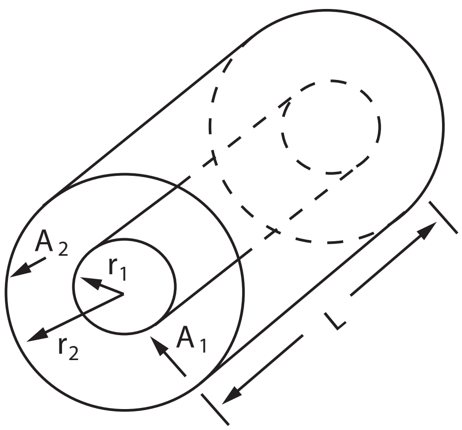
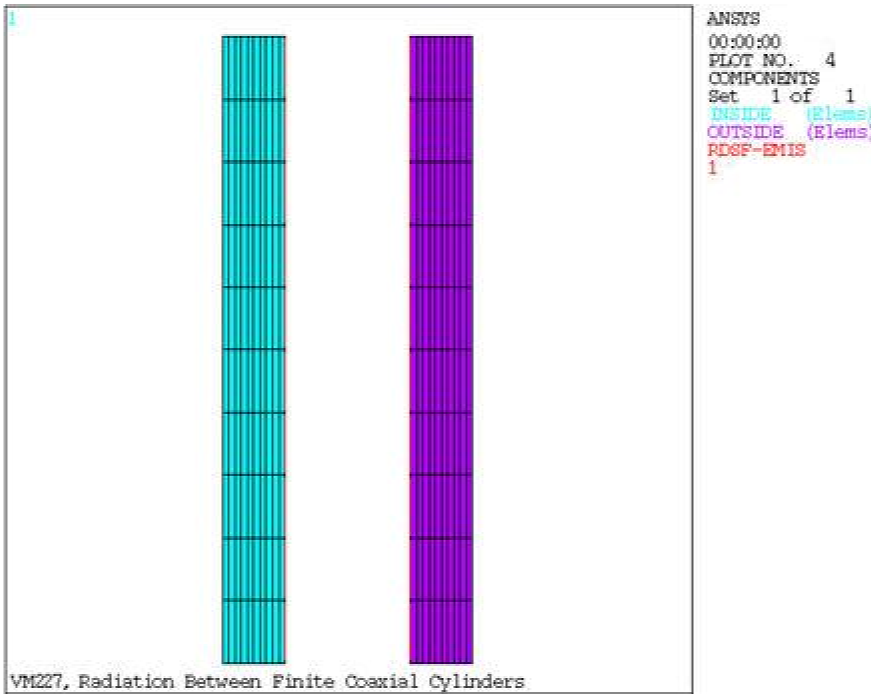


Figure 227.2: Problem Sketch



Geometric Properties	Loading
l = 10 r_1 = 1 r_2 = 3	Interior surface of external cylinder ε = 1 Axial surface of internal cylinder ε = 1 All other surfaces ε = 0

Analysis Assumptions and Modeling Notes

The model is reduced to a 2-D axisymmetric case. The material is assumed to be isotropic, the surface is assumed to have uniform emissivity.

A = 108

B = 92

Results

	Target	Mechanical APDL	Ratio
VF (1-1)	0.000	0.000	0.000
VF (2-1)	0.288	0.288	1.000
VF (2-2)	0.503	0.480	0.950

VM228: Radiation between Infinite Coaxial Cylinders

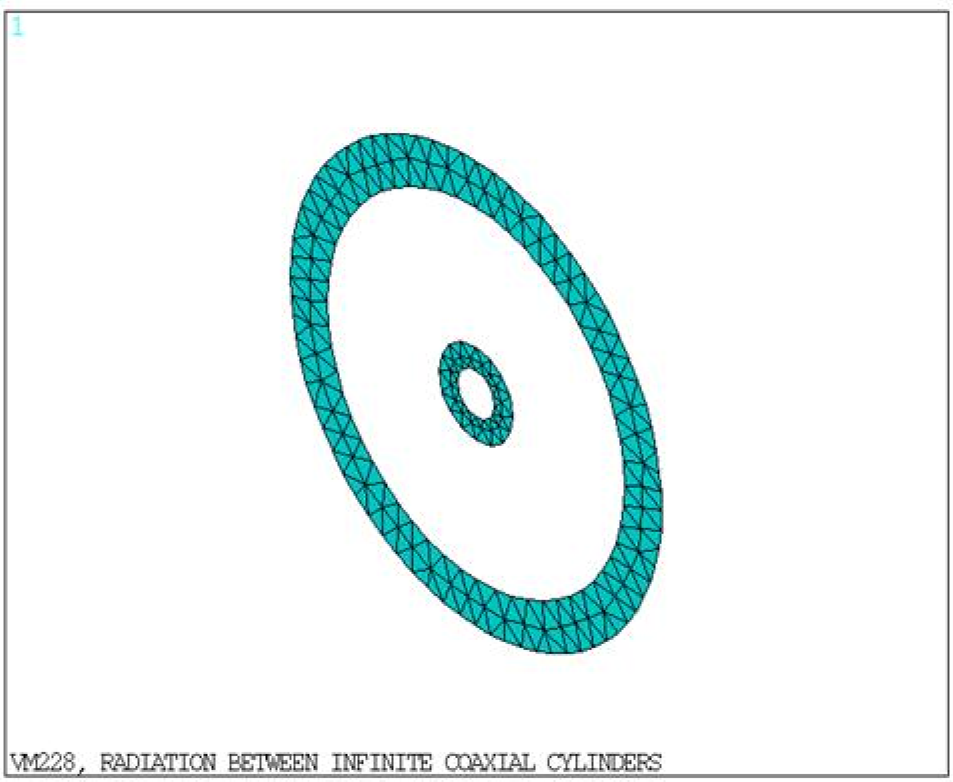
Overview

Reference:	R. Siegel, J. R. Howell, *Thermal Radiation Heat Transfer*. 3d ed. Hemisphere Publishing, 1992, p. 204–205, and 240.
Analysis Type(s):	Steady State Radiosity
Element Type(s):	2-D 6-Node Triangular Thermal Solid Elements (PLANE35) 2-D Radiosity Surface Elements (SURF251) 3-D 20-Node Tetrahedral Thermal Solid Elements (SOLID90) 3-D Radiosity Surface Elements (SURF252)
Input Listing:	vm228.dat

Test Case

Two concentric infinite cylinders are transferring heat to each other through radiation. The problem is modeled as a 2-D and 3-D pair of concentric circles. The facing surfaces are given surface emissivity values, the non facing surfaces are at fixed temperatures.

Figure 228.1: Finite Element Model of Problem using Triangular Thermal Solid Elements (PLANE35)



Material Properties	Geometric Properties	Loading
E = 30e6 K_{xx} = 1 ρ = 0.21	r1 = 1 r2 = 4 σ = 1.19e-11	Interior of exterior cylinder ε = 1 Exterior of interior cylinder ε =1

Material Properties	Geometric Properties	Loading
α_x = .21 ν_{xy} = .27		All other surfaces ε = 0 Exterior of Exterior cylinder T = 1000 Interior of Interior cylinder T = 100

Analysis Assumptions and Modeling Notes

The cylinders are assumed to be infinite length, with no end effects, and with uniform surface characteristics. As such, any point on one surface should have the same view factor and characteristics as any other point on the same surface.

F(11) = 0 As a circle, it cannot see itself from any part of its surface.
F(12) = 1 Consequence of no radiation to space
F(21) = (A1/A2)F(12) Basic rule of view factors
F(21) = (r1/r2)F(12)
F(21) = r1/r2
F(22) = 1 - (r1/r2) Consequence of no radiation to space

As a check on the system, the heat flux at two points are compared to that expected by $\sigma(T_1^4 - T_2^4)$

A second solution of the test case is performed using radiosity surface elements. These elements are applied to all surfaces which have loads with the RDSF flag. The total number of radiation elements is reduced using the **RDEC** command. These two solutions are performed again using a 3-D model, one without radiosity surface elements and the other using radiosity surface elements.

Results Comparison

	Target	Mechanical APDL	Ratio
PLANE35			
$F_{(11)}$	0.000	0.000	0.00
$F_{(21)}$	0.250	0.249	1.00
$F_{(22)}$	0.750	0.751	1.00
Heat flux (interior) at node(0,-1,0)	11.537	11.035	0.96
Heat flux (exterior) at node(0,-4,0)	2.884	2.742	0.95
PLANE35 and SURF251			
$F_{(11)}$	0.000	0.000	0.00
$F_{(21)}$	0.250	0.249	1.00
$F_{(22)}$	0.750	0.751	1.00
Heat flux (interior) at node(0,-1,0)	11.537	11.035	0.96
Heat flux (exterior) at node(0,-4,0)	2.884	2.747	0.95

	Target	Mechanical APDL	Ratio
SOLID90			
F(11)	0.000	0.000	0.00
F(21)	0.250	0.250	1.00
F(22)	0.750	0.750	1.00
Heat flux (interior) at node(0,-1,0)	11.537	11.001	0.95
Heat flux (exterior) at node(0,-4,0)	2.884	2.714	0.94
SOLID90 and SURF252			
F(11)	0.000	0.000	0.00
F(21)	0.250	0.249	1.00
F(22)	0.750	0.751	1.00
Heat flux (interior) at node(0,-1,0)	11.537	11.001	0.95
Heat flux (exterior) at node(0,-4,0)	2.884	2.704	0.94

VM229: Friction Heating of Sliding Block

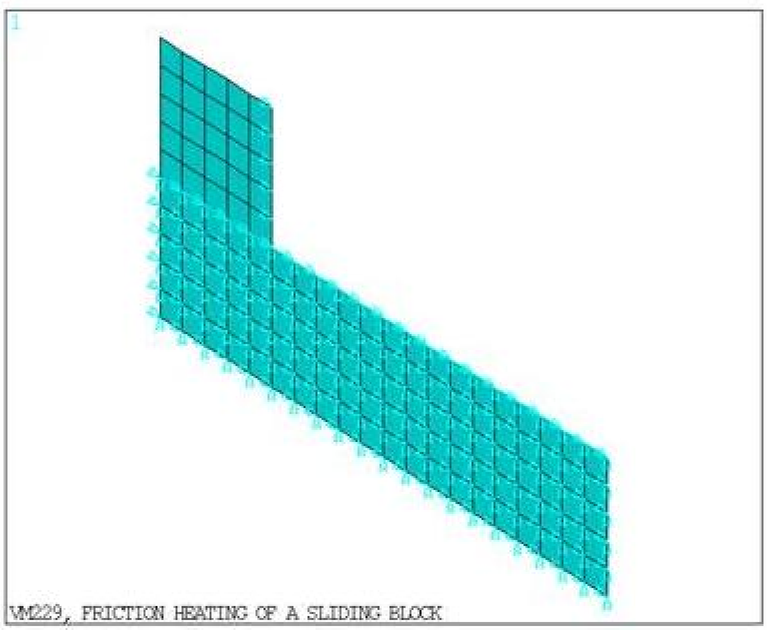
Overview

Reference:	P. Wiggers, C. Miehe, "Contact Constraints Within Coupled Thermomechanical Analysis - A Finite Element Model", *Computer Methods in Applied Mechanics and Engineering*, Vol. 113, 1994, pp. 301-319.
Analysis Type(s):	Transient (**ANTYPE** = 4)
Element Type(s):	2-D Coupled-Field Solid Elements (PLANE13) 2-D Target Segment Elements (TARGE169) 2-D 2-Node Surface-to-Surface Contact Elements (CONTA171) 2-D 8-Node Coupled-Field Solid (PLANE223)
Input Listing:	vm229.dat

Test Case

Consider a block sliding over another fixed block. Calculate the temperature changes caused by friction between the blocks.

Figure 229.1: Finite element model of sliding block



Material Properties	Geometric Properties	Loading
E= 7000 Mpa ρ = 2.7E-9 N s^2/mm^4 α = 23.86E-6 K^{-1} ν = 0.3 μ = 0.2 K_{xx} = 150 N/s K	**Sliding Block:** Height = 1.25mm Width = 1.25mm **Fixed Block:** Height = 1.25mm Width = 5mm	Displacement = 3.75mm

Material Properties	Geometric Properties	Loading
C = 9E8 mm^2/s^2 K		

Analysis Assumptions and Modeling Notes

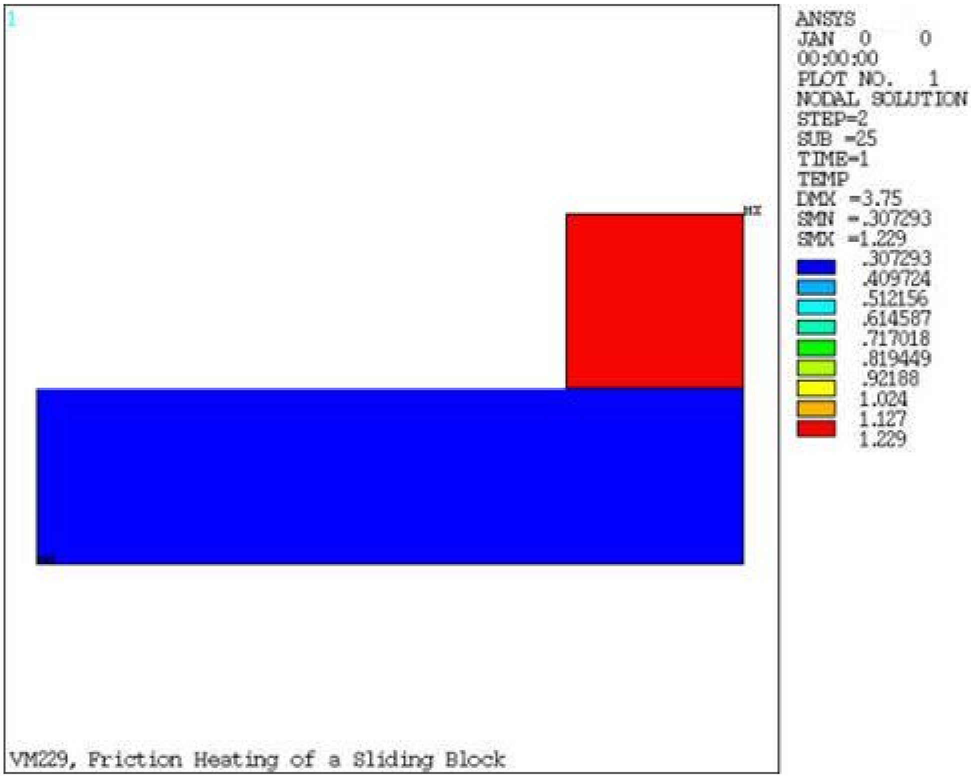
In this test the two blocks are modeled using PLANE13 elements with CONTA171 elements placed on the bottom surface of the sliding block, and TARGE169 elements placed at the top surface of the fixed block. In the first load step, the sliding block moves 3.75 mm on the surface of the fixed block with an applied pressure of 10 N/mm^2. The displacement of the sliding block occurs within a time period of 3.75 ms. Heat is generated by friction and is absorbed by the two blocks. To obtain the steady-state solution, a second load step with 100 time steps was performed with no loading at a duration of 1s. The calculated steady-state results were taken from the end of the final load step.

The same analysis is repeated using Pure Lagrange Multipliers method (KEYOPT(2) = 4 -- Pure Lagrange multiplier on contact normal and tangent) of CONTA171 elements.

Results Comparison

	Target	Mechanical APDL	Ratio
PLANE13			
Temp 1 (K)	1.235	1.2346	1.000
Temp 2 (K)	0.309	0.3087	0.999
With KEYOPT (2) = 3 of CONTA171			
Temp 1 (K)	1.2350	1.2346	1.000
Temp 2 (K)	0.3090	0.3087	0.999
PLANE223			
Temp 1 (K)	1.2350	1.2619	1.022
Temp 2 (K)	0.3090	0.3155	1.021

Figure 229.2: Temperature Change for Sliding Block with Friction



VM230: Analytical Verification of PDS Results

Overview

Reference:	A. H-S. Ang and W. H. Tang, *Probability Concepts in Engineering Planning and Design*, Vol 1 - Basic Principles, John Wiley & Sons, 1975.
Analysis Type(s):	PDS
Element Type(s):	None
Input Listing:	vm230.dat

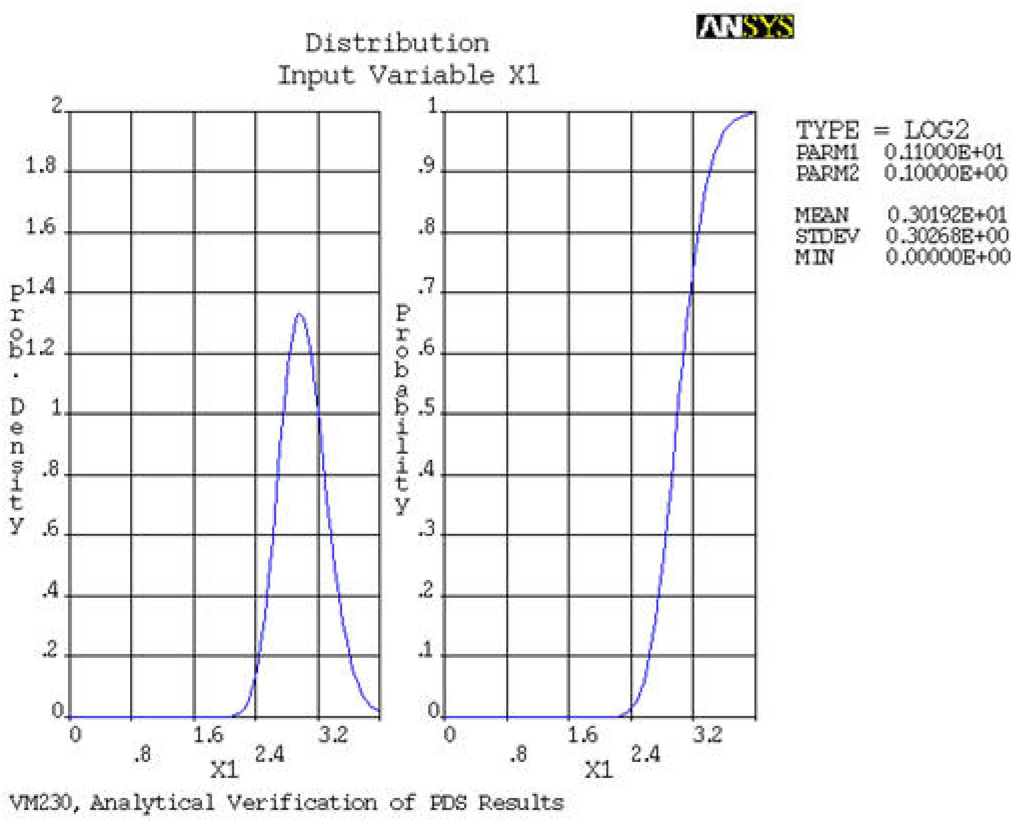
Test Case

Five statistically independent random input variables are defined, X_1 to X_5. All random input variables follow log-normal distribution with a logarithmic mean value ξ_i and a logarithmic deviation δ_i and i = 1,...,5 as distribution parameters. A random output parameter Y is defined as a function of the random input variables.

$$Y = \frac{X_1 X_2 X_3}{X_4 X_5}$$

Verify the mean value and the standard deviation of the random output parameter Y.

Figure 230.1: Distribution of Input Variable



Analysis Assumptions and Modeling Notes

From the reference A. H-S. Ang and W. H. Tang, *Probability Concepts in Engineering Planning and Design*, the random output parameter Y follows a log-normal distribution with a logarithmic mean of:

$$Y = \frac{X_1 X_2 X_3}{X_4 X_5}$$

$$\xi_y = \xi_1 + \xi_2 + \xi_3 - \xi_4 - \xi_5$$

and a logarithmic deviation of

$$\delta_y = \sqrt{\delta_1^2 + \delta_2^2 + \delta_3^2 + \delta_4^2 + \delta_5^2}$$

The mean value of the random output parameter *Y* is:

$$\mu_y = \exp(\xi_y + 0.5\delta_y^2)$$

and the standard deviation is:

$$\sigma_y = \sqrt{\exp(2\xi_y + \delta_y^2)(\exp(\delta_y^2) - 1)} = \mu_y \sqrt{(\exp(\delta_y^2) - 1)}$$

Using the following values:

$\xi_1 = 1.1$ $\delta_1 = 0.1$

$\xi_2 = 1.2$ $\delta_2 = 0.2$

$\xi_3 = 1.3$ $\delta_3 = 0.3$

$\xi_4 = 1.4$ $\delta_4 = 0.4$

$\xi_5 = 1.5$ $\delta_5 = 0.5$

the following analytical results are obtained:

$\xi_y = 0.7$

$\delta_y = 0.74162$

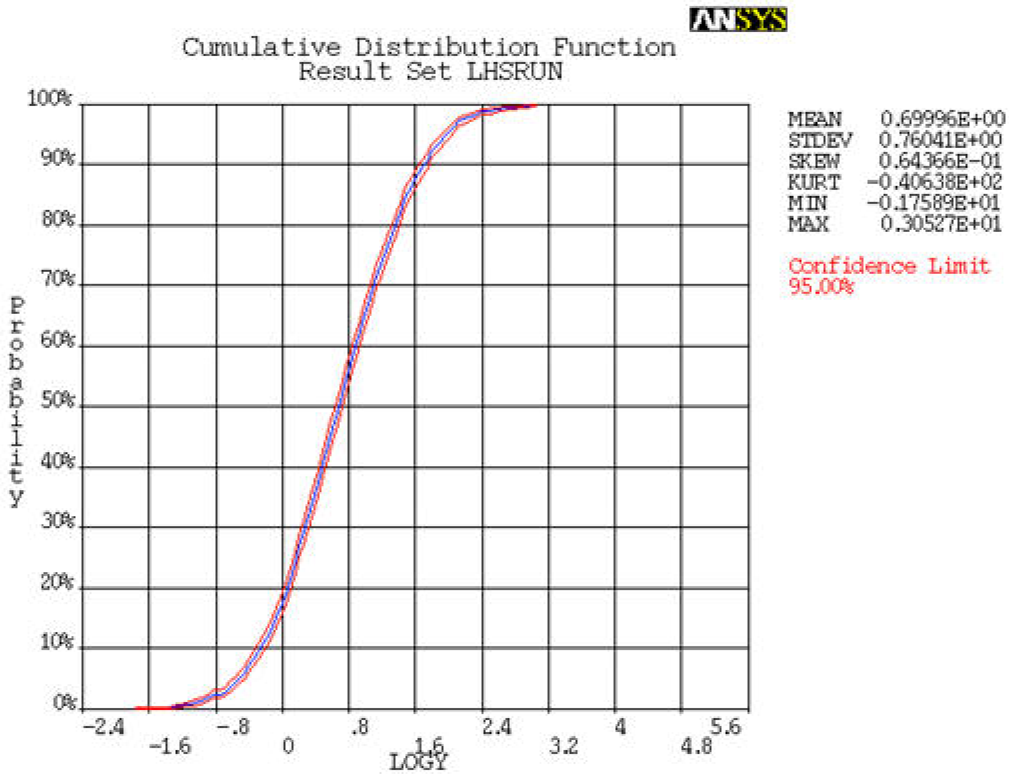
$\mu_y = 2.651167$

$\sigma_y = 2.2701994$

For the Mechanical APDL PDS analysis, a loop file is created which contains the random input variables and the random output variable. In the /PDS module, X_1 through X_5 are defined as probabilistic design variables and *Y* is defined as a response parameter. The PDS mean parameter values and deviations are defined with the values used in the analytical solution above.

The 2000 Latin Hypercube samples were post-processed to determine the logarithmic mean and logarithmic deviation of Y. A cumulative distribution function was plotted for Y showing the 95% confidence limit. This confirms that the distribution type of Y is log-normal, because the CDF is very close to a straight line.

Figure 230.2: Cumulative Distribution Function (Probability vs. Log Y)



Results Comparison

	Target	Mechanical APDL	Ratio
Mean Value of Y	2.6957898	2.65116721	1.000
Standard Deviation of Y	2.3744199	2.27019963	1.000

VM231: Piezoelectric Rectangular Strip Under Pure Bending Load

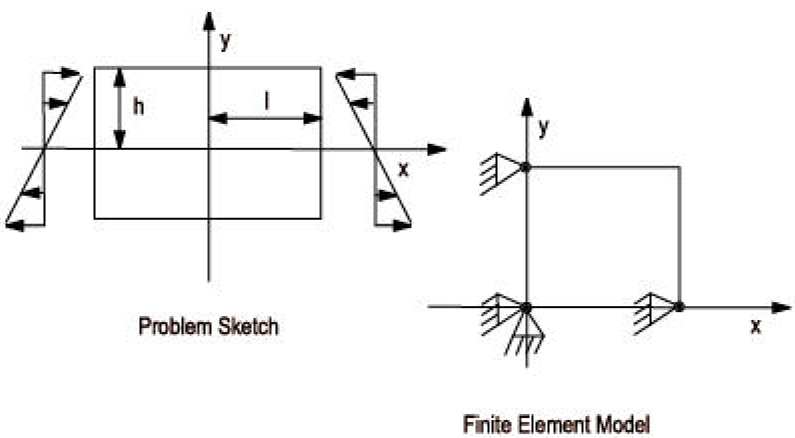
Overview

Reference:	V. Z. Parton, B. A. Kudryavtsev, N. A, Senik, *Applied Mechanics: Soviet Review*, Vol. 2: Electromagnetoelasticity, pg. 28.
Analysis Type(s):	Static
Element Type(s):	2-D Coupled-Field Solid Elements (PLANE13) 2-D 8-Node Coupled-Field Solid Elements (PLANE223)
Input Listing:	vm231.dat

Test Case

A piezoceramic (PZT-4) rectangular strip occupies the region $|x| \leq l$, $|y| \leq h$. The material is oriented such that its polarization direction is aligned with the Y axis. The strip is subjected to the pure bending load $\sigma_x = \sigma_1 y$ at $x = \pm l$. Determine the electro-elastic field distribution in the strip.

Figure 231.1: Piezoelectric Strip Problem Sketch



Material Properties	Geometric Properties	Loading
See "Constitutive Matrices for PZT4 Polarized Along the Y Axis" (p. 647)	l = 1mm h = 0.5 mm	Pressure slope σ_1 = -20 N/mm^3

Constitutive Matrices for PZT4 Polarized Along the Y Axis

PZT4 Dielectric Matrix $[\varepsilon_r]$

$$\begin{bmatrix} 728.5 & 0 & 0 \\ 0 & 634.7 & 0 \\ 0 & 0 & 728.5 \end{bmatrix}$$

PZT4 Piezoelectric Matrix [e] C/m^2

$$\begin{bmatrix} 0 & -5.2 & 0 \\ 0 & 15.1 & 0 \\ 0 & -5.2 & 0 \\ 12.7 & 0 & 0 \\ 0 & 0 & 12.7 \\ 0 & 0 & 0 \end{bmatrix}$$

PZT4 Stiffness matrix [c] x 10^{-10} N/m^2

$$\begin{bmatrix} 13.9 & 7.43 & 7.78 & 0 & 0 & 0 \\ & 11.5 & 7.43 & 0 & 0 & 0 \\ & & 13.9 & 0 & 0 & 0 \\ & & & 2.56 & 0 & 0 \\ & & & & 2.56 & 0 \\ & & & & & 3.06 \end{bmatrix}$$

Analysis Assumptions and Modeling Notes

The problem is first solved using PLANE13 elements and then solved using PLANE223 elements.

Only a one-quarter symmetry sector of the rectangular strip is modeled. Symmetric and antisymmetric boundary conditions are applied.

For the first case, the finite element model uses a single 4-node 2-D quadrilateral element (PLANE13) with extra displacement and potential modes to produce a correct response to the pure bending load. For the second case, the finite element model uses a single 8-node 2-D quadrilateral element (PLANE223).

Results Comparison

Node 3	Target	Mechanical APDL	Ratio
PLANE13			
UX, μm	-0.110	-0.110	1.000
UY, μm	0.115	0.115	1.000
VOLT, V	27.378	27.379	1.000
Stress x, N/mm^2	-10.000	-10.000	1.000
Electric Field y, V/mm	-109.511	-109.515	1.000
PLANE223			
UX, μm	-0.110	-0.110	1.000
UY, μm	0.115	0.115	1.000
VOLT, V	27.378	27.379	1.000
Stress x, N/mm^2	-10.000	-10.000	1.000
Electric Field y, V/mm	-109.511	-109.515	1.000

VM232: PDS Response Surface Study

Overview

Reference:	A. H-S. Ang and W. H. Tang, *Probability Concepts in Engineering Planning and Design*, Vol 1 - Basic Principles, John Wiley & Sons, 1975.
Analysis Type(s):	PDS
Element Type(s):	None
Input Listing:	vm232.dat

Test Case

Assume that there are two random input variables, defined as X_W and X_E. The random input variable X_W follows a Weibull distribution with a Weibull exponent of m = 2.0, a Weibull characteristic value of x_{chr} = 1.0 and a lower limit of $x_{W,min}$ = 0.0. The random input variable X_E follows an exponential distribution with a decay parameter generally expressed as λ and lower limit of $x_{E,min}$ = 0.0.

Figure 232.1: Distribution of Input Variable X_W

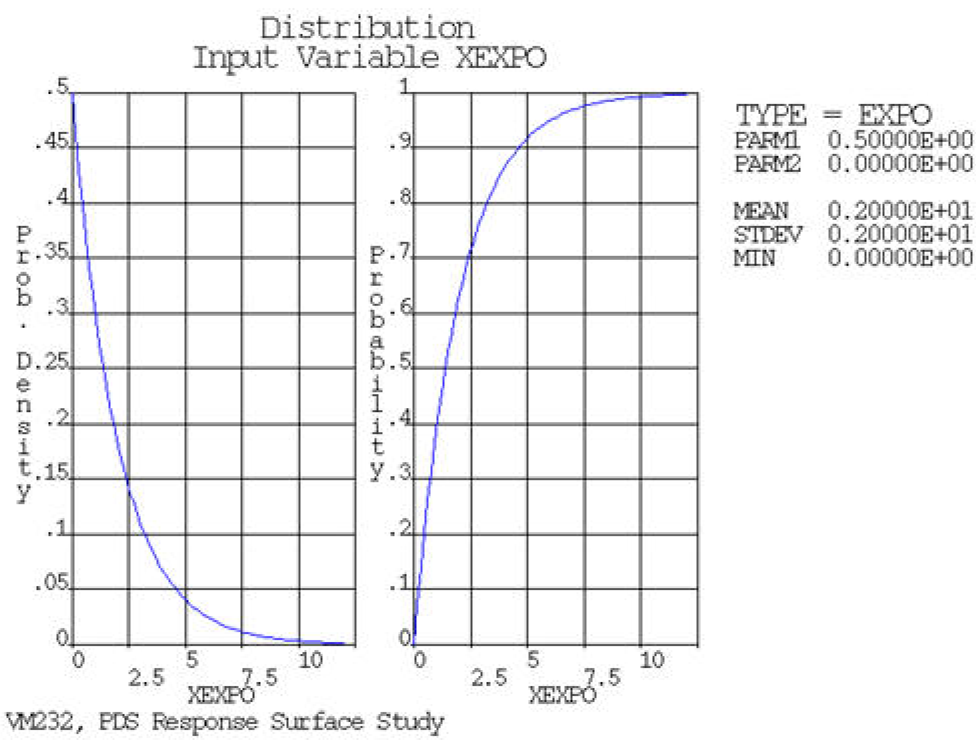
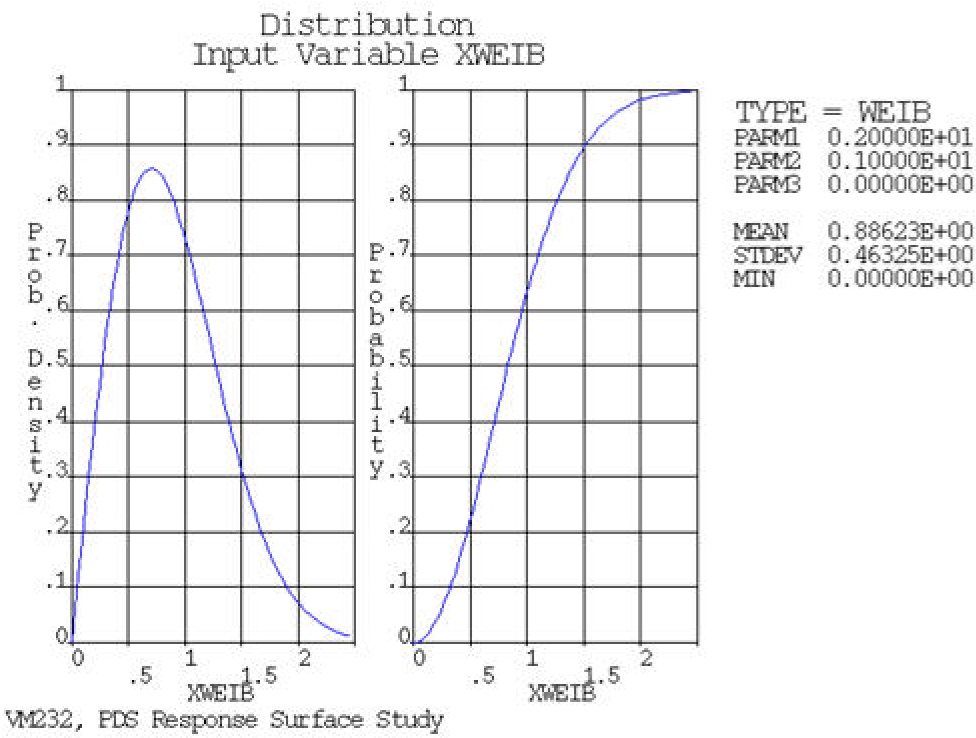


Figure 232.2: Distribution of Input Variable X_E



Analysis Assumptions and Modeling Notes

The probability density function of X_W is:

$$f_W(x_W) = \frac{m\,(x_W - x_{W,min})^{m-1}}{(x_{chr} - x_{W,min})^m} \exp\left(-\left(\frac{x_W - x_{W,min}}{x_{chr} - x_{W,min}} \right)^m \right)$$

Using the values of m = 2.0, x_{chr} = 1.0 and x_{min} = 0.0, the probability density function of X_W reduces to:

$$f_W(x_W) = 2x_W \exp(-x_W^2)$$

The probability density function of X_E is:

$$f_E(x_E) = \lambda \exp(-\lambda(x - x_{E,min}))$$

Using the value x_{min}, the probability density function of X_E reduces to:

$$f_E(x_E) = \lambda \exp(-\lambda x_E)$$

The random output parameter Y as a function of the random input variables is defined as:

$$y = c_1 x_W^2 - c_2 x_E$$

Next, the probability that Y is negative, i.e. $P(Y < 0)$ is evaluated. For this case the probability is:

$$P(Y < 0) = \iint_{Y<0} f_W(x_W) f_E(x_E)\, dx_W\, dx_E$$

The integration domain *Y < 0* can be expressed as:

$$c_1 x_W^2 - c_2 x_E < 0$$

or

$$c_2 x_E > c_1 x_W^2$$

or

$$x_E > \frac{c_1}{c_2} x_W^2$$

Therefore, the integration domain of the integral can be written as:

$$P(Y<0) = \int_0^\infty \int_{\frac{c_1}{c_2} x_W^2}^\infty f_W(x_W) f_E(x_E) dx_E dx_W$$

Separating the product in the integrator leads to:

$$P(Y<0) = \int_0^\infty f_W(x_W) \left(\int_{\frac{c_1}{c_2} x_W^2}^\infty f_E(x_E) dx_E \right) dx_W$$

Using eqs. 2 and 4 leads to:

$$P(Y<0) = \int_0^\infty 2x_W \exp(-x_W^2) \left(\int_{\frac{c_1}{c_2} x_W^2}^\infty \lambda \exp(-\lambda x_E) dx_E \right) dx_W$$

Solving the inner integral is:

$$P(Y<0) = \int_0^\infty 2x_W \exp(-x_W^2) \left[\exp(-\lambda x_E)\Big|_{x_E = \frac{c_1}{c_2} x_W^2} - \exp(-\lambda x_E)\Big|_{x_E = \infty} \right] dx_W$$

or

$$P(Y<0) = \int_0^\infty 2x_W \exp(-x_W^2) \exp\left(-\lambda \frac{c_1}{c_2} x_W^2 \right) dx_W$$

or

$$P(Y<0) = \int_0^\infty 2x_W \exp\left(-\left(1 + \lambda \frac{c_1}{c_2} \right) x_W^2 \right) dx_W$$

The solution of this integral is:

$$P(Y<0) = \frac{1}{1 + \lambda \frac{c_1}{c_2}} \left[\exp\left(-\left(1 + \lambda \frac{c_1}{c_2} \right) x_W^2 \right)\Bigg|_{x_W = 0} - \exp\left(-\left(1 + \lambda \frac{c_1}{c_2} \right) x_W^2 \right)\Bigg|_{x_W = \infty} \right]$$

or

$$P(Y < 0) = \frac{1}{1 + \lambda \dfrac{c_1}{c_2}}$$

For $\lambda = 0.5$, $c_1 = 1.0$ and $c_2 = 0.1$ the probability $P(Y < 0)$ becomes:

$$P(Y < 0) = \frac{1}{6} \cong 0.1666667$$

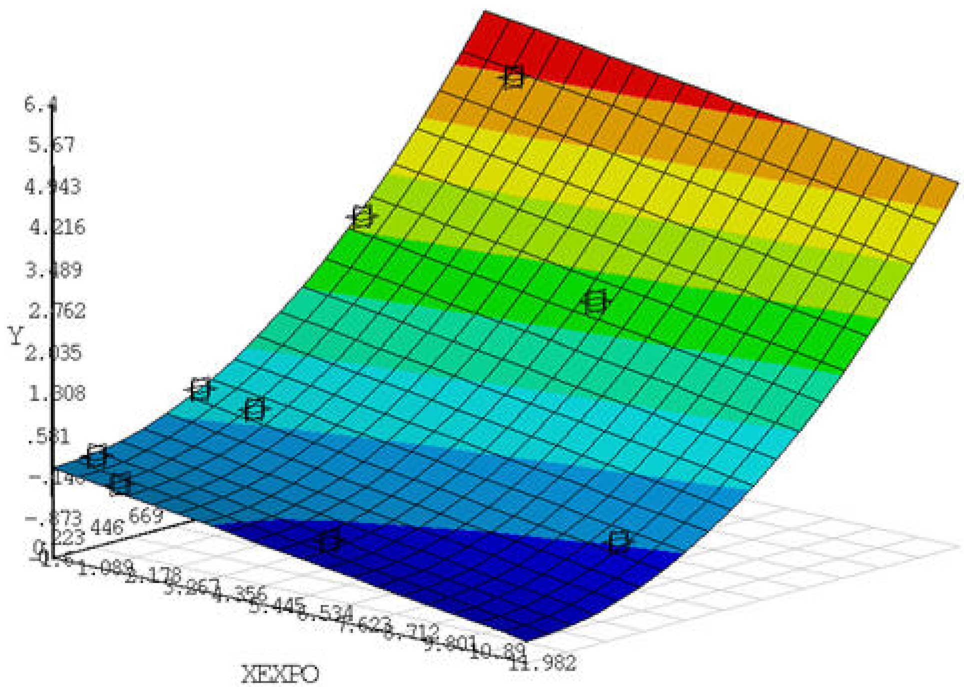
In this test case, numerical results are first obtained from a Monte Carlo analysis method using Latin Hypercube Sampling.

$P(Y < 0) = 0.165096$

A response surface method using a central composite design is evaluated to show that it delivers an acceptable analysis.

$P(Y < 0) = 0.166829$

Figure 232.3: Response Surface plot



Results Comparison

	Target	Mechanical APDL	Ratio
P (Y < 0) from Monte Carlo	0.16666667	0.165096	0.9906
P (Y < 0) from Response Surface	0.16666667	0.166829	1.001

VM233: Static Force Computation of a 3-D Solenoid Actuator

Overview

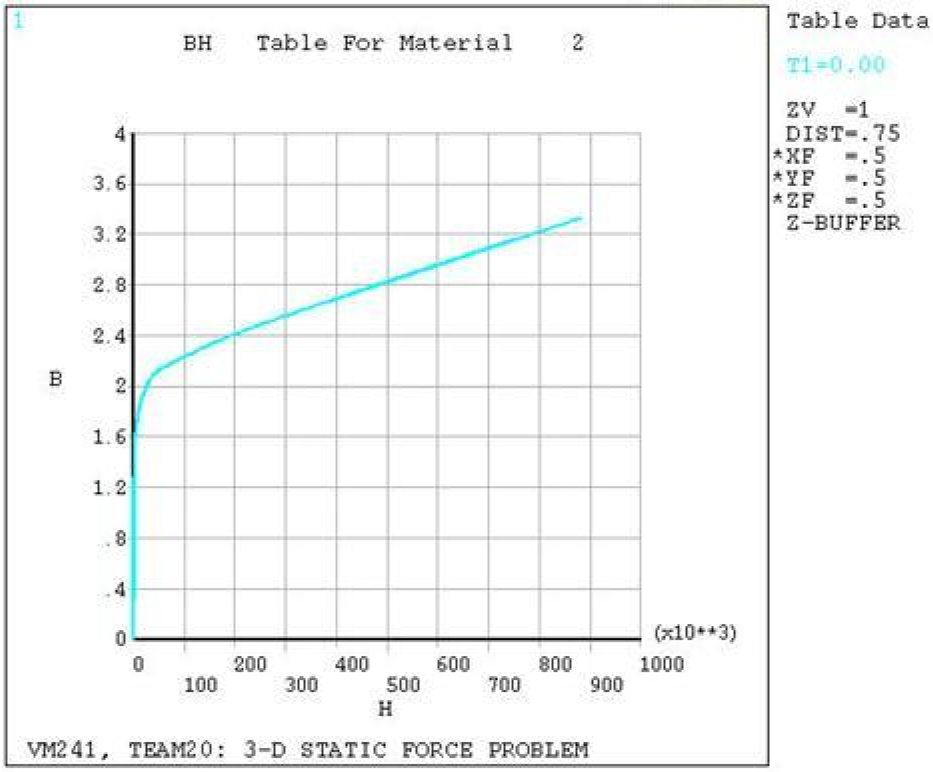
Reference:	M. Gyimesi, D. F. Ostergaard, "Analysis of Benchmark Problem TEAM20 with Various Formulations", *Proceedings of TEAM Workshop, COMPUMAG, Rio*, 1997. M. Gyimesi, D. F. Ostergaard, "Mixed Shape Non-Conforming Edge Elements", *IEEE Transactions on Magnetics*, Vol. 35 No. 3, 1999, pp. 1407-1409. M. Gyimesi, D. F. Ostergaard, "Non-Conforming Hexahedral Edge Elements for Magnetic Analysis", *IEEE Transactions on Magnetics*, Vol 34 No. 5, 1998, pp. 2481-2484.
Analysis Type(s):	Static (**ANTYPE** = 0)
Element Type(s):	Tetrahedral Coupled-Field Solid Elements (SOLID98)
Input Listing:	vm233.dat

Test Case

For the given solenoid actuator with an applied total coil current of 5000 A-turns, find the magnetic flux density (BZ) of the Pole, the magnetic flux density (BZ) of the Arm, and the Virtual Work Force in the Z-direction (See Problem Description for location of parts).

Material Properties	Geometric Properties	Loading
Murx =1	X1 = 63.5mm X2 = 12.5mm Y1 = 12.5mm Y2 = 5mm Y3 = 18mm Z1 = 25 mm Z2 = 100mm Z3 = 98.5mm Z4 = 96.6mm	Total Current = 5000 A-turns

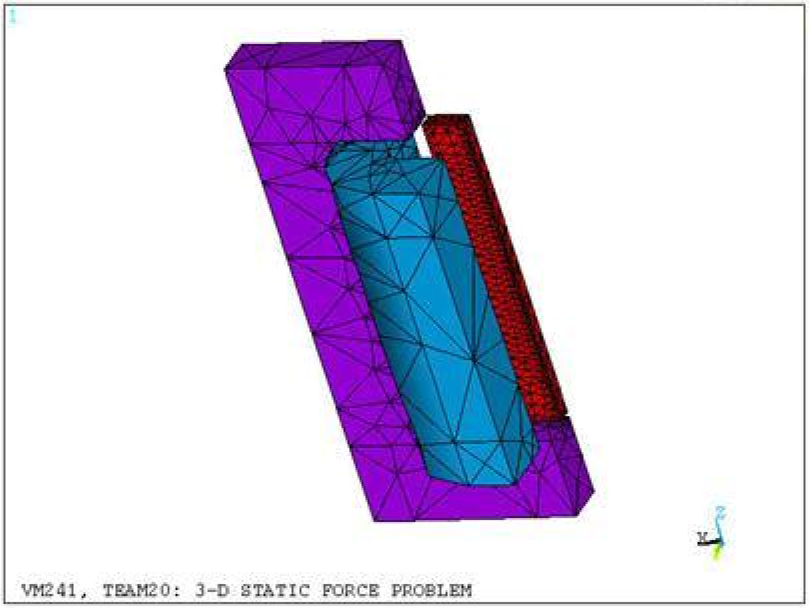
Figure 233.1: B-H Curve

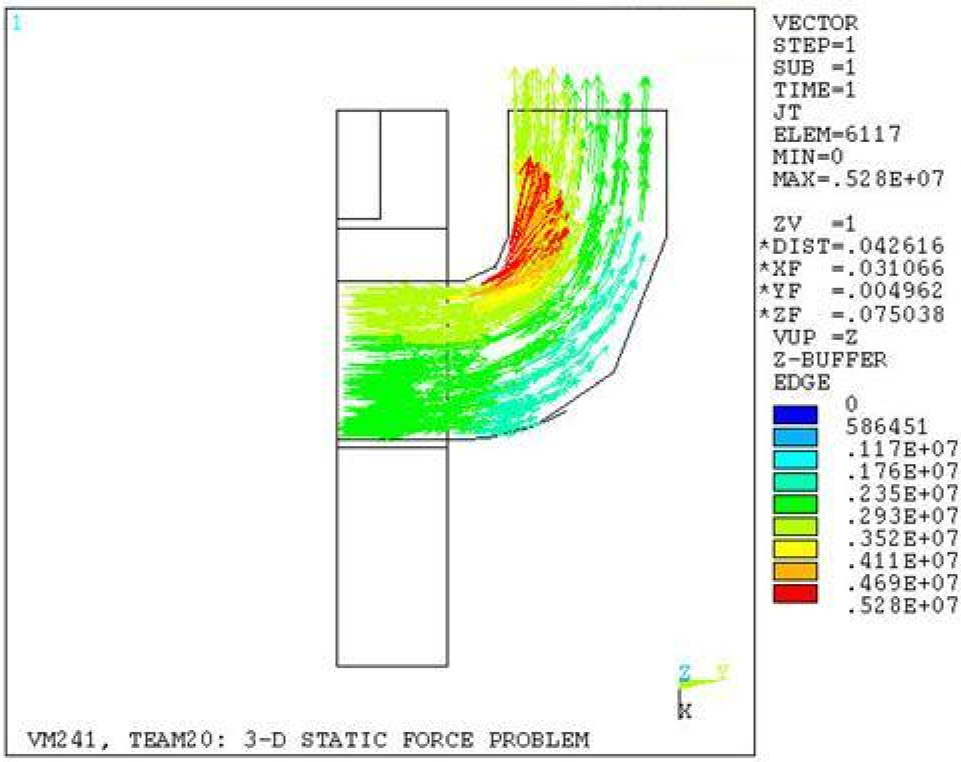


Analysis Assumptions and Modeling Notes

This analysis is based on the TEAM workshop problem 20. It utilizes the Difference Scalar Potential (DSP) element formulation with tetrahedral shaped SOLID98 elements. DSP formulation was used because it has much better accuracy than the Magnetic Vector Potential (MVP) method. Additionally, it is more efficient than the EDGE formulation method. To simplify meshing, the **SMRTSIZE** meshing option was used to automatically determine line divisions and spacing ratios while taking into account the line proximity effects. Mesh density can be adjusted using the SmartSize parameter, for this case, a SmartSizing level of 10 was applied. The analysis is performed using a quarter symmetry model of the solenoid actuator. The magnetic coil was created using the **RACE** command. Magnetic force and boundary conditions were placed on the armature component by using the **FMAGBC** command.

Figure 233.2: Finite Element Model





Results Comparison

Total Current = 5000 A-turns	Target	Mechanical APDL	Ratio
Virtual Work Force (N)	80.1	80.208	1.001
Pole Flux Density (BZ, Tesla)	0.46	0.474	1.031
Arm Flux Density (BZ, Tesla)	2.05	2.048	0.999

VM234: Cyclic Loading of a Rubber Block

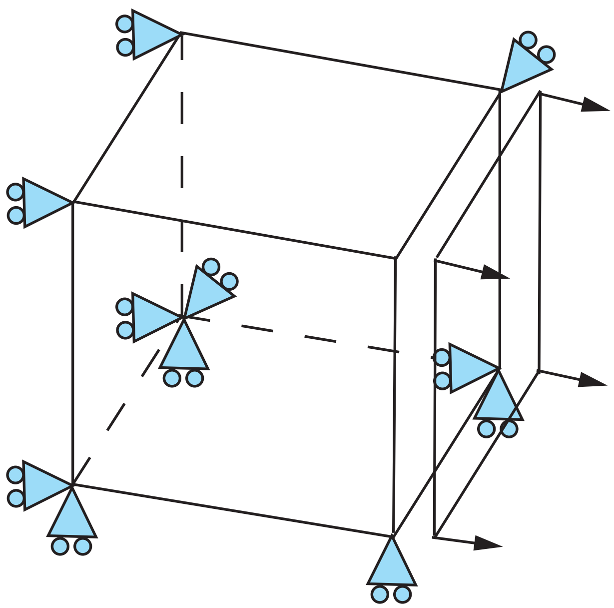
Overview

Reference:	G. A. Holzapfel, "On Large Strain Viscoelasticity: Continuum Formulation and Finite Element Applications to Elastomeric Structures", *International Journal for Numerical Methods in Engineering*, Vol. 39, 1996, pp. 3903-3926.
Analysis Type(s):	Static Structural Analysis (**ANTYPE** = 4)
Element Type(s):	3-D 8-Node Structural Solid Elements (SOLID185)
Input Listing:	vm234.dat

Test Case

A cube of rubber is subjected to a sinusoidal displacement controlled load with a mean value of zero (completely reversed). The load amplitude is constant within a full cycle (4 seconds) and increases with each successive cycle. For the first period A = 0.01 and it increases by 0.01 each cycle until the fourth when A = 0.04. At t = 16 seconds the load is removed and the residual stresses are permitted to relax.

Figure 234.1: Rubber Block Model

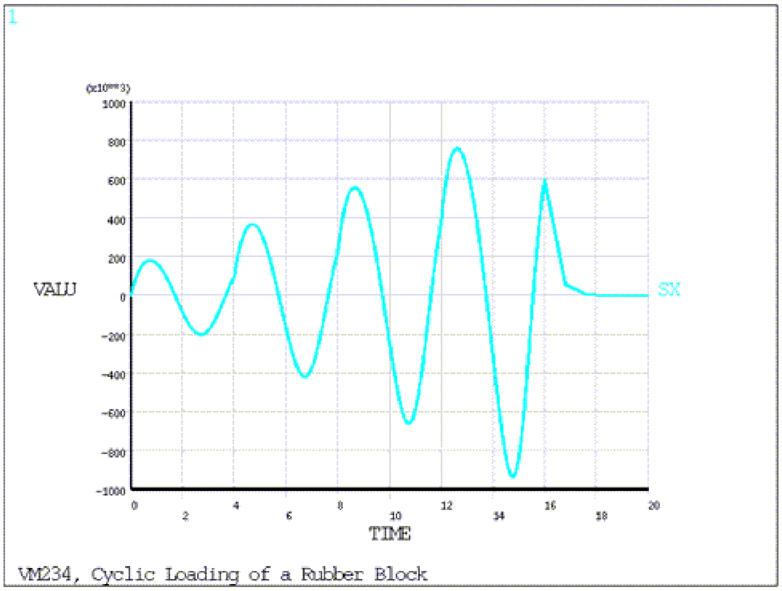


Material Properties	Geometric Properties	Loading
τ_1 = 0.40 sec τ_2 = 0.20 sec $\beta_1 = \beta_2 = 1$	L = 0.1 m	A = 0.01

Analysis Assumptions and Modeling Notes

The analysis was performed using a single SOLID185 element. The rubber was simulated with an Ogden material model. The load was applied using a looping application of the displacement boundary condition. The plot displays the Cauchy stress evolution over the specified time periods. The accumulated stress relaxes after the load is removed at t = 16 seconds. The accumulated stress at t = 16 seconds and the relaxed stress state at t = 20 seconds are the verified results for this test.

Figure 234.2: Stress Evolution Over Time



Results Comparison

	Target	Mechanical APDL	Ratio
Cauchy Stress *(N/m²)* t = 16 sec	6.013E5	5.993889E5	0.997
Cauchy Stress *(N/m²)* t = 20 sec	0.0	17.7	0.000

VM235: Frequency Response of a Prestressed Beam

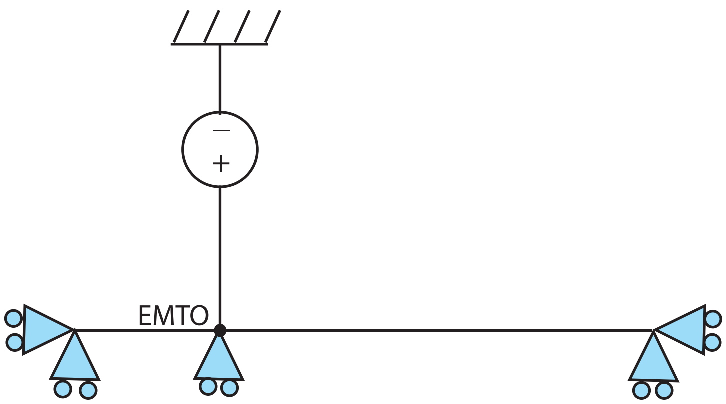
Overview

Reference:	R. D. Blevins, *Formulas for Natural Frequency and Mode Shape*, Van Nostrand Reinhold Co., pg. 144, equation 8-20.
Analysis Type(s):	Modal (**ANTYPE**=2)
Element Type(s):	2-D Elastic Beam Elements (BEAM188) Electromechanical Transducer Elements (TRANS126)
Input Listing:	vm235.dat

Test Case

A beam is in series with an electromechanical transducer. With a voltage applied to the beam, determine the prestressed natural frequencies of the beam.

Figure 235.1: Element Plot



Material Properties	Geometric Properties	Loading
Ex = 169E3 μN/μm^2 DENS = 2332E-18 kg/μm^3 Beam Stiff = 112666.667 μN/μm Gap Stiff = 20.022 μN/μm	L = 150μm W = 4 μm H = 2 μm Initial Gap = 1 μm Gap = 0.999 μm	Volt = 150.162V

Analysis Assumptions and Modeling Notes

The beam is created using BEAM188 elements which are used in series with one TRANS126 element. The node that connects the transducer and beam is free to move in the X-direction, while the end node of the beam and the ground node of the transducer are constrained in both the X and Y directions. It should also be noted that the transducer gap stiffness is much less than the beam stiffness and will not have any effect on the frequency solution.

Figure 235.2: Mode Shape 1

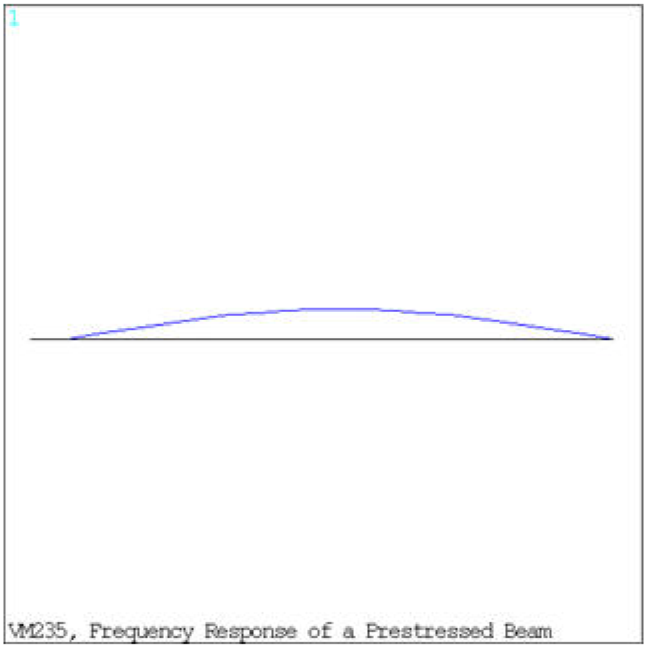


Figure 235.3: Mode Shape 2

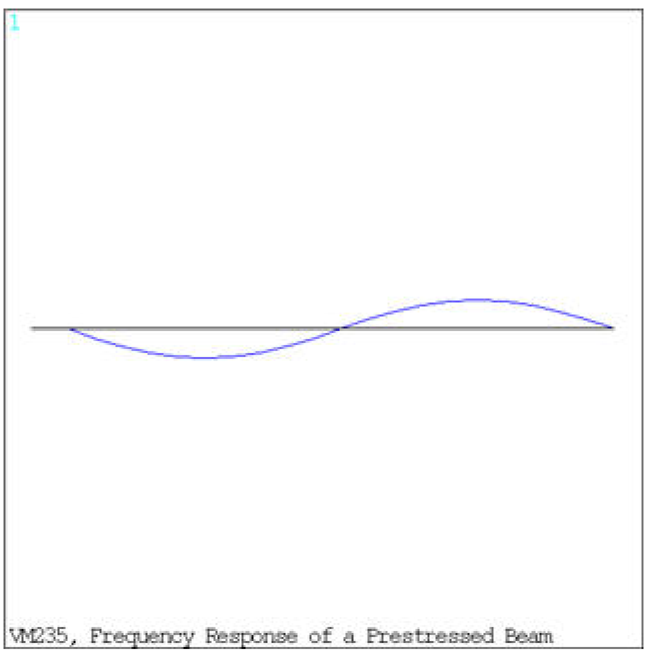
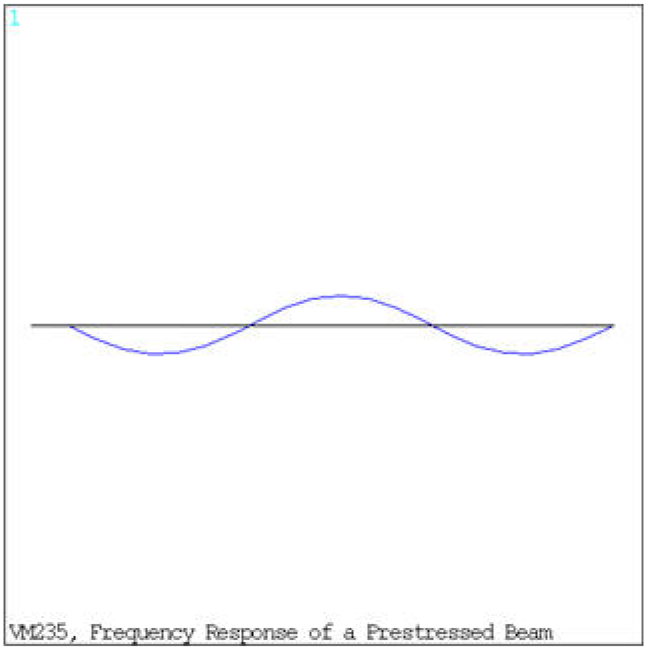


Figure 235.4: Mode Shape 3



Results Comparison

	Target	Mechanical APDL	Ratio
Frequency (mode 1)	351699.332	351609.996	1.000
Frequency (mode 2)	1381162.303	1379724.174	1.001
Frequency (mode 3)	3096816.034	3089542.986	1.002

VM236: Hysteresis Calculation of a Beam Under Electrostatic Load

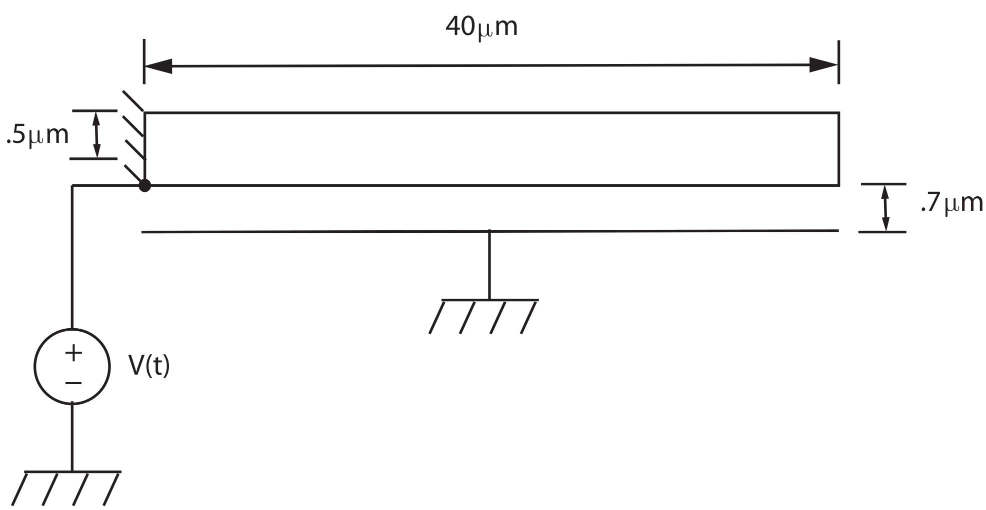
Overview

Reference:	J. R. Gilbert, G. K. Ananthasuresh, S. D. Senturia, "3D Modeling of Contact Problems and Hysteresis in Coupled Electro-Mechanics", MEMS, 1996, pp. 127-132.
Analysis Type(s):	Static (**ANTYPE** = 0)
Element Type(s):	2-D Coupled-Field Solid Elements (PLANE223, KEYOPT(1) = 1001) 2-D 4-Node Structural Solid Elements (PLANE182) 3-D Node-to-Node Contact Elements (CONTA178)
Input Listing:	vm236.dat

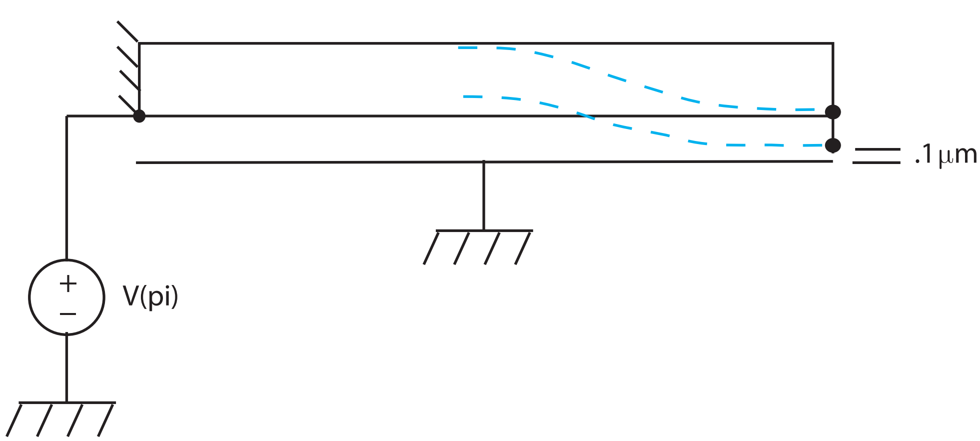
Test Case

A beam of length L = 80 μm at a height T = 0.5 μm is suspended 0.7 μm above a ground plane and is clamped at either end. Using this beam, model the hysteresis (pull-in and release behaviors) when it is placed under electrostatic load.

Figure 236.1: Beam Under Electrostatic Load



Beam at beginning and unloading.



Beam at pull-in voltage.

Model the hysteresis (pull-in and release behaviors) of a structural beam under electrostatic load.

Material Properties	Geometric Properties	Loading
EX = 169E3 NUXY = 0.25 PERX = 1 MU = 0	Beam Length = 80 microns Beam Height = 0.5 microns Gap = 0.7 microns	V(1) = 11.0V V(2) = 14.5V V(3) = 18.0V

Analysis Assumptions and Modeling Notes

Using symmetry at a length L=40 µm, the solid beam is modeled with quad shaped PLANE182 elements. The air gap is modeled with 2-D coupled-field PLANE223 elements with KEYOPT(1) = 1001 for an electroelastic analysis. Node-Node contact is modeled in the air gap using CONTA178 elements. The beam is constrained in the X and Y directions on the left side and is free only in the Y-direction along the span. The beam is suspended 0.7 µm over the ground plane with a contact stop at 0.1µm.

Results Comparison

	Target	Mechanical APDL	Ratio
UY @ 11.0V	-0.0722	-0.0724	1.002
UY @ 14.5V	-0.1451	-0.1456	1.004
UY @ 18.0V	-0.6004	-0.6002	1.000
UY @ 14.5V	-0.6002	-0.6002	1.000
UY @ 11.0V	-0.0723	-0.0725	1.002

VM237: RLC Circuit with Piezoelectric Transducer

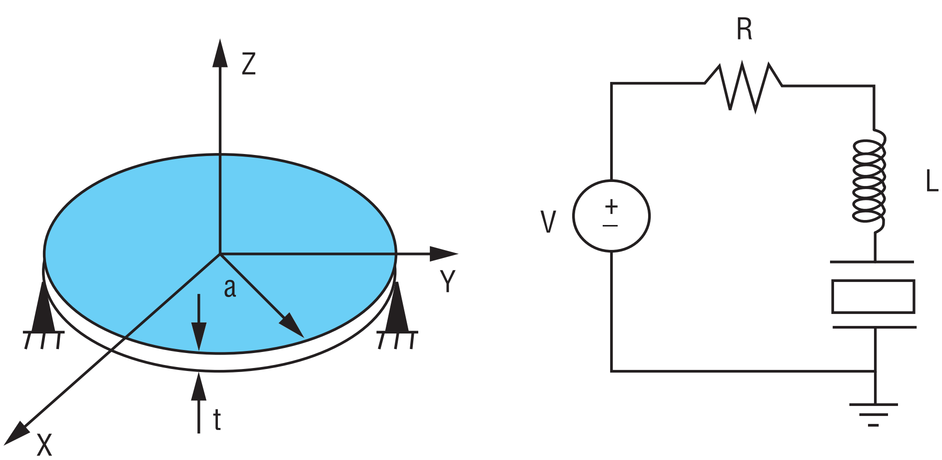
Overview

Reference:	*IEEE Standard on Piezoelectricity*, Piezoelectric part of the problem: 176-1987. J. Vlach, *Basic Network Theory with Computer Applications*, Circuit part of the problem: Ch. 9, Van Nostrand Reinhold, 1992.
Analysis Type(s):	Static (**ANTYPE** = 1) Transient (**ANTYPE** = 4)
Element Type(s):	2-D 8-Node Coupled-Field Solid (PLANE223) Piezoelectric Circuit (CIRCU94)
Input Listing:	vm237.dat

Test Case

A piezoelectric transducer consists of a simply supported circular plate of radius a and thickness t (figure a below) made of PZT-5A ceramic polarized along the Z axis. The circular surfaces of the plate are fully covered by electrode and connected in series with a resistor (R), inductor (L), and a source of constant voltage (V) (figure b below). Determine the voltage across the piezoelectric transducer over the time interval of 2 ms.

Figure 237.1: Problem Sketch



(a) (b)

Material Properties	Geometric Properties	Loading
ρ = 7750 kg/m^3 See "Constitutive Matrices" **Circuit Parameters** R = 3kΩ L = 15 H	a = 1 mm t = 0.1 mm	Stepped voltage V = 1 V

Constitutive Matrices (polar axis aligned along the Y axis)

PZT-5A Dielectric Permittivity Matrix at Constant Stress $[\varepsilon^T_r]$

$$\begin{bmatrix} 1730 & 0 & 0 \\ & 1700 & 0 \\ \text{Symmetric} & & 1730 \end{bmatrix}$$

PZT-5A Piezoelectric Strain Matrix [d], 10^{-10} C/N

$$\begin{bmatrix} 0 & -1.71 & 0 \\ 0 & 3.74 & 0 \\ 0 & -1.71 & 0 \\ 5.84 & 0 & 0 \\ 0 & 0 & 5.84 \\ 0 & 0 & 0 \end{bmatrix}$$

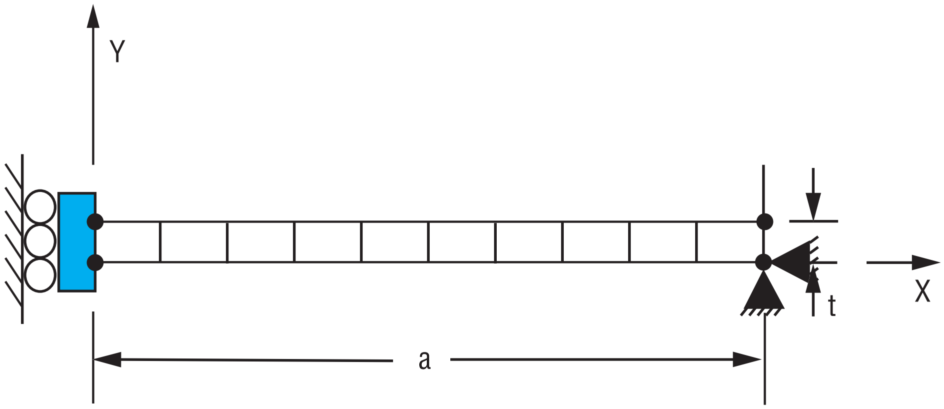
PZT-5A Elastic Compliance Matrix [s], 10^{-12} m^2/N

$$\begin{bmatrix} 16.4 & -7.22 & -5.74 & 0 & 0 & 0 \\ & 18.8 & -7.22 & 0 & 0 & 0 \\ & & 16.4 & 0 & 0 & 0 \\ & & & 47.5 & 0 & 0 \\ \text{Symmetric} & & & & 47.5 & 0 \\ & & & & & 44.3 \end{bmatrix}$$

Analysis Assumptions and Modeling Notes

The piezoelectric circular plate is modeled with 10 axisymmetric PLANE223 elements (Figure 237.2: Finite Element Model of a Transducer (p. 667)). The constitutive matrices used by the 2-D model are adjusted to orient the PZT-5A polarization direction along the Y axis. The electrodes are modeled by coupling the VOLT dof on the top and bottom surfaces of the plate. The resistor, inductance, and voltage source are modeled using the respective options of the CIRCU94 element. A transient analysis is performed to determine the time response of the circuit to the unit (1V) step voltage load. Numerical results are compared with an analytical solution, obtained using the Laplace transformation technique applied to an equivalent RLC-circuit, where C is the static capacitance of the piezoelectric transducer.

Figure 237.2: Finite Element Model of a Transducer



Results Comparison

VC for t @	Target	Mechanical APDL	Ratio
1.8E-2s	1.5201	1.4951	0.984
4.0E-2s	0.9726	0.9974	1.026
8.8E-2s	1.4829	1.5094	1.018
1.3E-2s	1.8437	1.8022	0.978
1.86E-1s	1.8273	1.8099	0.990

VM238: Wheatstone Bridge Connection of Piezoresistors

Overview

Reference:	M.-H. Bao, "Micro Mechanical Transducers: Pressure Sensors, Accelerometers and Gyroscopes", *Handbook of Sensors and Actuators*, v.8, ch.5.
Analysis Type(s):	Static (**ANTYPE** = 1)
Element Type(s):	2-D 8-Node Coupled-Field Solid (PLANE223) 2-D 8-Node Structural Solid (PLANE183)
Input Listing:	vm238.dat

Test Case

Four p-type silicon piezoresistors R_1-R_4 of length *a* and width *b* are placed on a silicon beam (Figure 238.1: Piezoresistors on a Beam Problem Sketch (p. 669)). The beam of length *l* and width *w* is oriented such that its length is in the <110> direction of silicon crystal. The resistors are connected to form a Wheatstone bridge (Figure 238.2: Wheatstone Bridge Arrangement of Piezoresistors (p. 670)) with a supply voltage V_s. The beam is subjected to a uniform pressure *p* in the X-direction. Determine the output voltage V_o of the Wheatstone bridge.

Figure 238.1: Piezoresistors on a Beam Problem Sketch

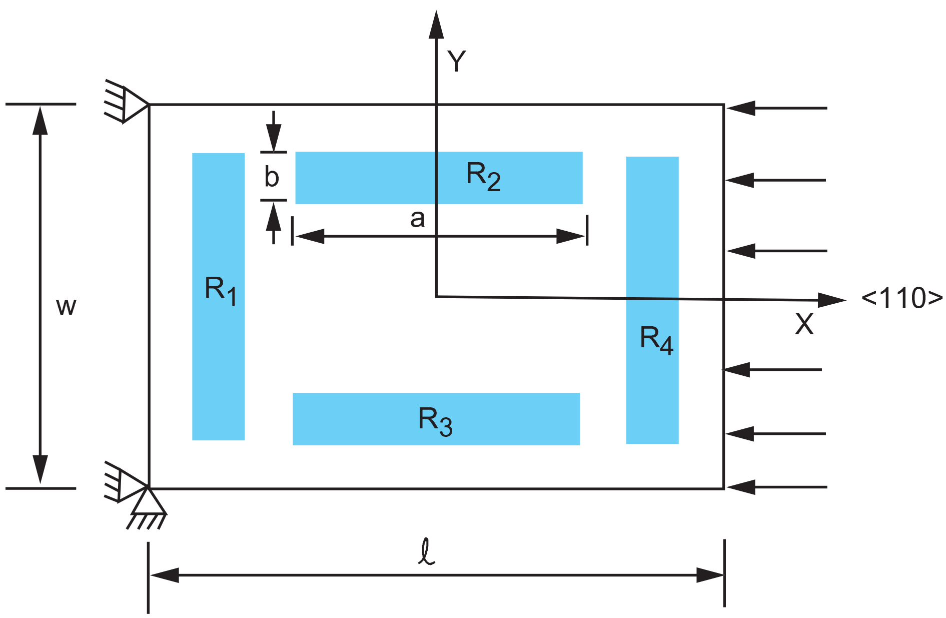
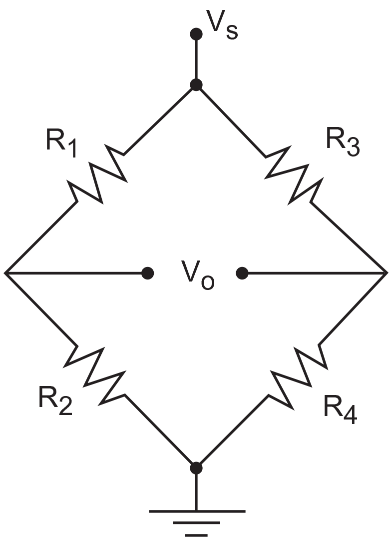


Figure 238.2: Wheatstone Bridge Arrangement of Piezoresistors



Material Properties	Geometric Properties	Loading
Elastic properties: E = 165e3 MPa ν = 0.25 Resistivity: ρ = 7.8e-8 TΩµm **Piezoresistive stress coefficients:** π_{11} = 6.5e-5 $(MPa)^{-1}$ π_{12} = -1.1e-5 $(MPa)^{-1}$ π_{44} = 138.1e-5 $(MPa)^{-1}$	*l* = 180 µm *w* = 120 µm *a*= 100 µm *b*= 20 µm	Supply voltage V_s=5 V Pressure *p* = 1MPa

Analysis Assumptions and Modeling Notes

The resistors areas are modeled using the piezoresistive option of the coupled-field solid PLANE223. The structural part of the beam is modeled using PLANE183. The resistors are connected into a Wheatstone bridge arrangement by coupling the VOLT degrees of freedom on width sides of the resistors. The supply voltage is applied to the master node of the driving electrode.

The applied pressure results in a uniform stress S_x distribution. Two of the resistors (R_2 and R_3) are parallel to the direction of stress, and change their resistance due to the longitudinal piezoresistive effect. Two other resistors (R_1 and R_4) are perpendicular to the applied stress, and change their resistance due to the transverse piezoresistive effect. A static analysis is performed to determine the output voltage V_o. Results are compared to the analytical solution given by

$$V_o = \frac{\pi_{44} S_x}{2\left(1 + \frac{\pi_{11} + \pi_{12}}{2}\right)} V_s$$

Results Comparison

	Target	Mechanical APDL	Ratio
Output voltage V_o, mV	3.4524	3.4524	1.000

VM239: Mechanics of the Revolute and Universal Joints

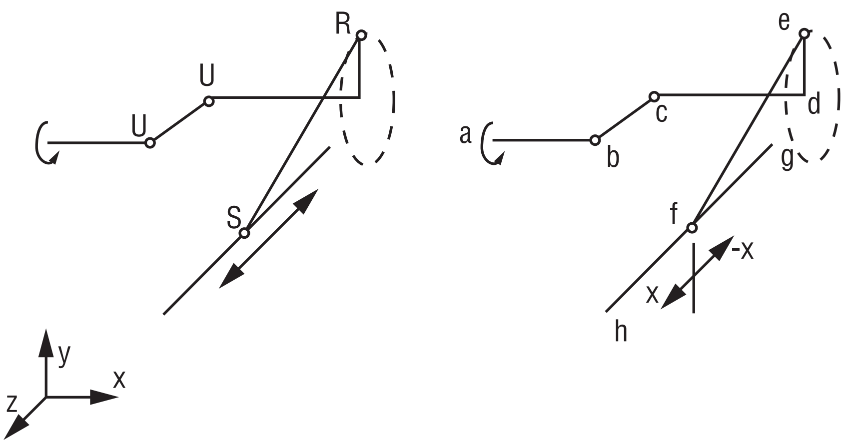
Overview

Reference:	J. E. Shigley, J. J. Uicker, Jr., *Theory of Machines and Mechanisms*, 2nd Edition, Mc-Graw-Hill, Inc., 1995, p.115.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Linear Finite Strain Beam (BEAM188) Multipoint Constraint Elements - Universal Joint, Revolute Joint, Slider Element (MPC184) 3-D Target (TARGE170)
Input Listing:	vm239.dat

Test Case

A double universal joint drive shaft drives a simple slider-crank mechanism. Compare the rotations at different points in the drive shaft with the applied rotation. Also, show the linear motion caused by the slider-crank satisfied the appropriate equation.

Figure 239.1: Shaft-driven Slider-Crank Mechanism



Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\upsilon = 0.33$	ab = 1.0 in. cd = 1.0 in. de = 0.5 in. ef = 1.5 in. gh = 1.5 in.	At "a": ROTX = 2π rad. (= 360°)

Analysis Assumptions and Modeling Notes

The rotation of 2π rad., which is applied at node "a", is first transmitted through the three shafts, existing in the x-y plane, that are joined together by the MPC184 universal joints. The rotation is compared with the resulting rotation at node "c". This graph should result in an expression determined by the following function:

$\alpha_2 = \text{arc tan}\ (\tan\alpha_1/\cos\beta)$

where:

$\alpha 1$ = the angle of twist of the drive shaft
α_2 = the angle of twist of the driven shaft
β = relative angle between axis of rotation of the shafts

The input rotation is next compared to the resulting rotation at node "d". The plot shows a linear relationship in which the rotations at "a" should be equal to the rotations at "d". It should be noted that the revolute joint at junction "e" is tested by comparing the results of the input rotation at "a" (which is transferred perfectly to "d") with the linear, sliding motion generated by the slider-crank mechanism lying in the y-z plane. This relationship is defined in the supplied reference, and reflected below in the results.

Two solutions are performed. The first solution is performed by modeling all links as flexible using BEAM188 beam elements. The second solution is performed by modeling all links as rigid using TARGE170 elements. For second solution two links with applied displacement boundary conditions were modeled as flexible in order to prevent over-constrained models. The second solution demonstrates how to define rigid bodies in Mechanical APDL and how to prevent over-constrained models. Both solutions produce similar expected results.

Results Comparison

Input Rotation vs. Linear Motion of Slider-Crank Mechanism

Applied Rotation	Target	Mechanical APDL	Ratio
Results for analysis with all flexible bodies			
Linear Motion (x) for $\pi/4$ (45°)	0.39708	0.39708	1:1
Linear Motion (x) for $\pi/2$ (90°)	0.58579	0.58579	1:1
Linear Motion (x) for $3\pi/4$ (135°)	0.39708	0.39708	1:1
Results for analysis with all rigid bodies			
Linear Motion (x) for $\pi/4$ (45°)	0.39708	0.39708	1:1
Linear Motion (x) for $\pi/2$ (90°)	0.58579	0.58579	1:1
Linear Motion (x) for $3\pi/4$ (135°)	0.39708	0.39708	1:1

Figure 239.2: Relationship of Rotations at "a" and "c"

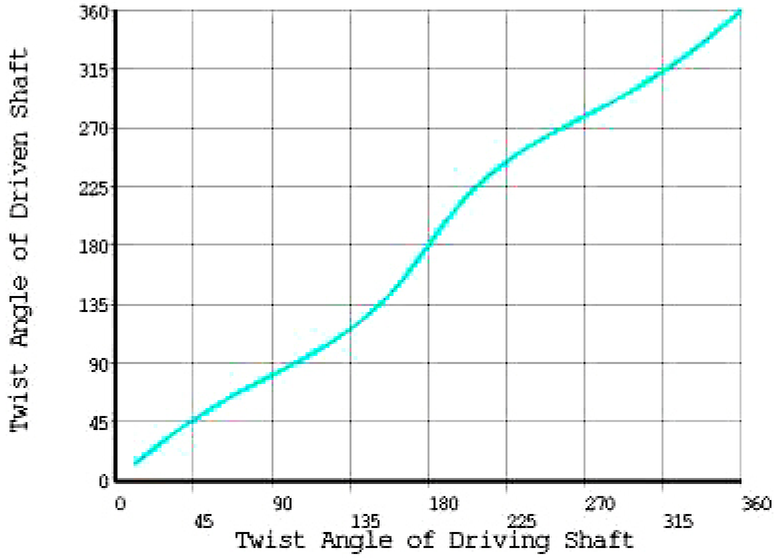
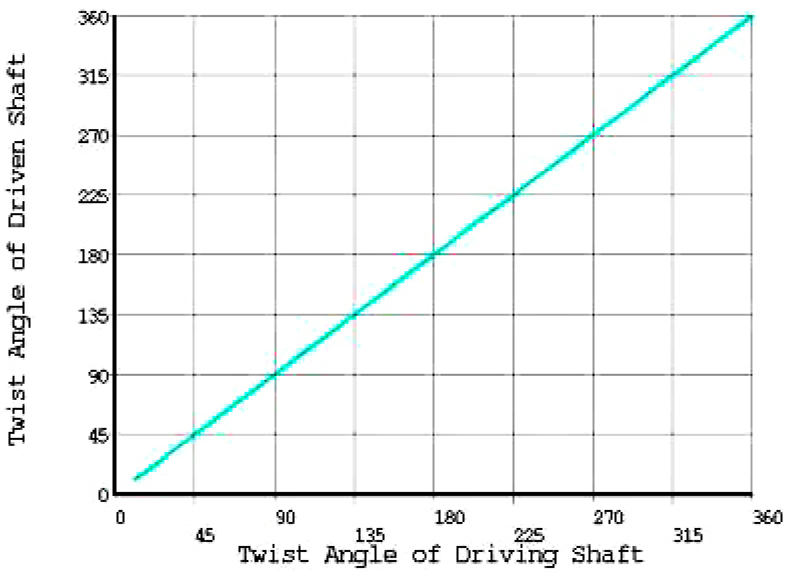


Figure 239.3: Relationship of Rotations at "a" and "d"



VM240: Thermal Expansion of Rigid Beams in a Composite Bar

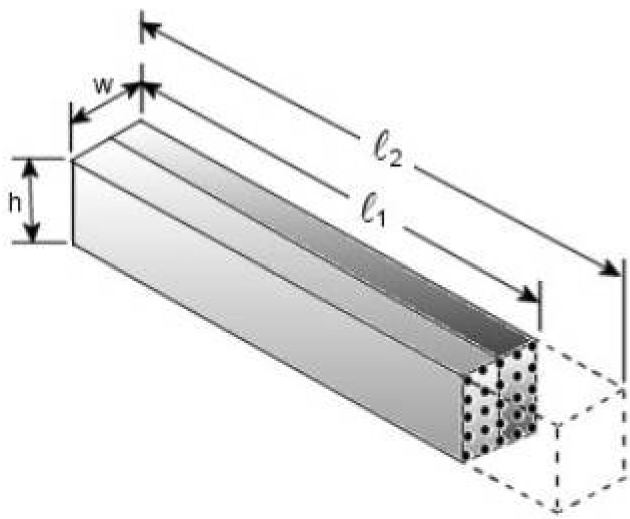
Overview

Reference:	J.M. Gere, S.P. Timoshenko, *Mechanics of Materials*, 2nd Edition, PWS Publishers, 1984, p. 20-21,71
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Nonlinear (8-Node) Solid Elements (SOLID185) Multipoint Constraint Elements - Rigid Beams (MPC184)
Input Listing:	vm240.dat

Test Case

A composite bar consists of two base materials with 25 rigid beams embedded along its length. A coefficient of thermal expansion is defined for only the rigid beams. Compare the stresses resulting in both solid composite materials when a temperature is applied.

Figure 240.1: Thermal Expansion of Composite Bar



Material Properties	Geometric Properties	Loading
E_1 = 10 x 10e^6 psi υ_1 = 0.3 E_2 = 5 x 10e^6 psi υ_2 = 0.3 $\alpha_x = \alpha_y = \alpha_z$ = 0.0003/in./°F (at 100 °F)	ℓ_1 = 40 in. w = 4 in. h = 4 in.	T_1 = 0 °F T_2 = 100 °F

Analysis Assumptions and Modeling Notes

A composite bar with a 4″ x 4″ cross-section is modeled using SOLID185 elements. The bar consists of two different materials with the material properties E_1, E_2, υ_1, and υ_2 as shown above. Twenty five MPC184 rigid beam elements are then modeled running along the length of the bar. The rigid beam elements are given a coefficient of thermal expansion, α_3. The bar is fixed in all DOF's at one end. As a temperature is applied to the model, the rigid beam elements expand, in turn deforming the rest of the composite bar. As a result, two distinctly different stress levels can be seen through the bar's cross-section. These stresses reflect the material property differences of the two materials making up the composite

The equations below are used to calculate theoretical stress values for comparison:

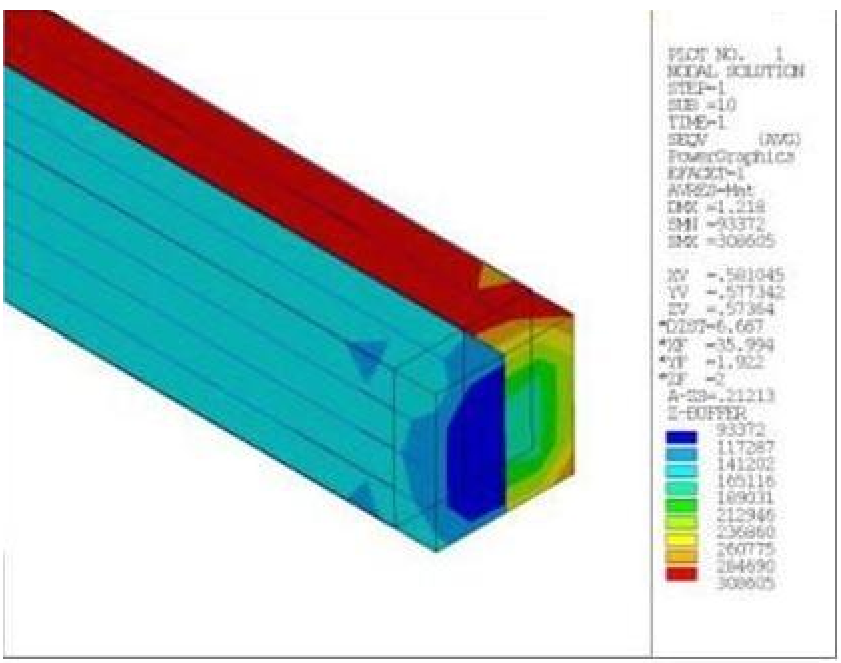
$$\ell 2 = \ell_1 [1 + \alpha(T_2 - T_1)]$$

$$\sigma = \frac{E(\ell_2 - \ell_1)}{\ell_1}$$

Results Comparison

	Target	Mechanical APDL	Ratio
1 - Equivalent Stress (von Mises)	300,000	297,700	0.992
2 - Equivalent Stress (von Mises)	150,000	148,900	0.992

Figure 240.2: Stress Results in Composite Material



VM241: Static Force Computation of a 3-D Solenoid Actuator

Overview

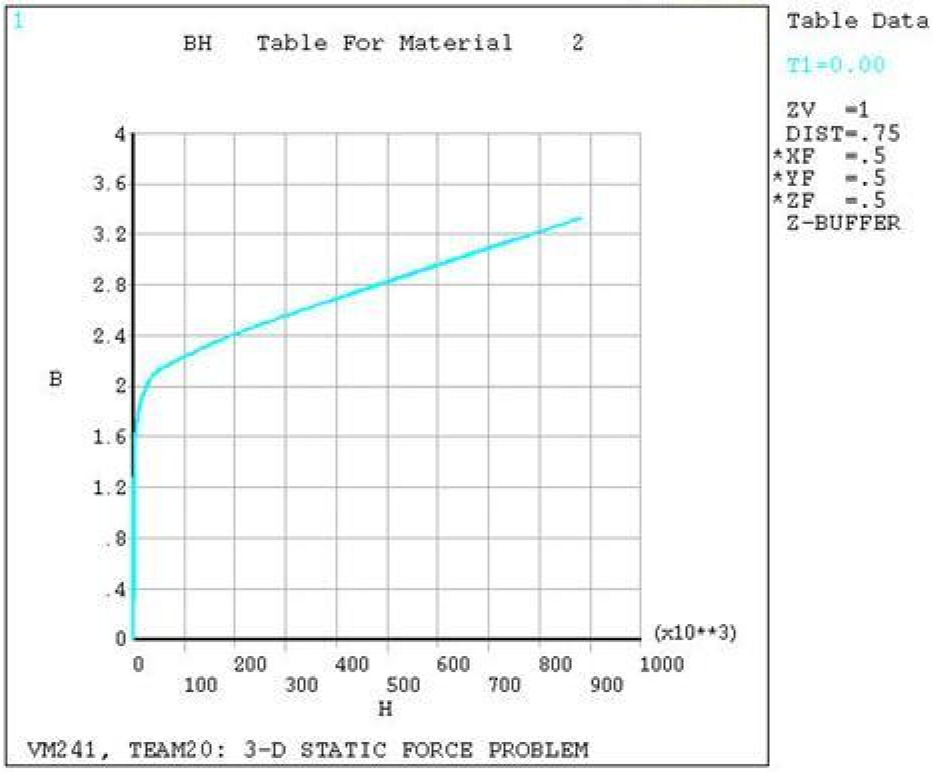
Reference:	N.Takahashi, T. Nakata, and H. Morishige, "Summary of Results for Problem 20 (3-D Static Force Problem)", COMPEL, Vol.14 (1995), pp. 57-75.
Analysis Type(s):	Static (**ANTYPE** = 0)
Element Type(s):	3-D 20 node Electric Solid (SOLID231) 3-D 10 node Tetrahedral Electric Solid (SOLID232) 3-D 20 node Electromagnetic Solid (SOLID236) 3-D 10 node Tetrahedral Electromagnetic Solid (SOLID237) Meshing Facet (MESH200)
Input Listing:	vm241.dat

Test Case

For the given solenoid actuator with an applied total coil current of 5000 A-turns, find the magnetic flux density (BZ) of the Pole, the magnetic flux density (BZ) of the Arm, and the Magnetic Force in the Z-direction. The center pole and yoke are made of steel characterized by the B-H curve shown in Figure 241.1: B-H Curve (p. 680).

Material Properties	Geometric Properties	Loading
Murx =1	X1 = 63.5mm X2 = 12.5mm Y1 = 12.5mm Y2 = 5mm Y3 = 18mm Z1 = 25 mm Z2 = 100mm Z3 = 98.5mm Z4 = 96.6mm	Total Current = 5000 A-turns

Figure 241.1: B-H Curve



Analysis Assumptions and Modeling Notes

This analysis is based on the TEAM workshop problem 20. It utilizes the edge-flux element formulation with SOLID236 and tetrahedral SOLID237 elements. To simplify meshing, the **SMRTSIZE** option was used to automatically determine line divisions and spacing ratios while taking into account the line proximity effects. Mesh density can be adjusted using the SMT parameter, for this case, a SMT level of 10 was applied.

The static analysis is performed using a quarter symmetry model (Figure 241.2: Finite Element Model with SOLID232 and SOLID237 Elements (p. 681)). The current source density in the coil (Figure 241.3: Current Density in the Coil with SOLID232 and SOLID237 Elements (p. 681)) was modeled using the electric tetrahedral SOLID231 and SOLID232 and elements and transferred to the magnetic element SOLID236 and SOLID237 respectively via **LDREAD**.

The calculated magnetic field B in the armature is shown in Figure 241.4: Magnetic Field Flux Density with SOLID232 and SOLID237 Elements (p. 682). To calculate the total magnetic force acting on the armature, all the nodes and elements of component ARM were selected for FMAG force summation. Note that for more accurate results, the option to output magnetic element forces FMAG at the corner nodes (KEYOPT (7) =1 with SOLID236 and SOLID237) was used.

Figure 241.2: Finite Element Model with SOLID232 and SOLID237 Elements

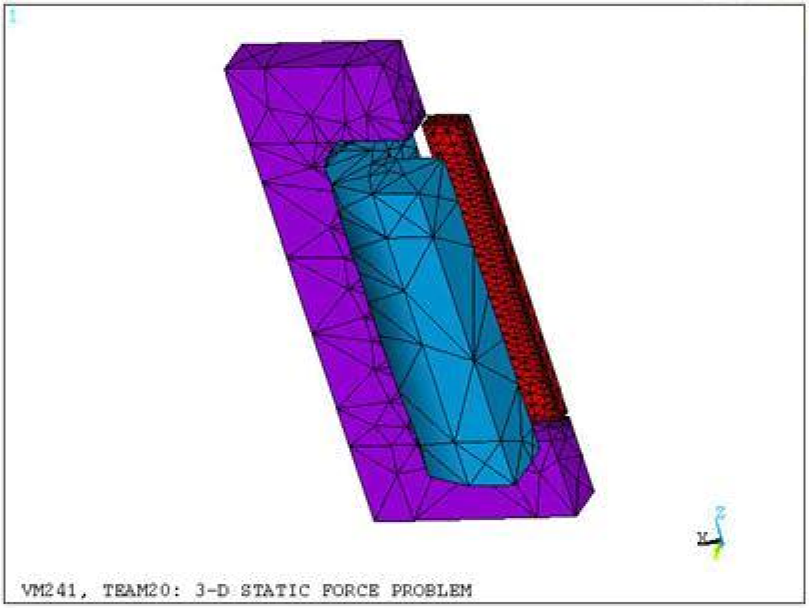


Figure 241.3: Current Density in the Coil with SOLID232 and SOLID237 Elements

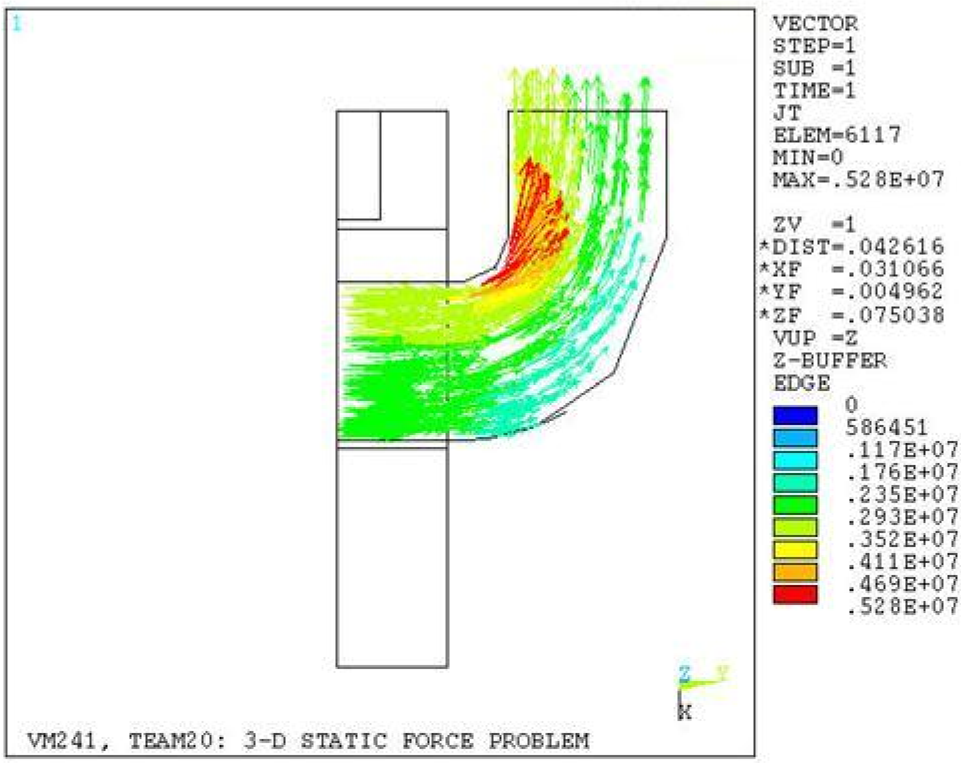


Figure 241.4: Magnetic Field Flux Density with SOLID232 and SOLID237 Elements

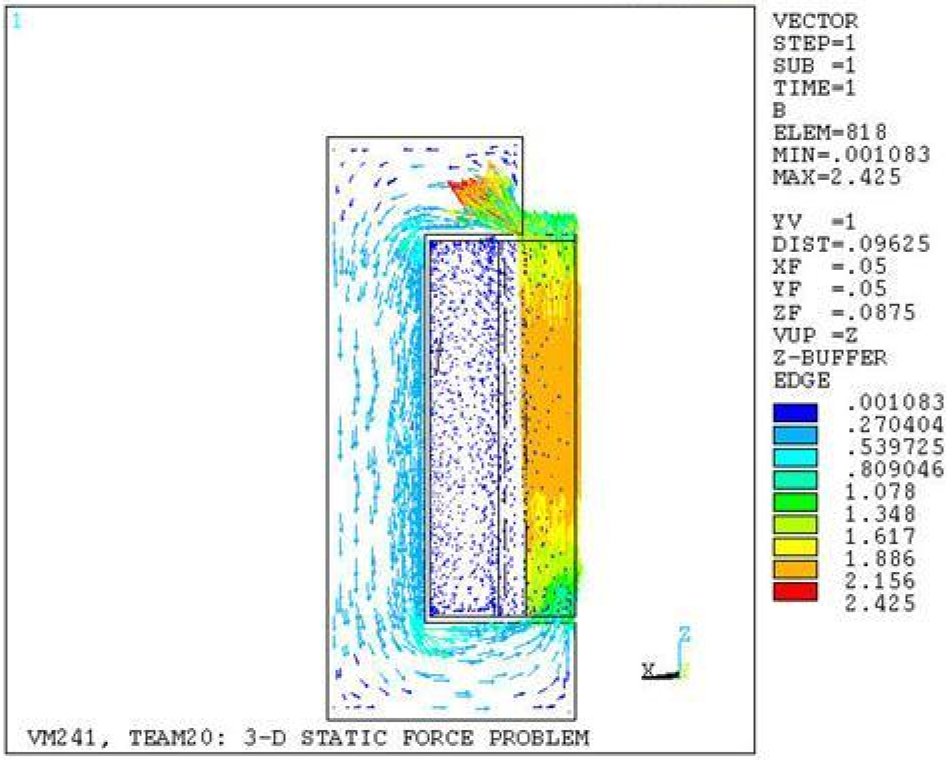


Figure 241.5: Current Density in the Coil with SOLID231 and SOLID236 Elements

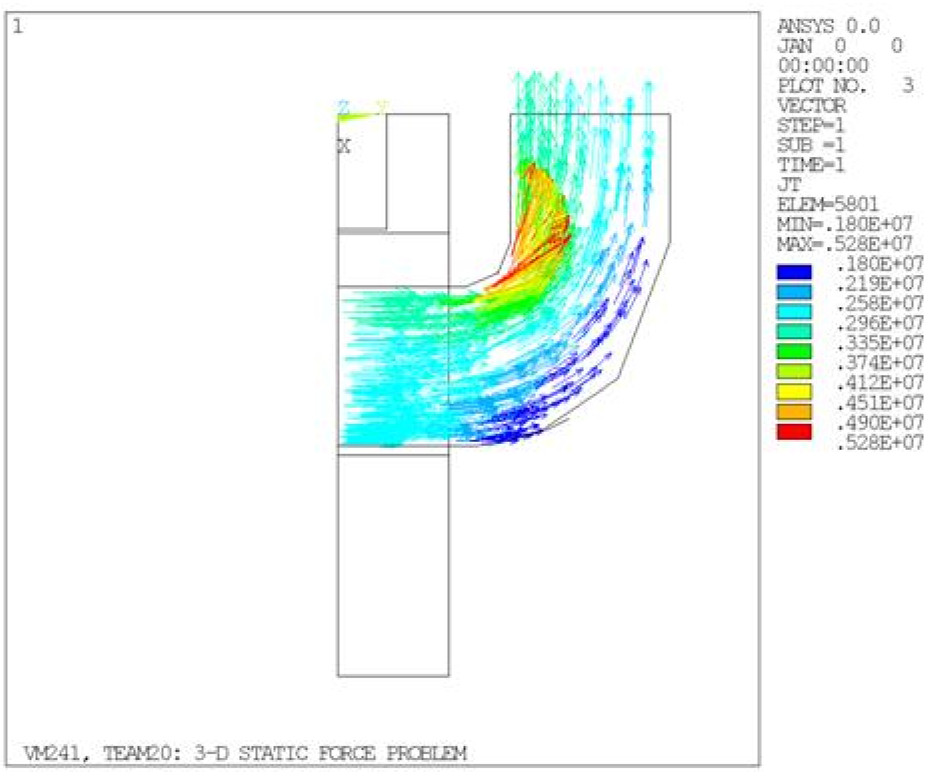
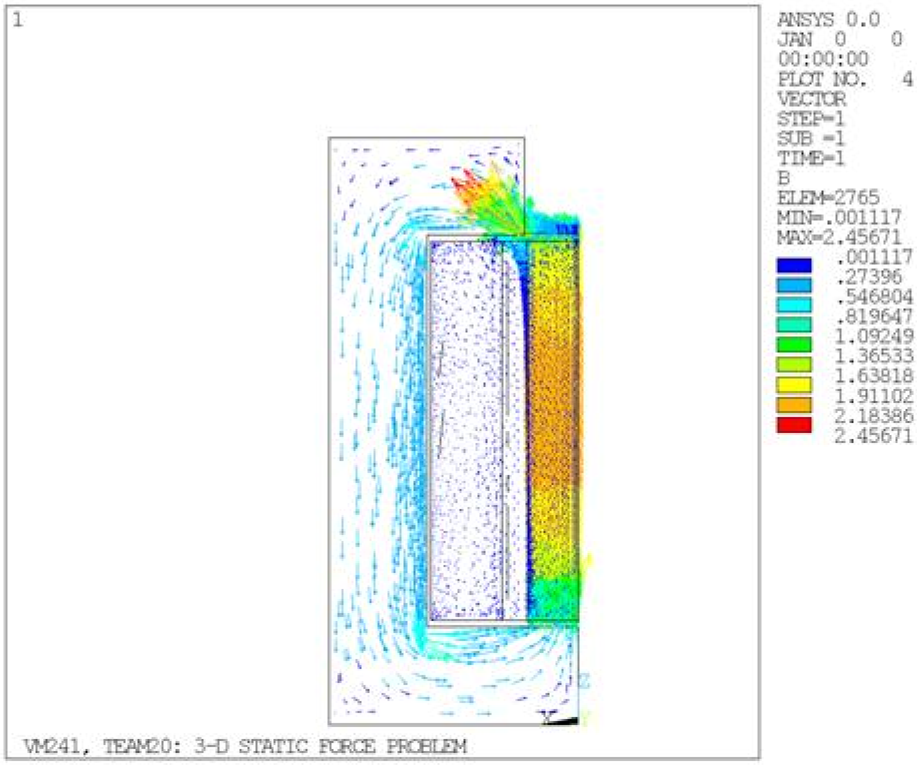


Figure 241.6: Magnetic Flux Density with SOLID231 and SOLID236 Elements



Results Comparison

SOLID236			
Total Current = 5000 A-turns	**Target**	**Mechanical APDL**	**Ratio**
Magnetic Force (N)	80.100	79.495	0.992
Pole Flux Density (BZ, Tesla)	0.460	0.451	0.981
Arm Flux Density (BZ, Tesla)	2.050	2.029	0.990

SOLID237			
Total Current = 5000 A-turns	**Target**	**Mechanical APDL**	**Ratio**
Magnetic Force (N)	80.100	79.495	0.992
Pole Flux Density (BZ, Tesla)	0.460	0.451	0.981
Arm Flux Density (BZ, Tesla)	2.050	2.029	0.990

VM242: Johnson-Champoux-Allard Equivalent Fluid Model

Overview

Reference:	O. Doutres, Y. Salissou, N. Attalla, R. Panneton, "Evaluation of the acoustic and non-acoustic properties of sound absorbing materials using a three-microphone impedance tube", *Applied Acoustics 71*. (2010). pp 506-509.
Analysis Type(s):	Harmonic Analysis (**ANTYPE** = 3)
Element Type(s):	3-D Acoustic Fluid 20-Node Solid Element (FLUID220)
Input Listing:	vm242.dat

Test Case

The absorption coefficient of a sound absorbing porous material (Material A) is determined and compared against the target value shown in the reference. It is evaluated using the indirect method based on a three-microphone impedance tube setup. The sound absorption coefficient is predicted by the five-parameter Johnson-Champoux-Allard equivalent fluid model.

Material Properties	Geometric Properties
Speed of sound: 343 m/s Density: 1.2 kg/m^3 Fluid resistivity: 10800 Ns/m^4 Porosity: 0.98 Tortuosity: 1.04 Viscous characteristic length: 129 μm Thermal characteristic length: 198 μm	Depth of sound-absorbing material: 51.44 mm

Analysis Assumptions and Modeling Notes

Due to the 1-D nature of the waves, an arbitrary width (smaller than the wavelength) is used to create a row of fluid elements for this model. The loading is not important in this application, so an arbitrary value is used: a planar mass source that would create 1e3 Pa pressure waves in an infinite pipe is applied. The sound source is specified with Robin boundary surface to absorb reflected waves out of the system.

The impedance is calculated at the interface of the sound-absorbing material, and from that, the absorption coefficient is calculated and compared with the reference.

$$Z = \frac{P}{v}$$

$$\zeta = \frac{Z}{\rho c}$$

$$\Re = \frac{\zeta - 1}{\zeta + 1}$$

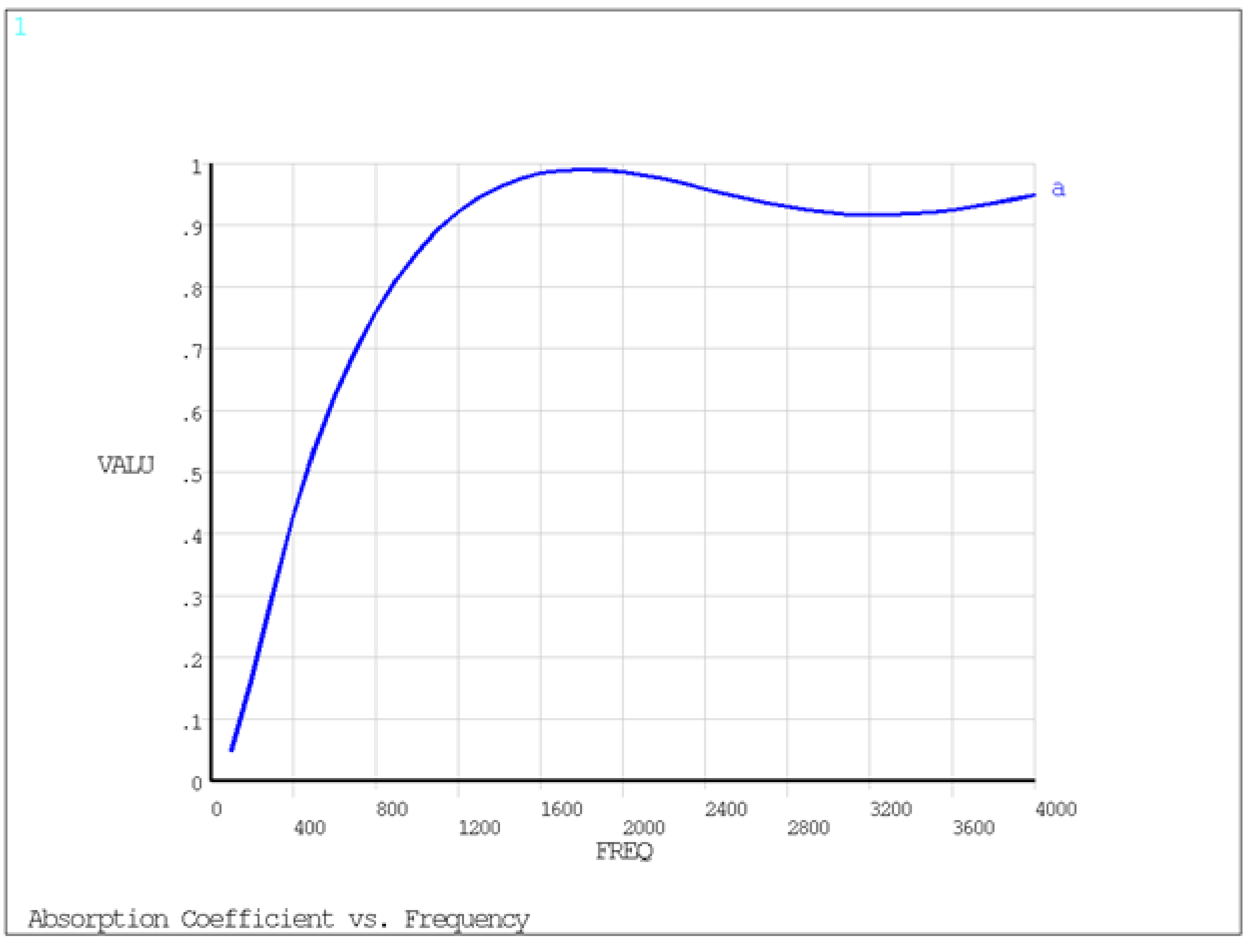
$$\alpha = 1 - |\Re|^2$$

The specific acoustic impedance *Z* is calculated as the ratio of the pressure *P* and velocity ν at the interface. The ratio ζ of specific acoustic impedance *Z* to the characteristic impedance (product of density ρ and speed of sound *c*) can be related to the reflection coefficient *R*. The absorption coefficient α can be determined from the reflection coefficient *R*. These calculations are done in the Time-History Post-processor /POST26 over the calculated frequency range.

Results Comparison

	Target	Mechanical APDL	Ratio
Absorption coefficient at 1700 Hz	0.988	0.988	1.00

Figure 242.1: Absorption Coefficient vs. Frequency



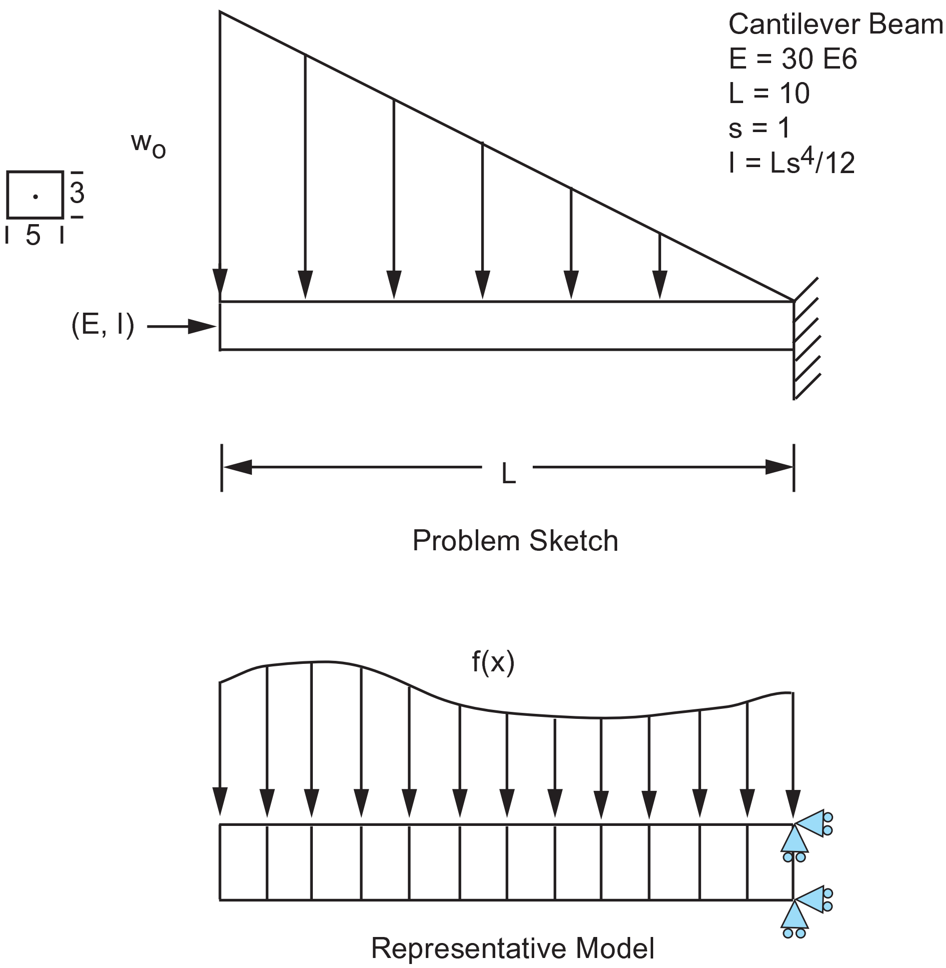
VM243: Cantilever Beam with Triangular Loading Defined by Function

Overview

Reference:	F. P. Beer and E. J. Johnston, Jr., *Mechanics of Materials*, McGraw-Hill, New York, NY, 1981, pp. 356, 366, 397, 613
Analysis Type(s):	Static
Element Type(s):	PLANE183
Input Listing:	vm243.dat

Test Case

Figure 243.1: Cantilever Beam with Triangular Loading



Material Properties	Geometric Properties	Loading
E = 30E6 $I = \frac{s^4}{12}$	s = 1 L = 10	w(x = 0) = 1 w(x = L) = 0 linear variation between them

Analysis Assumptions and Modeling Notes

Two models are used to test the method of creating a functional load. In the first case, the loading function P(x) is applied using the functional loading to create a load corresponding to P(x) = (x/L) In the second case, the loading is applied using the established two value linear loading. According to beam theory, the equation for maximum displacement of this loading is:

$$U_{max} = \frac{11L^4 w(0)}{120EI}$$

This result is then compared against the results

Results Comparison

	Target	Mechanical APDL	Ratio
Displacement (max), tabular loading	0.367E-3	0.370E-3	1.01
Displacement (max), two value linear loading	0.367E-3	0.370E-3	1.01

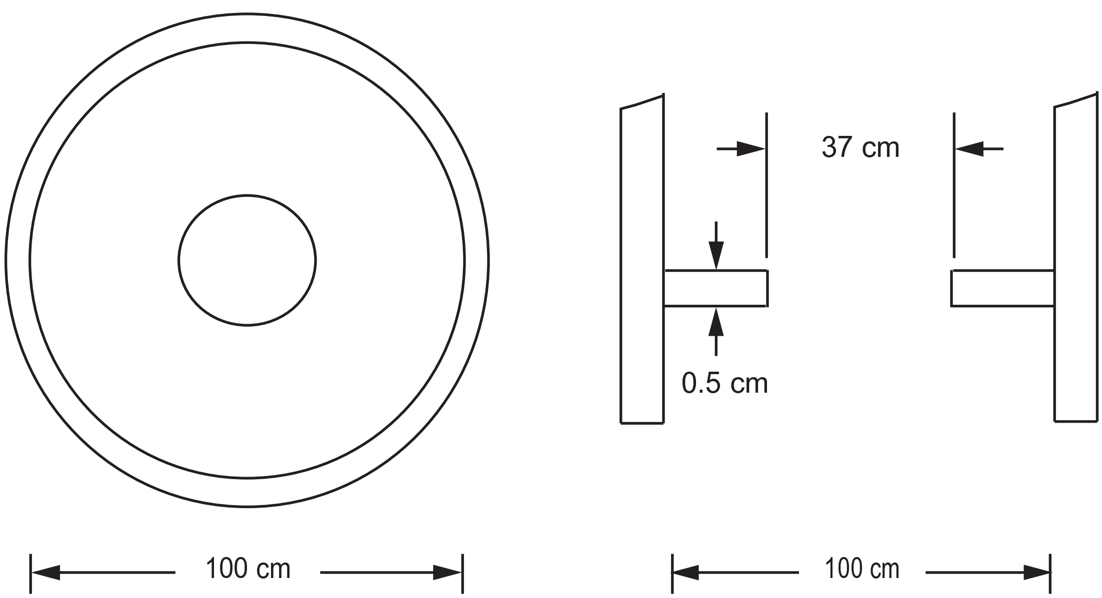
VM244: Modal Analysis of a Cyclic Symmetric Annular Plate

Overview

Reference:	R. D. Blevins, *Formulas for Natural Frequency and Mode Shape*, New York, NY, Van-Nostrand Reinhold Publishing Inc., 1979, PP. 246-247, 286-287.
Analysis Type(s):	Mode-frequency analysis (**ANTYPE** = 2)
Element Type(s):	3-D 8-Node Structural Solid (SOLID185) 3-D 20-Node Structural Solid (SOLID186) 3-D 10-Node Tetrahedral Structural Solid (SOLID187) 4-Node Finite Strain Shell (SHELL181) 3-D 8-Node Layered Solid Shell (SOLSH190) 8-Node Finite Strain Shell (SHELL281)
Input Listing:	vm244.dat

Test Case

Figure 244.1: An Annular Plate



The fundamental natural frequency of an annular plate is determined using a mode-frequency analysis. The lower bound is calculated from the natural frequency of the annular plates, which are free on the inner radius and fixed on the outer. The bounds for the plate frequency are compared to the theoretical results.

Material Properties	Geometric Properties	Loading
E = 7.03×10^5 kg/cm^2 ν = 0.3 ρ = 2.79×10^{-9} kg/cm^2	Outside Radius (a) = 50 cm Inside Radius (b) = 18.5 cm Thickness (h) = 0.5 cm	Free modal analysis

Material Properties	Geometric Properties	Loading
$\gamma = 1.415 \times 10^{-6}$ kg-sec^2/cm^3		

Analysis Assumptions and Modeling Notes

According to Blevins, the lower bound for the fundamental natural frequency of the annular plate is found using the formula presented in Table 11-2:

$$f = \frac{\lambda^2}{2\pi a^2}\left[\frac{Eh^3}{12\gamma(1-\upsilon^2)}\right]^{\frac{1}{2}}$$

Where,

$\lambda^2 = 4.80$

In Mechanical APDL, a 30° symmetric sector of the annular plate is created via CYCLIC expansion with **CYCOPT**, NODDIA. The outer edge of the model is constrained in all directions and no dampening or loading is applied. The element types SOLID185, SOLID186, SOLID187, SHELL181, SHELL281, and SOLSH190 are used to solve for the lower bound of the fundamental natural frequency (Hz).

Results Comparison

	Target	Mechanical APDL	Ratio
Frequency (SOLID185)	23.38	23.14	0.99
Frequency (SOLID186)	23.38	23.12	0.99
Frequency (SOLID187)	23.38	23.15	0.99
Frequency (SHELL181)	23.38	22.96	0.98
Frequency (SOLSH190)	23.38	23.13	0.989
Frequency (SHELL281)	23.38	23.04	0.986

VM245: Squeeze Film Damping: Rectangular Plate

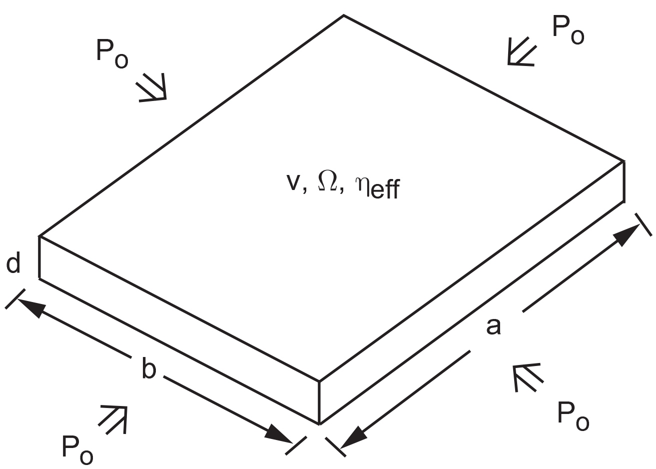
Overview

Reference:	J. J. Blech, *On Isothermal Squeeze Films*, Journal of Lubrication Technology, Vol. 105, pp. 615-620, 1983.
Analysis Type(s):	Harmonic analysis (**ANTYPE**=3)
Element Type(s):	3-D squeeze film fluid element (FLUID136)
Input Listing:	vm245.dat

Test Case

A rectangular plate is modeled with length (b) and width (a). Pressure is made zero on all exterior nodes. Velocity loading is applied on the plate and harmonic analysis is performed at an excitation frequency of 100000 Hz.

Figure VM245.1: Problem sketch of rectangular plate



Material Properties	Geometric Properties	Loading
Fluid Viscosity = 1.83e - 12Ns/(μm)^2	a = 2000μm b = 1000 μm d = 5 μm	Operating frequency, Ω = 100000 Hz Velocity, v = 2000(μm)/s Pressure at edges = 1e5 Pa

Analysis Assumptions and Modeling Notes

The problem is modeling the fluid gap region between two rigid, non-deforming surfaces. The pressure of the fluid entering and exiting the gap creates a damped elastic response which can be modeled by a spring-damper system. The calculations of the stiffness and damping constants are done by summing the pressure distribution over the area, then taking these force calculations and feeding them into the equations

$$C = \frac{F^{Re}}{v_z}$$

$$K = \frac{F^{Im}\omega}{\nu_z}$$

where F(im) and F(re) are the "imaginary" and "real" parts of the force calculated from the harmonic analysis.

According to Blech an analytical solution for the damping and squeeze coefficient for a rigid plate moving with a transverse motion is given by:

$$C(\Omega) = \frac{64\sigma(\Omega)p_o A}{\pi^6 d\Omega} \sum_{m=odd} \sum_{n=odd} \frac{(2m-1)^2 + (2n-1)^2 c^2}{(2m-1)^2 (2n-1)^2 \left[\left((2m-1)^2 + (2n-1)^2 c^2 \right)^2 + \frac{\sigma(\pi)^2}{\pi^4} \right]}$$

$$K_s(\Omega) = \frac{64\sigma(\Omega)p_o A}{\pi^8 d} \sum_{m=odd} \sum_{n=odd} \frac{1}{(2m-1)^2 (2n-1)^2 \left[\left((2m-1)^2 + (2n-1)^2 c^2 \right)^2 + \frac{\sigma(\pi)^2}{\pi^4} \right]}$$

where:

$C(\Omega)$ = frequency-dependent damping coefficient
$K_S(\Omega)$ = squeeze stiffness coefficient,
p_o = ambient pressure
A = surface area
c = ratio of plate length a divided by plate width b
d = film thickness
Ω = response frequency
σ = squeeze number of the system

The squeeze number is given by:

$$\sigma(\Omega) = \frac{12\eta b^2}{p_o d^2} \pi$$

for rectangular plates where η_{eff} is the effective viscosity.

Results Comparison

	Target	Mechanical APDL	Ratio
Stiffness, K (Ns/m)	28650.00	28551.38	0.997
Damping constant, C (N/m)	0.0153	0.0151	0.989

VM246: Cyclic Analysis of an End-Loaded Hollow Cylindrical Cantilever Beam

Overview

Reference:	F. P. Beer, E. R. Johnston, Jr., *Mechanics of Materials*, McGraw-Hill, Inc., New York, NY, 1981, pg 598.
Analysis Type(s):	Static-structural analysis
Element Type(s):	3-D 8-Node Structural Solid (SOLID185) 3-D 20-Node Structural Solid (SOLID186) 3-D 10-Node Tetrahedral Structural Solid (SOLID187)
Input Listing:	vm246.dat

Test Case

Figure 246.1: Hollow Cylindrical Cantilever Beam and Loading

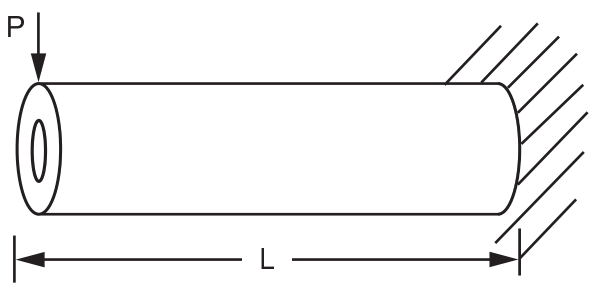
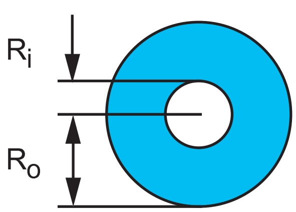


Figure 246.2: Beam Cross-Section



Determine the maximum deflection of an end-loaded hollow cylindrical beam. The beam is fixed at one end and free on the other. The load consists of a downward force of 5 pounds at the free end.

Material Properties	Geometric Properties	Loading
$E = 70 \times 10^3$ psi $\nu = 0.3$	Outside Radius (R_o) = 0.5 in Inside Radius (R_i) = 0.25 in Length (L) = 10 in	P = 5 lb

Analysis Assumptions and Modeling Notes

From the reference, the maximum deflection (δ) in a cantilever beam with end loading can be found using:

$$\delta = -\frac{PL_3}{3EI} = 0.519\,\text{in}$$

Where,

$$I = \frac{\pi}{4}(R_o^4 - R_i^4) = 0.046\,\text{in}^4$$

The analysis is accomplished with SOLID185, SOLID186, and SOLID187 element types. For each run, a 30° portion of the beam is modeled, meshed and then expanded using the **CYCLIC** and **/CYCEXPAND** commands.

To obtain accurate results, KEYOPT settings were issued for each element type. Enhanced strain formulation (KEYOPT,1,2,2) was used for SOLID185. Full integration (KEYOPT,1,2,1) was used for SOLID186. Pure displacement formulation (KEYOPT,1,6,0) was necessary for SOLID187.

Results Comparison

	Target	Mechanical APDL	Ratio
Deflection (SOLID185)	0.5187	0.5213	1.005
Deflection (SOLID186)	0.5187	0.5212	1.005
Deflection (SOLID187)	0.5187	0.5221	1.007

VM247: Campbell Diagrams and Critical Speeds Using Symmetric Bearings

Overview

Reference:	Nelson and McVaugh,"The Dynamics of Rotor-Bearing Systems Using Finite Elements", Journal of Engineering for Industry, May 1976.
Analysis Type(s):	Modal analysis (**ANTYPE** =2)
Element Type(s):	3-D Linear finite strain beam element (BEAM188) Structural mass element (MASS21) Spring damper element (COMBIN14)
Input Listing:	vm247.dat

Test Case

A rotor-bearing system is analyzed to determine the whirl speeds. The distributed rotor was modeled as a configuration of six elements with each element composed of subelements. See Table 247.1: Geometric Data of Rotor-Bearing Elements (p. 696) for a list of the geometrical data of the elements. Two undamped linear bearings were located at positions four and six. Modal analysis is performed on rotor bearing system with multiple load steps to determine the critical speeds and Campbell values for the system.

Figure 247.1: Rotor-bearing Configuration

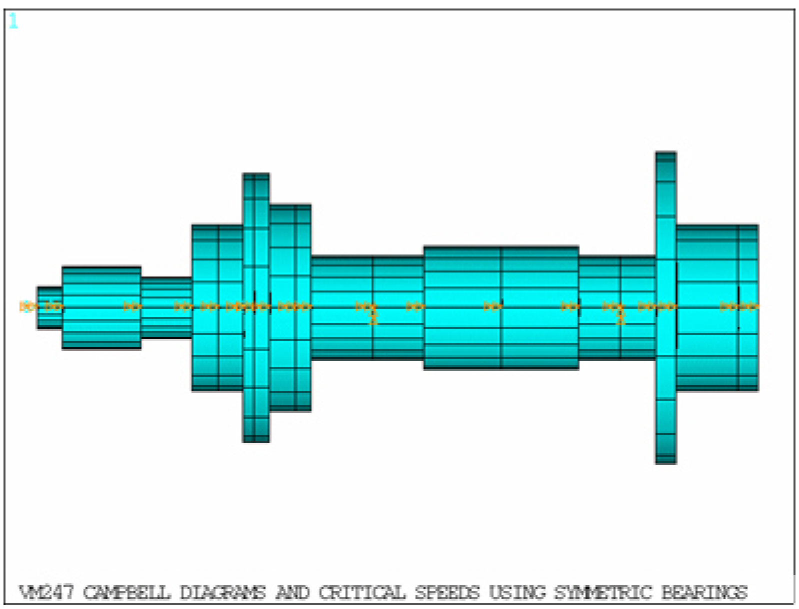


Figure 247.2: Isometric View of the Rotor Bearing System

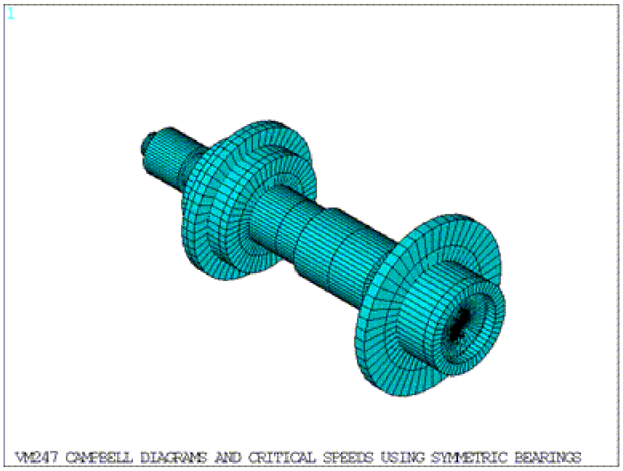


Table 247.1: Geometric Data of Rotor-Bearing Elements

Element No.	Subelement No.	Axial Distance to Subelement (cm)	Inner Diameter (cm)	Outer Diameter (cm)
1	1	0.00		0.51
	2	1.27		1.02
2	1	5.08		0.76
	2	7.62		2.03
3	1	8.89		2.03
	2	10.16		3.30
	3	10.67	1.52	3.30
	4	11.43	1.78	2.54
	5	12.70		2.54
	6	13.46		1.27
4	1	16.51		1.27
	2	19.05		1.52
5	1	22.86		1.52
	2	26.67		1.27
6	1	28.70		1.27
	2	30.48		3.81
	3	31.50		2.03
	4	34.54	1.52	203

Material Properties	Geometric Properties	Loading
Shaft E_{11} = 2.078E11 Pa G_{12} = 1.0E12 Pa DENS = 7806 kg/m^3 **Mass Element**	Refer to Table 247.1: Geometric Data of Rotor-Bearing Elements (p. 696)	**Rotational Velocity** Spin (1) = 0 rpm Spin (2) = 35,000 rpm

Material Properties	Geometric Properties	Loading
Mass = 1.401 kg Polar inertia = .002 kg m^2 Diametral inertia =.00136 kg m^2 **Bearing Element** Spring constant = 4.378E7 N/m		Spin (3) = 70,000 rpm Spin (4) = 105,000 rpm

Analysis Assumptions and Modeling Notes

A modal analysis is performed on a rotor bearing system with QR Damp method to determine the whirl speeds and Campbell values. The rotor shaft is modeled with BEAM188 elements with quadratic shape function and an internal node to enhance element accuracy. MASS21 element is used to model the rigid disk (concentrated mass) and COMBIN14 element is used to model symmetric bearings. No shear effect is included in the rotor-bearing system. The displacement along X as well as the rotation around X axis is constrained so that the rotor bearing system does not have any torsion or traction related displacements. The **CORIOLIS** command is activated in a stationary reference frame to apply gyroscopic effect to the rotating structure. The whirl speeds for slope (excitation per revolution) 1 and 4 are determined and compared with the numerical solution.

Note

In the "Results Comparison" (p. 697) table below, the values listed from the reference article are the whirl speeds (frequencies) and not the critical speeds. Also, the definition of the ratio differs between the reference article and this application. In the article, the whirl ratio equals the rotational velocity divided by the frequency. In this application, the ratio is the slope, which is equal to the frequency divided by the rotational velocity. As a result, the values listed in the reference article for a whirl ratio of 1/4 (see the "Results Comparison" (p. 697) table below) are divided by 4 so that they can be compared to the critical speeds obtained from this application with a slope of 4.

Results Comparison

	Target	Mechanical APDL	Ratio
Whirl speeds for slope = 1 (rpm)			
Mode 1	15470.0000	15478.5247	1.001
Mode 2	17159.0000	17128.0842	0.998
Mode 3	46612.0000	46711.5585	1.002
Mode 4	49983.0000	50093.9640	1.002
Mode 5	64752.0000	64875.3791	1.002
Mode 6	96547.0000	95636.2738	0.991
Whirl speeds for slope = 4 (rpm)			
Mode 1	4015.0000	4013.3857	1.000
Mode 2	4120.2500	4116.1717	0.999

	Target	Mechanical APDL	Ratio
Mode 3	11989.2500	12015.4449	1.002
Mode 4	12200.0000	12227.0010	1.002
Mode 5	18184.2500	18205.2845	1.001
Mode 6	20162.2500	20127.0570	0.998

VM248: Delamination Analysis of Double Cantilever Beam

Overview

Reference:	G. Alfano and M. A. Crisfield*Finite Element Interface Models for the Delamination Analysis of Laminated Composites: Mechanical and Computational Issues*, International Journal for Numerical Methods in Engineering, Vol. 50, pp. 1701-1736 (2001).
Analysis Type(s):	Static analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4-Node Structural Solid Elements(PLANE182) 2-D 4-Node Cohesive Zone Elements (INTER202) 2-D 8-Node Structural Solid Elements(PLANE183) 2-D 6-Node Cohesive Zone Elements (INTER203) 3-D 8-Node Structural Solid Elements(SOLID185) 3-D 8-Node Cohesive Zone Elements (INTER205)
Input Listing:	vm248.dat

Test Case

A double cantilever beam of length *l*, width *w* and height *h* with an initial crack of length *a* at the free end is subjected to a maximum vertical displacement U_{max} at top and bottom free end nodes. Determine the vertical reaction at point *P* based on the vertical displacement for the interface model.

Figure 248.1: Double Cantilever Beam Sketch

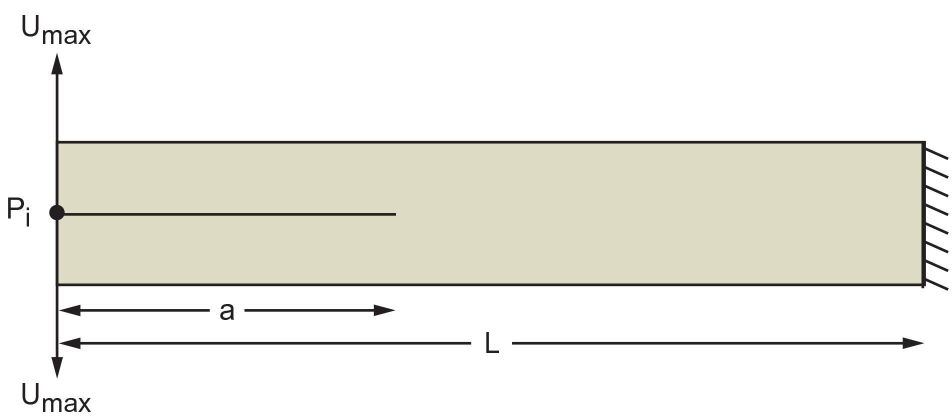
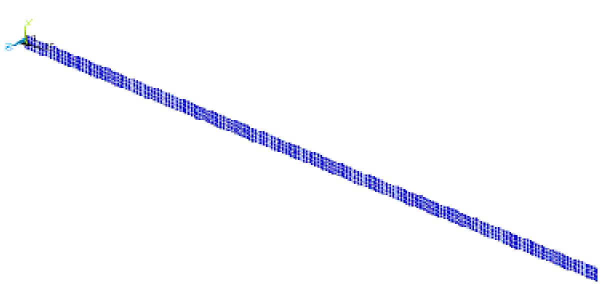


Figure 248.2: Representative Finite Element Model Using PLANE182 and INTER202 elements



Material Properties	Geometric Properties	Loading
Composite	L = 100 mm	U_{max} = 10 mm

Material Properties	Geometric Properties	Loading
E_{11} = 135.3 GPa E_{22} = 9.0 GPa E_{33} = 9.0 GPa G_{12} = 5.2 GPa ν_{12} = 0.24 ν_{13} = 0.24 ν_{23} = 0.46	a = 30 mm h = 3 mm w = 20 mm	
Interface C1 (maximum stress) = 25 MPa C2 (normal separation) = 0.004 mm C3 (shear separation) = 1000 mm		

Analysis Assumptions and Modeling Notes

Static analysis is performed using regular meshes of 4 x 200 4-node INTER202 elements with PLANE182 elements, 2 x 200 6-node INTER203 elements with PLANE183 elements, and 2 x 200 8-node INTER205 elements with SOLID185 elements . In the 3-D model (INTER205 and SOLID185 elements), all the UZ degrees of freedom are constrained to make it behave like a 2-D model. An imposed displacement of Uy = 10 mm acts at the top and bottom free nodes. Equivalent material constants of C1 = 25, C2 = 0.004 and C3 = 1000 are used for the interface material, as Mechanical APDL uses the exponential form of the cohesive zone model and the reference uses a bilinear constitutive model.

Results Comparison

INTER202			
	Target	Mechanical APDL	Ratio
Max RFORCE and corresponding DISP:			
RFORCE FY (N)	60.00	60.069	1.001
DISP UY(mm)	1.00	1.000	1.000
End RFORCE and corresponding DISP:			
RFORCE FY (N)	24.00	24.288	1.012
DISP UY(mm)	10.00	10.00	1.00

INTER203			
	Target	Mechanical APDL	Ratio
Max RFORCE and corresponding DISP:			
RFORCE FY (N)	60.00	60.063	1.001
DISP UY(mm)	1.00	1.000	1.000
End RFORCE and corresponding DISP:			
RFORCE FY (N)	24.00	24.289	1.012
DISP UY(mm)	10.00	10.00	1.00

INTER205			
	Target	**Mechanical APDL**	**Ratio**
Max RFORCE and corresponding DISP:			
RFORCE FY (N)	60.00	60.086	1.001
DISP UY(mm)	1.00	1.000	1.000
End RFORCE and corresponding DISP:			
RFORCE FY (N)	24.00	24.275	1.011
DISP UY(mm)	10.00	10.00	1.00

VM249: Gasket Material Under Uniaxial Compression Loading - 2-D Analysis

Overview

Reference:	Any Nonlinear Material Verification Text.
Analysis Type(s):	Static analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4-Node Structural Solid Elements (PLANE182) 2-D 8-Node or 6-Node Structural Solid (PLANE183) 2-D 4-Node Gasket Elements (INTER192) 2-D 6-Node Gasket Elements (INTER193)
Input Listing:	vm249.dat

Test Case

A thin interface layer of thickness t is defined between two planes of length l and width W placed on top of each other. The planes are constrained on the left and bottom edges and loaded with pressure P on the top. Determine the pressure-closure response for gasket elements.

Figure 249.1: Gasket Finite Element Model Geometry Sketch

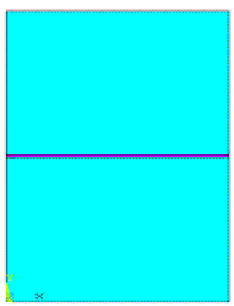
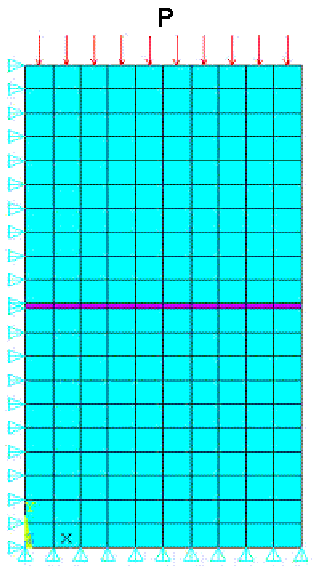


Figure 249.2: Representative Finite Element Model



Material Properties	Geometric Properties	Loading
E = 104728E6 N/m^2 ν = 0.21 Density = 7203 kg/m^3	L = 1m T = 0.02m	P1 = 44006400 pa P2 =157147000 pa

Analysis Assumptions and Modeling Notes

A 2-D plane stress analysis is performed first using INTER192 gasket elements and then using INTER193 gasket elements. In order to simulate the loading-unloading behavior of gasket material, the model is first loaded with a pressure P1 and unloaded and then loaded with a pressure P2 and unloaded. The pressure-closure responses simulated are compared to the material definition.

Results Comparison

	Target	Mechanical APDL	Ratio
Results Using INTER192 Elements:			
Gasket Pressure and Closure at End of 1st Loading:			
GK-PRES	0.440064E+08	0.440111E+08	1.000
GK-CLOS	0.406400E-03	0.406419E-03	1.000
Gasket Pressure and Closure at End of 2nd Loading:			
GK-PRES	0.157147E+09	0.157207E+09	1.000
GK-CLOS	0.683260E-03	0.683417E-03	1.000
Results Using INTER193 Elements:			
Gasket Pressure and Closure at End of 1st Loading:			
GK-PRES	0.440064E+08	0.440111E+08	1.000
GK-CLOS	0.406400E-03	0.406419E-03	1.000

	Target	Mechanical APDL	Ratio
Gasket Pressure and Closure at End of 2nd Loading:			
GK-PRES	0.157147E+09	0.157207E+09	1.000
GK-CLOS	0.683260E-03	0.683417E-03	1.000

VM250: Gasket Material Under Uniaxial Compression Loading - 3-D Analysis

Overview

Reference:	Any Nonlinear Material Verification Text.
Analysis Type(s):	Static analysis (**ANTYPE** = 0)
Element Type(s):	3-D 8-Node Structural Solid Elements (SOLID185) 3-D 20-Node Structural Solid Elements (SOLID186) 3-D 8-Node Gasket Elements (INTER195) 3-D 20-Node Gasket Elements (INTER194)
Input Listing:	vm250.dat

Test Case

A thin interface layer of thickness t is defined between two blocks of length l, width W, and height H placed on top of each other. The blocks are constrained on the left, bottom, and back faces and loaded with pressure P on the top face. Determine the pressure-closure response for gasket elements.

Figure 250.1: Gasket Finite Element Model Geometry Sketch

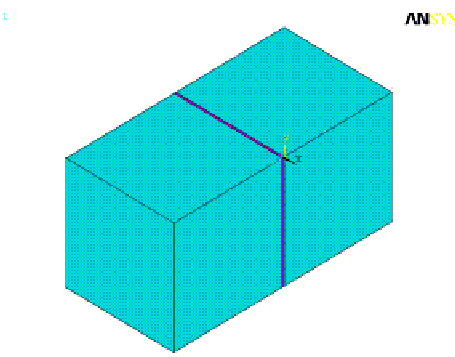
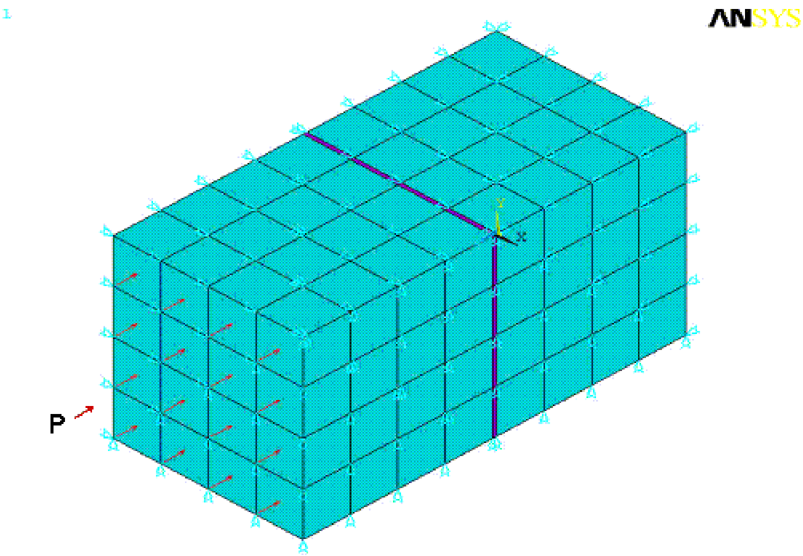


Figure 250.2: Representative Finite Element Model



Material Properties	Geometric Properties	Loading
E = 104728E6 N/m$_2$ ν = 0.21 Density = 7203 kg/m^3	L = 1 m W = 1 m H = 1 m T = 0.02 m	P1 = 44006400 pa P2 =157147000 pa

Analysis Assumptions and Modeling Notes

A 3-D analysis is performed first using 4 x 4 INTER195 gasket elements and then using 4 x 4 INTER194 gasket elements. In order to simulate the loading-unloading behavior of gasket material, the model is first loaded with a pressure P1 and unloaded and then loaded with a pressure P2 and unloaded. The pressure-closure responses simulated are compared to the material definition.

Results Comparison

	Target	Mechanical APDL	Ratio
Results Using INTER195 Elements:			
Gasket Pressure and Closure at End of 1st Loading:			
GK-PRES	0.440064E+08	0.440064E+08	1.000
GK-CLOS	0.406400E-03	0.406400E-03	1.000
Gasket Pressure and Closure at End of 2nd Loading:			
GK-PRES	0.157147E+09	0.157147E+09	1.000
GK-CLOS	0.683260E-03	0.683260E-03	1.000
Results Using INTER194 Elements:			
Gasket Pressure and Closure at End of 1st Loading:			
GK-PRES	0.440064E+08	0.440064E+08	1.000
GK-CLOS	0.406400E-03	0.406400E-03	1.000
Gasket Pressure and Closure at End of 2nd Loading:			

	Target	Mechanical APDL	Ratio
GK-PRES	0.157147E+09	0.157147E+09	1.000
GK-CLOS	0.683260E-03	0.683260E-03	1.000

VM251: Shape Memory Alloy Under Uniaxial Tension Load

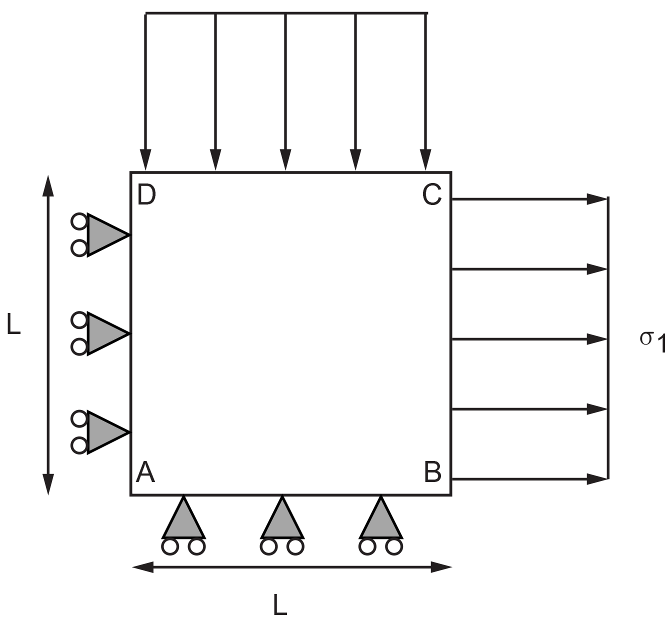
Overview

Reference:	Ferdinando Auricchio, Robert L. Taylor, and Jacob Lubliner, *Shape-memory alloys: macromodelling and numerical simulations of the superelastic behavior*, Comput. Methods Appl. Mech. Engrg., Vol. 146, pp. 281-312 (1997).
Analysis Type(s):	Static analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4-Node Structural Solid Elements (PLANE182) 2-D 8-Node Structural Solid Elements (PLANE183) 3-D 8-Node Structural Solid Elements (SOLID185)
Input Listing:	vm251.dat

Test Case

A square block of length, height and width L is constrained in the X-direction on the left face, constraint in the Y-direction rear on the bottom face and constrained in the Z-direction on the rear face (3-D case only). It is uniaxially loaded with tensile stress of s and unloaded on the top face. Determine the stress-strain response for a Ni-Ti alloy.

Figure 251.1: Shape Memory Alloy under Uniaxial Load Problem Sketch



Problem Sketch

Material Properties	Shape Memory Alloy	Loading
$E = 60 \times 10^3$ MPa $\nu = 0.3$ **Geometric Properties** L = 10 mm	$\sigma_s^{AS} = 520$ MPa $\sigma_f^{AS} = 600$ MPa $\sigma_s^{AS} = 300$ MPa	$\sigma_1 = 600$ MPa

Material Properties	Shape Memory Alloy	Loading
	$\sigma_s^{AS} = 200$ MPa $\varepsilon_L = 0.07$ $\alpha = 0$	

Analysis Assumptions and Modeling Notes

A 2-D axisymmetric analysis is performed first using a single 4-node PLANE182 element and then using a single 8-node PLANE183 element. 3-D analysis is then performed using SOLID185 elements. The stress-strain responses simulated are compared to the linear model in the reference.

Results Comparison

	Target	Mechanical APDL	Ratio
Results using PLANE182			
SIG-SAS	520.00	522.013	1.004
EPTO-SAS	0.010	0.010	1.046
SIG-FAS	600.00	599.992	1.000
EPTO-FAS	0.080	0.08	1.000
SIG-SSA	300.00	300.016	1.000
EPTO-SSA	0.074	0.075	1.013
SIG-FSA	200.00	197.500	0.988
EPTO-FSA	0.003	0.003	1.029
Results using PLANE183			
SIG-SAS	520.00	521.993	1.004
EPTO-SAS	0.010	0.010	1.044
SIG-FAS	600.00	600.203	1.000
EPTO-FAS	0.080	0.08	1.000
SIG-SSA	300.00	299.997	1.000
EPTO-SSA	0.074	0.075	1.014
SIG-FSA	200.00	197.587	0.988
EPTO-FSA	0.003	0.003	1.029
Results using SOLID185			
SIG-SAS	520.00	522.007	1.004
EPTO-SAS	0.010	0.010	1.046
SIG-FAS	600.00	599.996	1.000
EPTO-FAS	0.080	0.08	1.000
SIG-SSA	300.00	300.0086	1.000
EPTO-SSA	0.074	0.075	1.013
SIG-FSA	200.00	197.689	0.988
EPTO-FSA	0.003	0.003	1.029

VM252: Gurson Bar-Necking Benchmark with Applied Displacement - 2-D Analysis

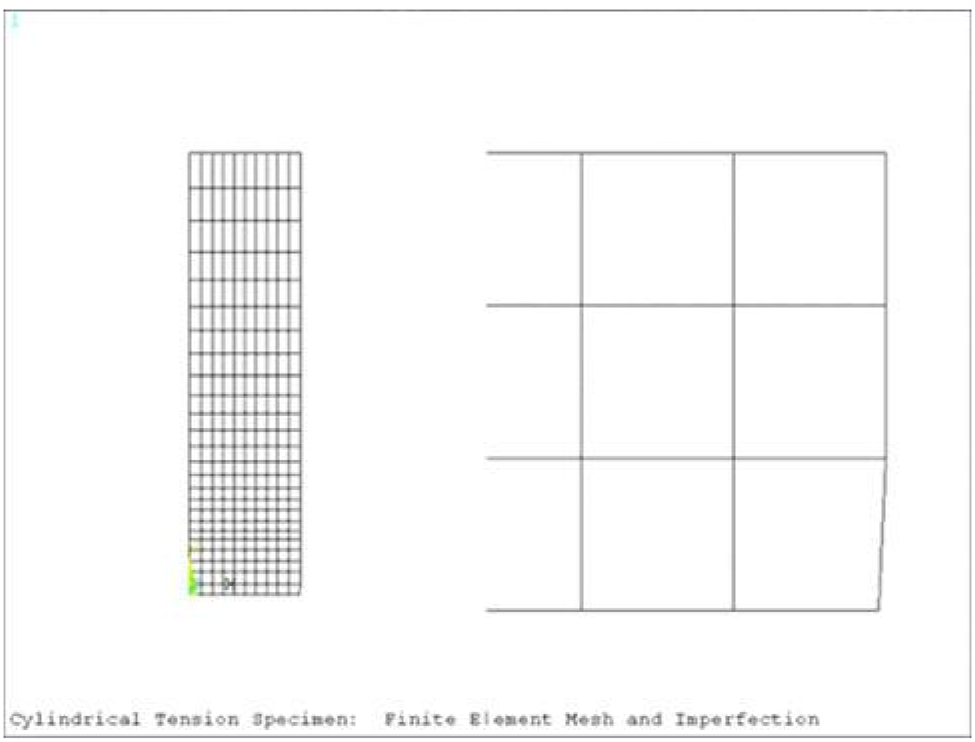
Overview

Reference:	N. Aravas, "On the Numerical Integration of a Class of Pressure Dependent Plasticity Models", *International Journal for Numerical Methods in Engineering*, Vol. 24, pp. 1395-1416, Section 5.3, Figure 10 (1987).
Analysis Type(s):	Static analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4-Node Structural Plane Elements (PLANE182) 2-D 8-Node Structural Plane Elements (PLANE183)
Input Listing:	vm252.dat

Test Case

The model represents the necking of an axisymmetric specimen. The initial radius of the specimen was described to be 1" and the length was set to four times the initial radius. A slight imperfection is found at the bottom of the model to create the initial notch, which is offset by $0.005*R_o$. For clarification, the finite element mesh and the geometric imperfection are found in Figure 252.1: Representative Finite Element Model (p. 713). To initiate growth of the notch, a displacement in the y-direction was applied to the top of the model that was set to 0.7602".

Figure 252.1: Representative Finite Element Model



Material Properties	Gurson Material Model	Elastic Material Model
E = 1000000 lb/in^2 ν = 0.30	q_1 = 1.5 q_2 = 1.0	ε_n = 0.3 σ_y = E/300.0

Material Properties	Gurson Material Model	Elastic Material Model
Geometric Properties L = 1 T = 0.02	$q_3 = q_1^2$ $\varepsilon_n = 0.3$ f_o = 1E-8 $f_n = 0.04$ $s_n = 0.1$	n = 0.1 **Loading** U_{app} = 0.7602" @ y = 4" U_x = 0 @ x = 0" U_y = 0 @ y = 0"

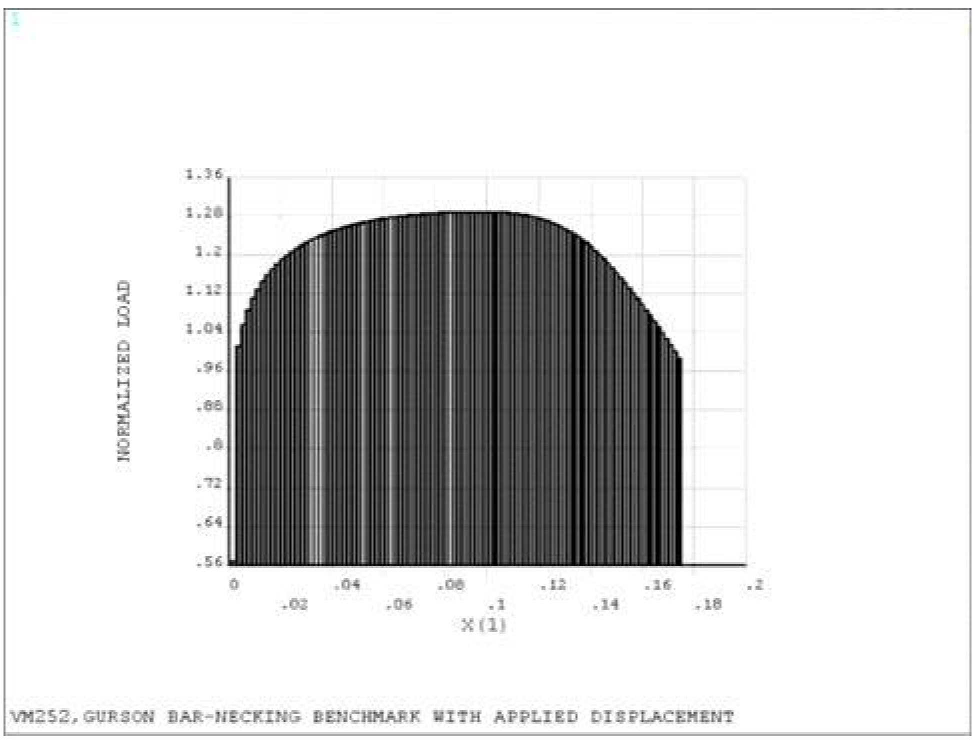
Analysis Assumptions and Modeling Notes

A 2-D analysis is performed with both PLANE182 and PLANE183 elements. Two material models are introduced into the model, an elastic and Gurson model. The elastic model is based upon a power law and is presented for hardening purposes. The coefficients for input were taken from the reference provided.

Due to the nonlinear behavior and complexity of the problem, it is suggested to first increase the number of substeps within the solution module until convergence is reached or perform mesh refinement. Within the provided input listing, the total force along y = 4.0" is recorded and plotted against x, where x is defined by the following relationship: x = log(1+ dispY/L_o).

Graphical Results Comparison

Figure 252.2: Material Behavior of Specimen



Numerical Results Comparison

	Target	Mechanical APDL	Ratio
Results using PLANE182 Elements	1.25	1.2895	0.969
Results using PLANE183 Elements	1.25	1.2896	0.969

VM253: Gurson Hydrostatic Tension Benchmark - 3-D Analysis

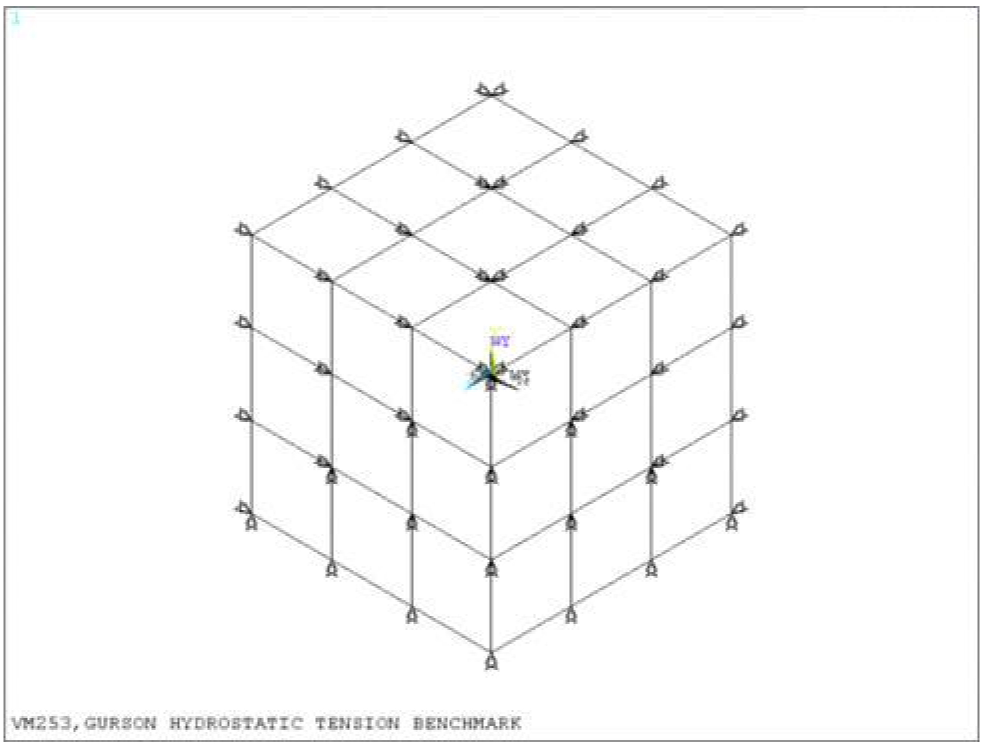
Overview

Reference:	N. Aravas, "On the Numerical Integration of a Class of Pressure Dependent Plasticity Models", *International Journal for Numerical Methods in Engineering*, Vol. 24, pp. 1395-1416, Section 5.2, Figure 7 (1987).
Analysis Type(s):	Static analysis (**ANTYPE** = 0)
Element Type(s):	3-D 8-Node Structural Solid Elements (SOLID185) 3-D 20-Node Structural Solid Elements (SOLID186)
Input Listing:	vm253.dat

Test Case

The model is a three dimensional bin with all sides equal to unity. An applied displacement of 0.15" is applied at the nodes corresponding to x = 1, y =1, and z =1. To prevent rigid body motion, the model is constrained in the x direction at x = 0, y-direction at y = 0, and z-direction at z = 0.

Figure 253.1: Representative Finite Element Model



Material Properties	Gurson Material Model	Elastic Material Model
$E = 1000000$ lb/in^2 $\nu = 0.30$ **Geometric Properties** L = H = W = 1"	$q_1 = 1.5$ $q_2 = 1.0$ $q_3 = {q_1}^2$ $\varepsilon_n = 0.3$ $f_o = 0.04$	$\varepsilon_n = 0.3$ $\sigma_y = E/300.0$ $n = 0.1$ **Loading**

Material Properties	Gurson Material Model	Elastic Material Model
	f_n = 0.04 s_n = 0.1	U_{app} = 0.15″ @ x = 1″ U_{app} = 0.15″ @ y = 1″ U_{app} = 0.15″ @ z = 1″ U_x = 0 @ x = 0″ U_y = 0 @ y = 0″ U_z = 0 @ z = 0″

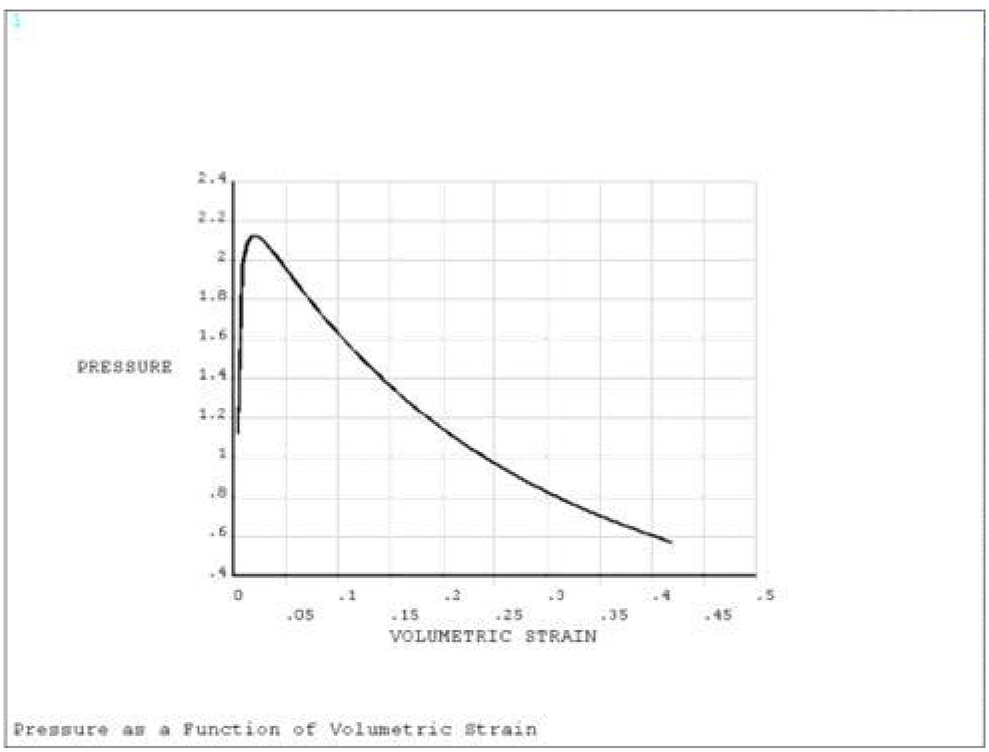
Analysis Assumptions and Modeling Notes

A 3-D analysis is performed with both SOLID185 and SOLID186 elements. Two material models are introduced into the model, an elastic and Gurson model. The elastic model is based upon a power law and is presented for hardening purposes. The coefficients for input were taken from the reference provided.

Due to the nonlinear behavior and complexity of the problem, it is suggested to first increase the number of substeps within the solution module until convergence is reached or perform mesh refinement. Within the provided input listing, the hydrostatic pressure data is gathered for a specified node and plotted against the volumetric strain.

Graphical Results Comparison

Figure 253.2: Material Behavior of Specimen



Numerical Results Comparison

Volumetric Strain	Target	Mechanical APDL	Ratio
Results using SOLID185			
0.10	1.62	1.6204	1.0002
0.24	1.00	1.0096	1.0096
0.40	0.62	0.6207	1.0012
Results using SOLID186			
0.10	1.62	1.6204	1.0002
0.24	1.00	1.0096	1.0096
0.40	0.62	0.6207	1.0012

VM254: Campbell Diagrams and Critical Speeds Using Symmetric Orthotropic Bearings

Overview

Reference:	Nelson, H.D., McVaugh, J.M., "The Dynamics of Rotor-Bearing Systems Using Finite Elements", *Journal of Engineering for Industry*, Vol 98, pp. 593-600, 1976
Analysis Type(s):	Modal analysis (**ANTYPE** = 2)
Element Type(s):	Elastic straight pipe (PIPE16) 3-D 2 Node pipe element (PIPE288) Structural mass element (MASS21) 2-D Spring damper bearing element (COMBI214)
Input Listing:	vm254.dat

Test Case

A rotor-bearing system is analyzed to determine the forward and backward whirl speeds. The distributed rotor was modeled as a configuration of six elements with each element composed of subelements. See Table 254.1: Geometric Data of Rotor-Bearing Elements (p. 722) for a list of the geometrical data of the elements. Two symmetric orthotropic bearings were located at positions four and six. Modal analysis is performed on rotor bearing system with multiple load steps to determine the whirl speeds and Campbell values for the system.

Figure 254.1: Rotor-Bearing Configuration

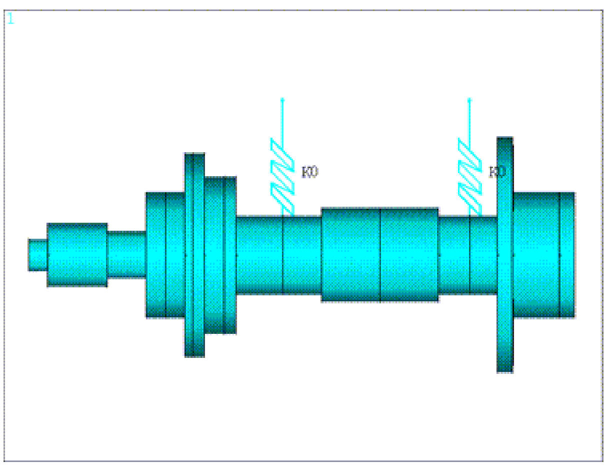


Figure 254.2: Isometric View of the Rotor-Bearing System

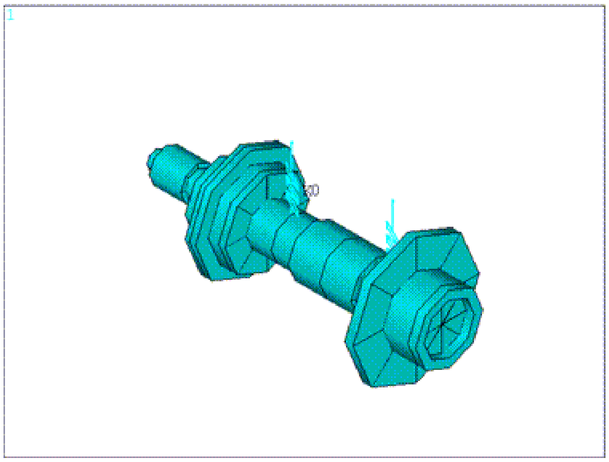


Table 254.1: Geometric Data of Rotor-Bearing Elements

Element No.	Subelement No.	Axial Distance to Subelement (cm)	Inner Diameter (cm)	Outer Diameter (cm)
1	1	0.00		0.51
	2	1.27		1.02
2	1	5.08		0.76
	2	7.62		2.03
3	1	8.89		2.03
	2	10.16		3.30
	3	10.67	1.52	3.30
	4	11.43	1.78	2.54
	5	12.70		2.54
	6	13.46		1.27
4	1	16.51		1.27
	2	19.05		1.52
5	1	22.86		1.52
	2	26.67		1.27
6	1	28.70		1.27
	2	30.48		3.81
	3	31.50		2.03
	4	34.54	1.52	2.03

Material Properties	Geometric Properties	Loading
Shaft E_{11} = 2.078E11 Pa G_{12} = 1.0E14 Pa DENS = 7,806 kg/m^3	Refer to Table 254.1: Geometric Data of Rotor-Bearing Elements (p. 722)	**Rotational Velocity** Spin (1) = 1,000 rpm Spin (2) = 20,000 rpm

Material Properties	Geometric Properties	Loading
Mass Element Mass = 1.401 kg Polar inertia = .002 kg m^2 Diametral inertia = .00136 kg m^2 **Bearing Element** Spring coefficients K11 = K22 = 3.503E7 N/m K12 = K21 = -8.756E6 N/m		Spin (3) = 40,000 rpm Spin (4) = 60,000 rpm Spin (5) = 80,000 rpm Spin (6) = 100,000 rpm

Analysis Assumptions and Modeling Notes

A modal analysis is performed on a rotor bearing system with DAMP (PIPE16) and QR Damp (PIPE288) methods to determine the whirl speeds and Campbell values. PIPE16 and PIPE288 elements are used to model the rotor shaft, MASS21 elements are used to model the rigid disk (concentrated mass), and COMBI214 elements are used to model symmetric bearings. No shear effect is included in the rotor-bearing system. The displacement along X as well as the rotation around X axis is constrained so that the rotor bearing system does not have any torsion or traction related displacements. The **CORIOLIS** command is activated in a stationary reference frame to apply gyroscopic effect to the rotating structure. The backward and forward whirl speeds are determined from modal analysis and compared with the numerical solution.

Results Comparison

	Target	Mechanical APDL	Ratio
Backward and forward whirl speeds for slope = 1 @ 100,000 rpm			
PIPE16			
Mode 1 (BW)	10747.0000	10808.6349	1.006
Mode 2 (FW)	19665.0000	19610.7142	0.997
Mode 3 (BW)	39077.0000	39186.3163	1.003
Mode 4 (FW)	47549.0000	47690.8995	1.003
PIPE288			
Mode 1 (BW)	10747.0000	10815.9699	1.006
Mode 2 (FW)	19665.0000	19622.0736	0.998
Mode 3 (BW)	39077.0000	39222.3299	1.004
Mode 4 (FW)	47549.0000	47772.2850	1.005

VM255: Delamination Analysis using Contact Based Debonding Capability

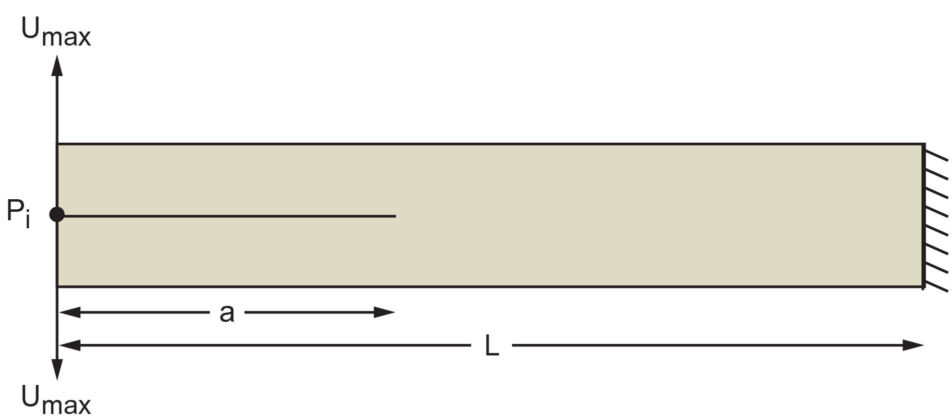
Overview

Reference:	G. Alfano and M. A. Crisfield, *Finite Element Interface Models for the Delamination Analysis of Laminated Composites: Mechanical and Computational Issues*, International Journal for Numerical Methods in Engineering, Vol. 50, pp. 1701-1736 (2001).
Analysis Type(s):	Static analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4-Node Structural Solid Element (PLANE182) 2-D 2-Node Surface-to-Surface Contact Element (CONTA171) 2-D Target Segment Element (TARGE169)
Input Listing:	vm255.dat

Test Case

A double cantilever beam of length *l*, width *w* and height *h* with an initial crack of length *a* at the free end is subjected to a maximum vertical displacement U_{max} at top and bottom free end nodes. Determine the vertical reaction at point *P* based on the vertical displacement using contact based debonding capability.

Figure 255.1: Double Cantilever Beam Sketch



Material Properties	Geometric Properties	Loading
Composite E_{11} = 135.3 GPa E_{22} = 9.0 GPa E_{33} = 9.0 GPa G_{12} = 5.2 GPa ν_{12} = 0.24 ν_{13} = 0.24 ν_{23} = 0.46 **Interface** C1 = 1.7 MPa C2 = 0.28 N/mm	L = 100 mm a = 30 mm h = 3 mm w = 20 mm	U_{max}= 10 mm

Material Properties	Geometric Properties	Loading
C5 = 1.0E-5		

Analysis Assumptions and Modeling Notes

A double cantilever beam has been analyzed under displacement control using 2-D plane strain formulation with a regular mesh of 4 x 200 4-node PLANE182 elements. An imposed displacement of Uy = 10 mm acts at the top and bottom free nodes. The interface is modeled with contact elements with a bonded contact option and a cohesive zone material model.

Bilinear material behavior with linear softening characterized by maximum traction and critical energy release rate (*TBOPT* = CBDE) cohesive zone material option is used with maximum traction t_o = 1.7 MPa and critical energy rate G_c= 0.28 N/mm. Debonding is often characterized by convergence difficulties during material softening. To overcome this problem artificial damping parameter of 1.0e-8 is used.

Based on the interface material parameters used, results obtained using Mechanical APDL should be compared to the results shown in Figure 15(a) in the reference.

Results Comparison

	Target	Mechanical APDL	Ratio
Max RFORCE and corresponding DISP using debonding:			
RFORCE FY (N)	50.00	50.663	1.013
DISP UY(mm)	1.50	1.50	1.000
RFORCE and corresponding DISP U = 10.0 using debonding:			
RFORCE FY (N)	24.00	24.862	1.036
DISP UY(mm)	10.00	10.00	1.00

VM256: Fracture Mechanics Stress for a Crack in a Plate using CINT Command

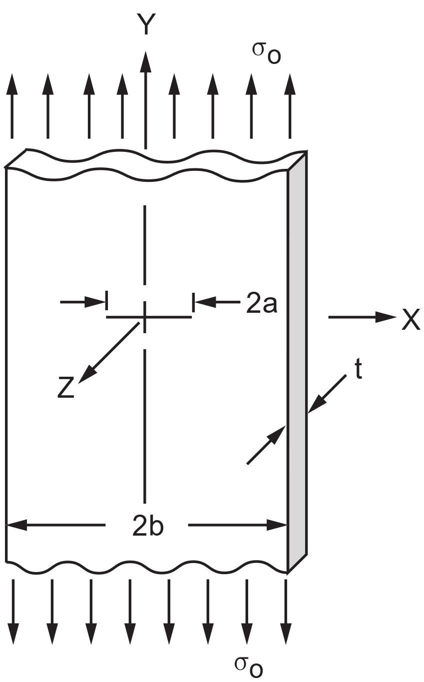
Overview

Reference:	W.F.Brown, Jr., J.E.Srawley, *Plane strain crack toughness testing of high strength metallic materials*, ASTM STP-410, (1966).
Analysis Type(s):	Static analysis (**ANTYPE** = 0)
Element Type(s):	2-D 8-Node Structural Solid Element (PLANE183) 3-D Structural Solid Element (SOLID185) 3-D Structural Solid or Layered Solid Element (SOLID186)
Input Listing:	vm256.dat

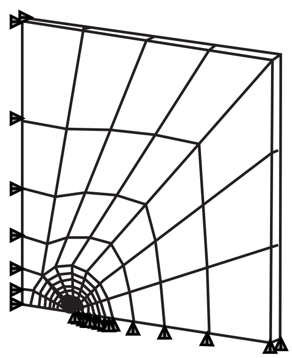
Test Case

A long plate with a center crack is subjected to an end tensile stress σ_0 as shown in problem sketch. Symmetry boundary conditions are considered and the fracture mechanics stress intensity factor KI is determined using **CINT** command.

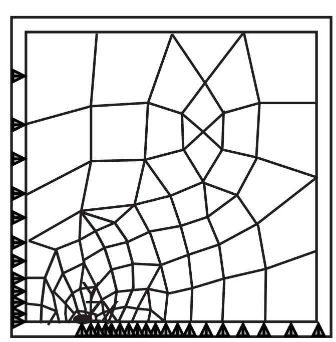
Figure 256.1: Finite Width Plate Problem Sketch



Problem Sketch



Representative Finite Element Model
(3-D Model with SOLID95 and SOLID45)



Representative Finite Element Model
(2-D Model with PLANE82)

Material Properties	Geometric Properties	Loading
$E = 30 \times 10^6$ psi $\nu = 0.3$	a = 1 in b = 5 in h = 5 in	$\sigma_0 = 0.5641895$ psi

Material Properties	Geometric Properties	Loading
	t = 0.25 in	

Analysis Assumptions and Modeling Notes

The problem is solved first using 2-D PLANE183 element with plain strain element behavior. A one-quarter plate is modeled and symmetry boundary conditions are considered. The crack tip nodes and the number of paths surrounding the crack tip nodes are defined using the **CINT** command. The plate is subjected to a tensile stress and the fracture mechanics stress intensity factor KI is computed for the crack tip nodes. In the 3-D analysis using SOLID185 and SOLID186 elements respectively, plain strain condition is achieved by constraining UZ degrees of freedom of all nodes (displacement in the Z-direction). The crack front and the path surrounding the crack front are defined using **CINT** command. The fracture mechanics parameter KI is then computed in POST1.

Results Comparison

	Target	Mechanical APDL	Ratio
Using PLANE183 Elements (2-D Analysis)			
Stress intensity KI	1.0249	1.0411	1.016
Using SOLID185 Elements (3-D Analysis)			
Stress intensity KI	1.0249	1.0438	1.018
Using SOLID186 Elements - Surface Crack (3-D Analysis)			
Stress intensity KI	1.0249	1.0529	1.027

VM257: Transient Analysis of a Swing with Two Rigid Links and Beam

Overview

Reference:	O.A. Bauchau, G. Damilano, and N.J. Theron *Numerical Integration of Non-Linear Elastic Multi-Body Systems*, International Journal for Numerical Methods in Engineering, Vol. 38, 2727-2751 (1995).
Analysis Type(s):	Transient Analysis (**ANTYPE** = 4)
Element Type(s):	3-D Linear Finite Strain Beam (BEAM188) Multipoint Constraint Element: Rigid Link or Rigid Beam (MPC184-Link/Beam) 3-D Target Segment (TARGE170)
Input Listing:	vm257.dat

Test Case

The swing shown in Figure 257.1: Swing comprising two rigid links and a beam with midspan mass (p. 729) consists of a long aluminum beam of rectangular cross-section (width = 1mm, depth = 5 mm) and a mid-span mass (mass = 0.5 kg). The modulus of elasticity, Poisson's ratio and density of aluminum are shown in the table below. The mass is rigidly connected to the beam at its mid-span position, labeled C in the figure. The beam is suspended at each end by two rigid links, and is initially at rest in the position as shown in the Figure 257.1: Swing comprising two rigid links and a beam with midspan mass (p. 729). The rigid links impose a kinematic constraint corresponding to fixed distance between points O1 and A, and O2 and E of 0.36 and $0.36\sqrt{2}\,\text{m}$ respectively. The points B and D indicate the quarter and three quarter span points of the beam, respectively. The loading of the system consists of a triangular pulse in the $\vec{i}_1$ direction applied at the mid-span mass. This pulse starts at time t = 0 s, reaches a peak value of 2N at t =0.128 s and goes back to zero at t = 0.256 s, as shown in Figure 257.2: Triangular-Pulse Loading (p. 730).

Figure 257.1: Swing comprising two rigid links and a beam with midspan mass

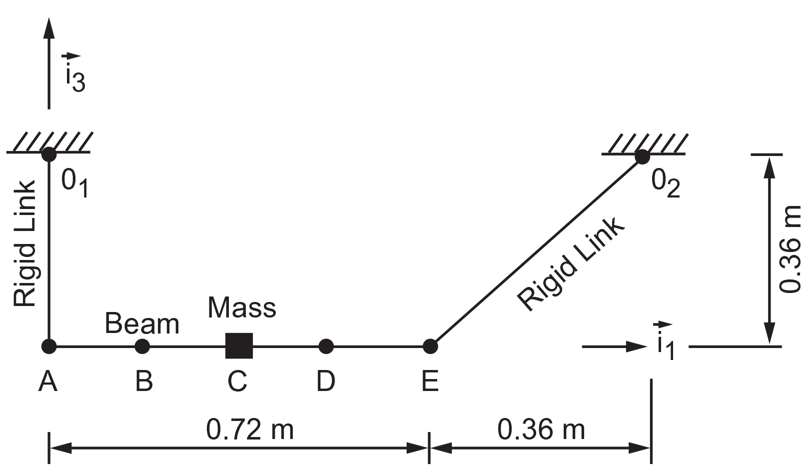
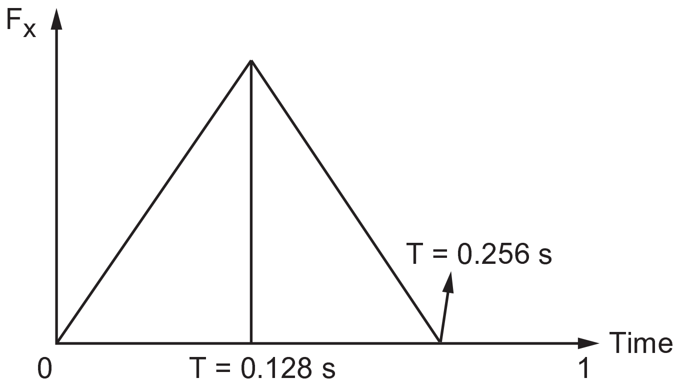


Figure 257.2: Triangular-Pulse Loading



Material Properties	Geometric Properties	Loading
$E = 73\ GN/m^2$ $\nu = 0.3$ $\rho = 2700\ kg/m^2$	$O_1A = 0.36$ m $AE = 0.72$ m $E\,O_2 = 0.36\sqrt{2}\,m$	$F_x = 0$ at time = 0 s $F_x = 2N$ at time = 0.128 s $F_x = 0$ at time = 0.256 s

Analysis Assumptions and Modeling Notes

The system is modeled with four equal length BEAM188 beam elements, two rigid links and a rigid mass. The dynamic response of the system was calculated over a period of 1 s using HHT method with 30% numerical damping and auto time stepping turned on with a minimum of 1000 time steps.

The system was solved twice. In the first case, the rigid links were modeled using MPC184 rigid links and in the second case the rigid links were modeled as rigid bodies using TARGE170 elements. Similar results were obtained in both analyses.

Figure 257.3: Predicted Time Histories for Displacement Components of Point B (p. 731) shows the predicted time histories for the $\vec{i}_1$ and $\vec{i}_3$ direction displacement components of point B and Figure 257.4: Calculated Time History of Axial Force at Point B (p. 732) shows the calculated time histories of the axial force at point B. These figures should be compared to Figures 15 and 16 respectively in the reference.

Figure 257.3: Predicted Time Histories for Displacement Components of Point B

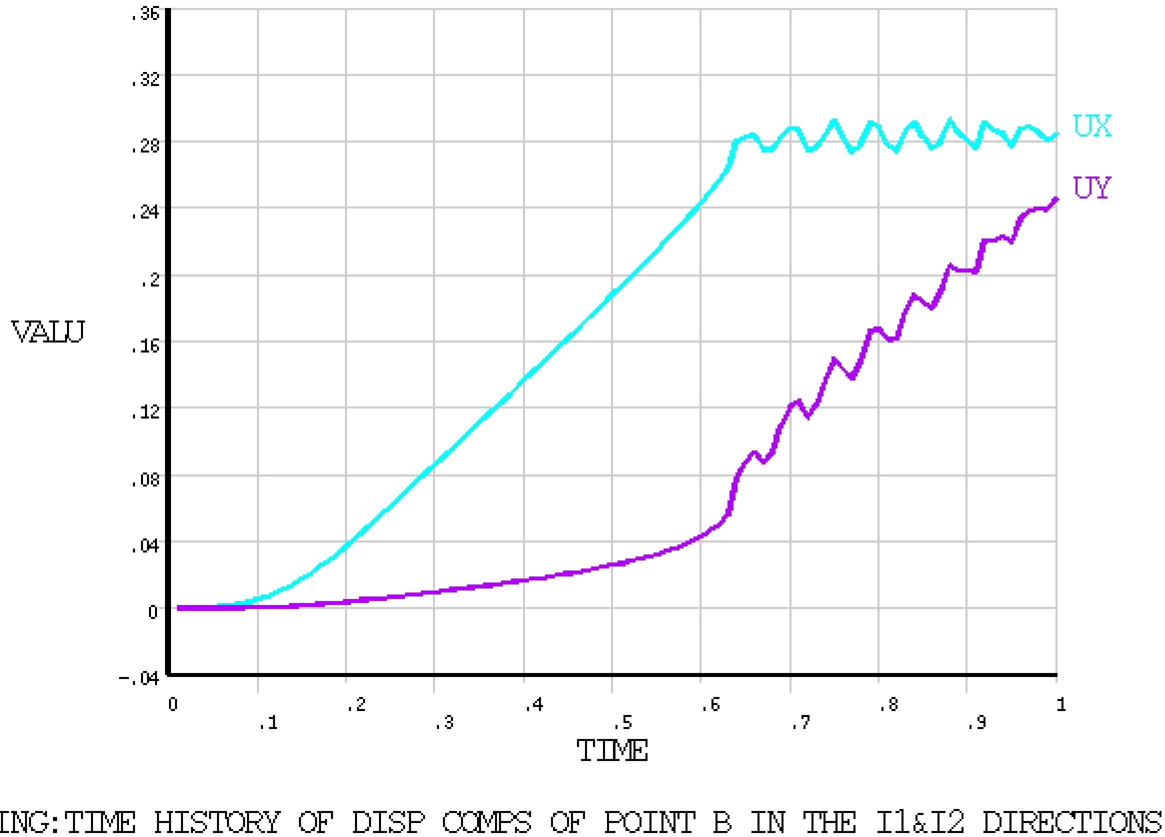
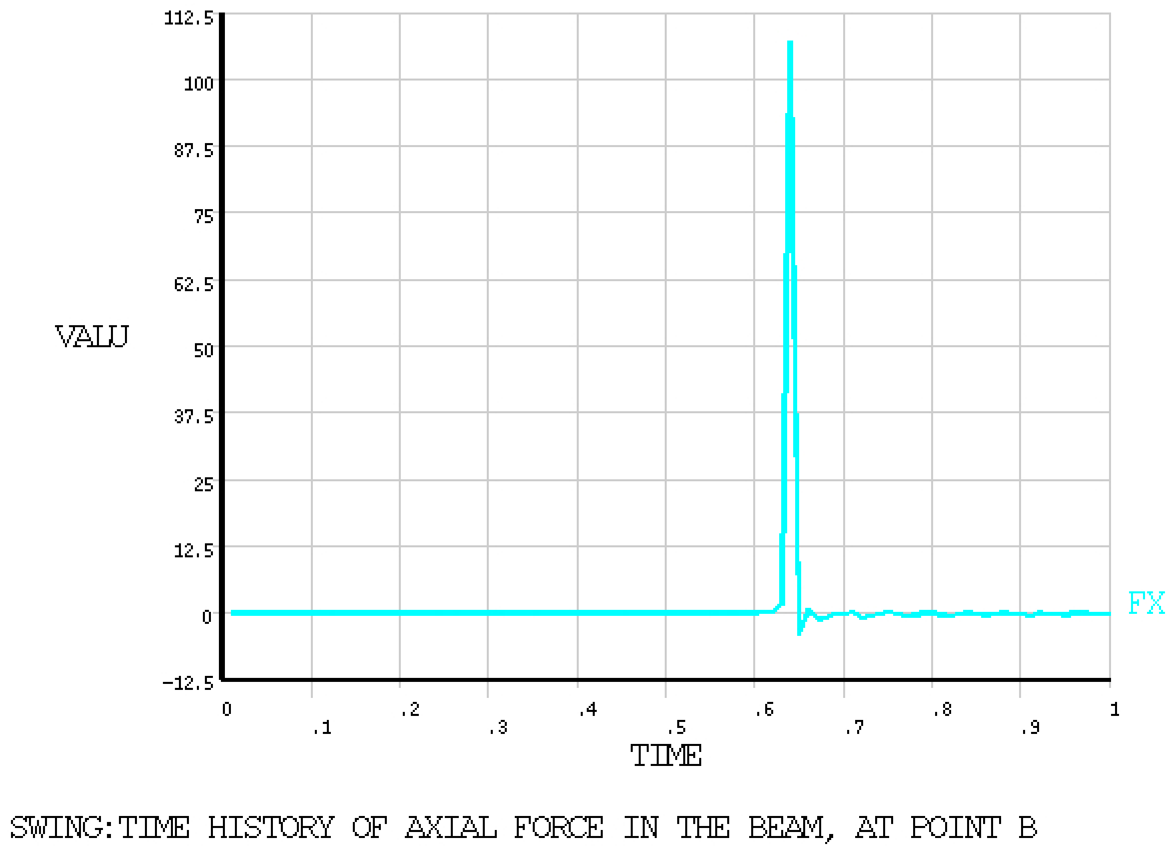


Figure 257.4: Calculated Time History of Axial Force at Point B



Results Comparison

	Target	Mechanical APDL	Ratio
Results using MPC184 rigid links			
TIME (sec)	0.6410	0.6400	0.998
DISP-UY (m)	0.2800	0.2807	1.003
DISP-UX (m)	0.0750	0.0783	1.043
FORCE-FX (N)	112.7000	107.1870	0.951
Results using TARGE170 rigid links			
TIME (sec)	0.6410	0.6400	0.998
DISP-UY (m)	0.2800	0.2807	1.003
DISP-UX (m)	0.0750	0.0783	1.043
FORCE-FX (N)	112.7000	107.1860	0.951

VM258: Spin-up Maneuver of a Flexible Beam

Overview

Reference:	J.C.Simo and L.Vu-Quoc, *On the Dynamics in Space of Rods Undergoing Large Motions - A Geometrically Exact Approach*, Computer Methods in Applied Mechanics and Engineering, Vol. 66, 125-161 (1988).
Analysis Type(s):	Transient Analysis (**ANTYPE** = 4)
Element Type(s):	3-D Quadratic Finite Strain Beam (BEAM189) Multipoint Constraint Element: General Joint (MPC184 – General) Multipoint Constraint Element: Revolute Joint (MPC184 – Revolute)
Input Listing:	vm258.dat

Test Case

The problem shown in Figure 258.1: Spin-up Maneuver Problem Model (p. 734) consists of a flexible beam characterized by a nonlinear generalized stress-generalized strain relationship. The material properties used to define the nonlinear general beam section are shown in the table below. The beam is pinned at one end and the other end is free, and is initially at rest.

Beam Section Properties
Axial Stiffness: A_E = 2.8e7
Bending Stiffness in xz Plane : I_1^E = 1.4e4
Bending Stiffness in xy Plane: I_2^E = 1.4e4
Torsional Stiffness: J_G =1.4e4
Transverse Shear Stiffness in xz Plane: A_1^G =1.0e7
Transverse Shear Stiffness in xy Plane: A_2^G =1.0e7
Mass density: $A\rho$ = 1.2 kg/m

The loading of the system consists of a prescribed rotation about the z-axis (normal to the plane) applied at the pinned end. The rotation varies with time as follows:

$$\psi(t)=\begin{cases}\dfrac{6}{15}\left[\dfrac{t^2}{2}+\left(\dfrac{15}{2\pi}\right)^2\left(\cos\dfrac{2\pi t}{15}-1\right)\right]\text{rad}, & 0\le t\le 15\text{s}\\ (6t-45)\text{rad} & t>15\text{s}\end{cases}$$

During transient analysis, the inertial/gyroscopic effects cause the beam to bend during the acceleration phase (0 ≤ t ≤ 15s) and stretch due to the centrifugal force during the steady-state motion at constant angular velocity (t > 15s). The prescribed rotation angle vs. time is shown in Figure 258.2: Rotation Angle Versus Time (p. 734).

Figure 258.1: Spin-up Maneuver Problem Model

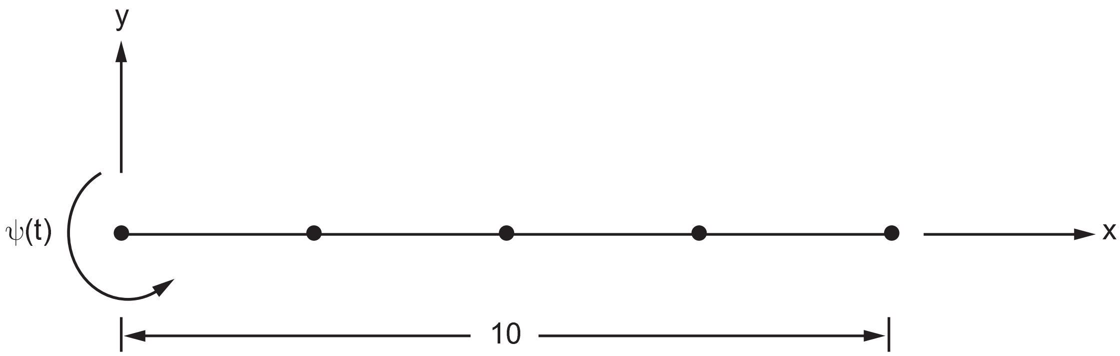
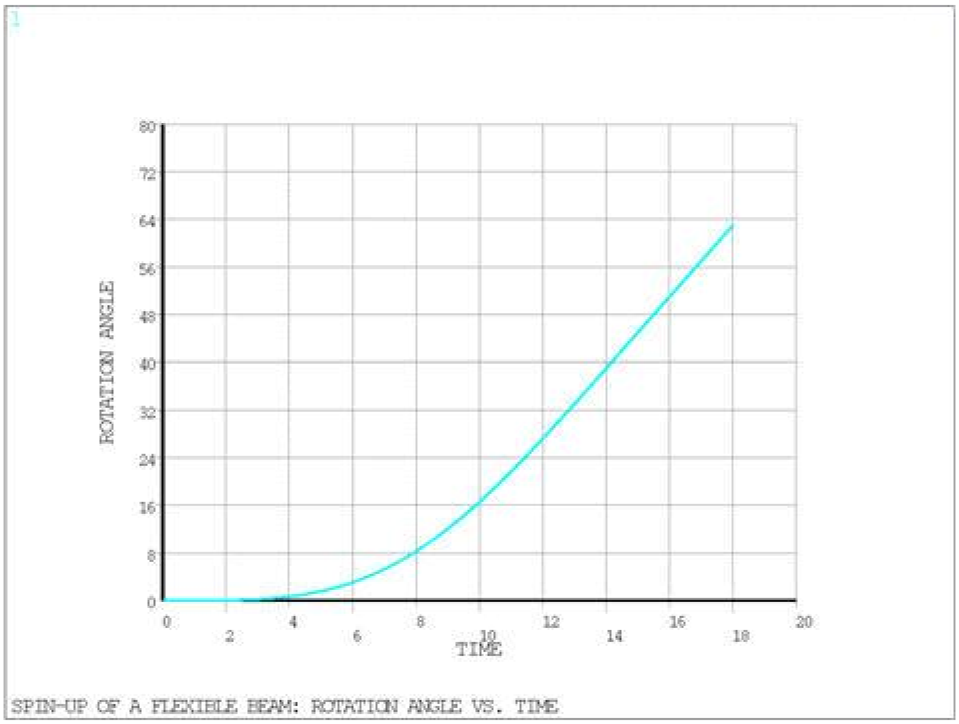


Figure 258.2: Rotation Angle Versus Time



Analysis Assumptions and Modeling Notes

The system is modeled with four equal length BEAM189 beam elements and two MPC 184 elements: a general joint element that spans the length of the beam and a revolute grounded joint element at the pinned end. The joint elements are used to get the output of nodal displacements in a coordinate system that rotates with the beam. The dynamic response of the system was calculated over a period of 18 s using the HHT time integration method with 10% numerical damping. Auto time stepping is used with midstep residual check and an initial time step size of 0.005s. Figure 258.3: Predicted Time History for Axial Displacement of Beam Tip (p. 735), Figure 258.4: Predicted Time History for Transverse Displacement of Beam Tip (p. 735), and Figure 258.5: Predicted Time History for Rotation of Beam Tip Relative to Base (p. 736) show the predicted time histories for the axial and transverse displacements of the beam tip and rotation of the beam tip relative to the base. These figures should be compared to Figure 6 in the reference.

Figure 258.3: Predicted Time History for Axial Displacement of Beam Tip

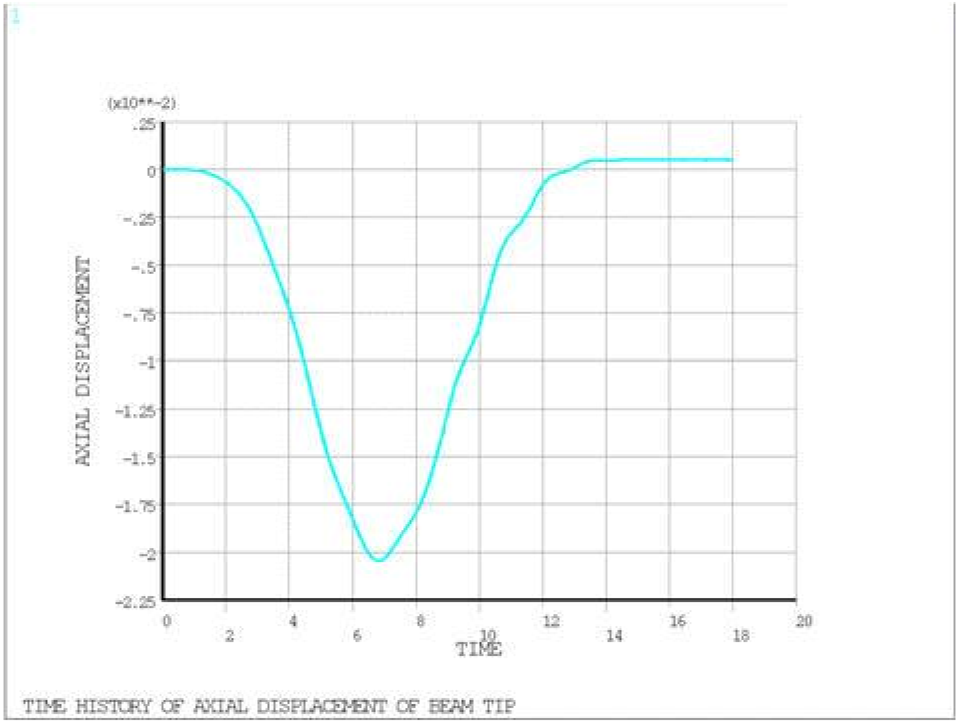


Figure 258.4: Predicted Time History for Transverse Displacement of Beam Tip

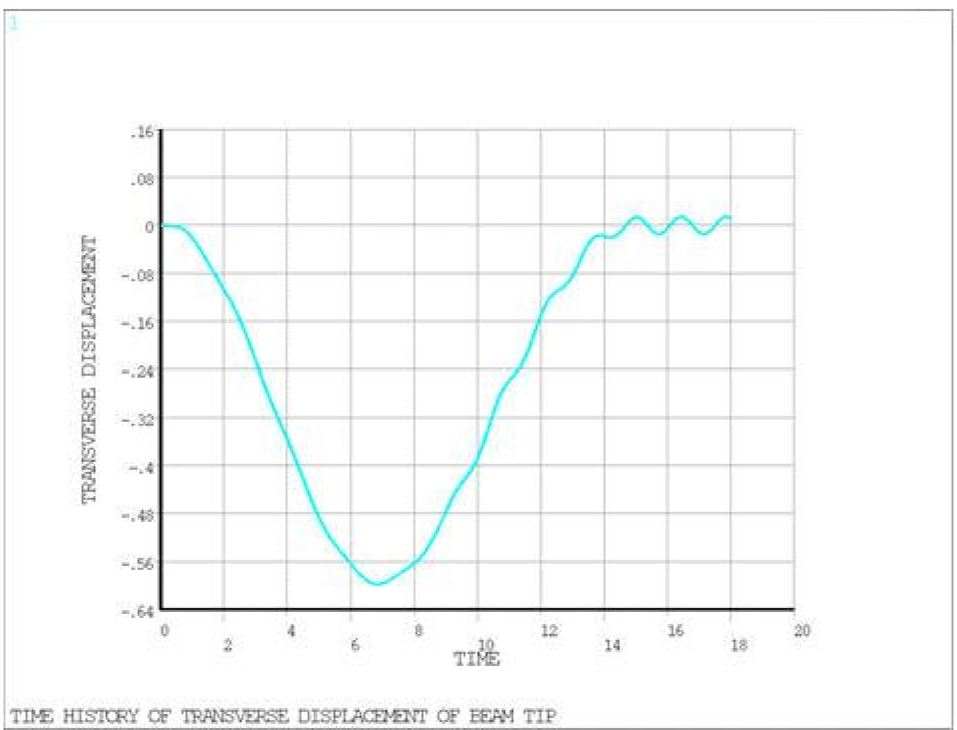
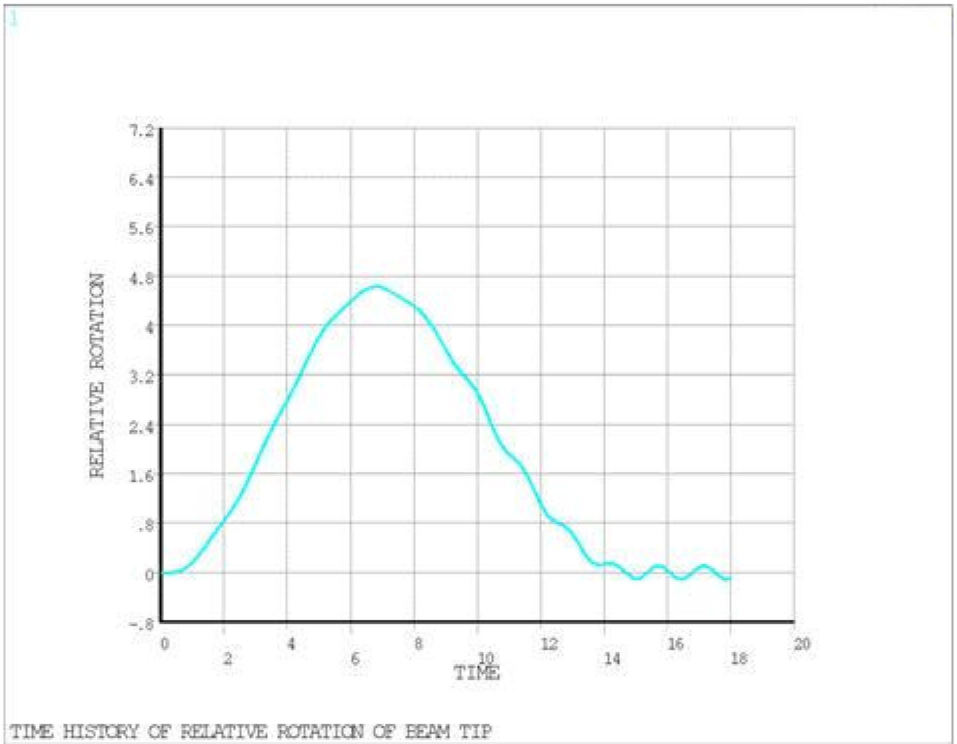


Figure 258.5: Predicted Time History for Rotation of Beam Tip Relative to Base



Results Comparison

In the tables below are presented comparisons of the peak values of Mechanical APDL results together with the times at which they occur to the corresponding reference values and their times.

Note

The expected values (Target) used in the following tables were extracted from the reference graphs (see Figure 6 in the reference) and cannot be considered precise values.

	Target	Mechanical APDL	Ratio
Peak Axial Displacement			
TIME (sec)	6.7	6.8256	1.019
TIP DISP-UX	-0.0190	-0.0204	1.076
Peak Transverse Displacement			
TIME (sec)	6.85	6.8256	0.996
TIP DISP-UY	-0.5750	-0.5976	1.039
Peak Relative Rotation			
TIME (sec)	6.7	6.7856	1.013
RELATIVE ROTATION-ROTZ (degrees)	4.4240	4.6273	1.046
Steady-state Stretch			
TIME (sec)	16	17.5275	1.095
TIP STRETCH-UX	5×10^{-4}	5×10^{-4}	1.003

VM259: Missing Mass with Rigid Responses Effects in Spectrum Analysis for BM3 Piping Model

Overview

Reference:	R. Morante, Y. Wang,*Reevaluation of regulatory guidance on modal response combination methods for seismic response spectrum analysis* (NUREG/CR-6645), Brookhaven National Laboratory, Dec 1999.
Analysis Type(s):	Spectrum analysis (**ANTYPE** = 8)
Element Type(s):	Elastic straight pipe elements (PIPE16) Elastic curved pipe elements (PIPE18) Spring-damper elements (COMBIN14)
Input Listing:	vm259.dat

Test Case

The BM3 piping model is meshed with PIPE16 and PIPE18 elements. The model is supported by elastic spring-damper elements (COMBIN14). Lumped mass matrix formulation is used in the modal analysis (**LUMPM**). Single point response spectrum analysis is then performed with an acceleration input spectra defined by 75 points (**FREQ** and **SV**). The first 14 modes are included in the spectrum analysis. The model is excited in X direction and the modal responses are combined using **SRSS** mode combination method with displacement solution output. The analysis is performed for three cases:

1. With missing mass effect (ZPA=0.54g).

2. With missing mass (ZPA=0.54g) and rigid responses effect (Lindley Method).

3. With missing mass (ZPA=0.54g) and rigid responses effect (Gupta Method, F1=2.8Hz and F2=6.0Hz).

Figure 259.1: Missing Mass with Rigid Response for BM3 Piping Model

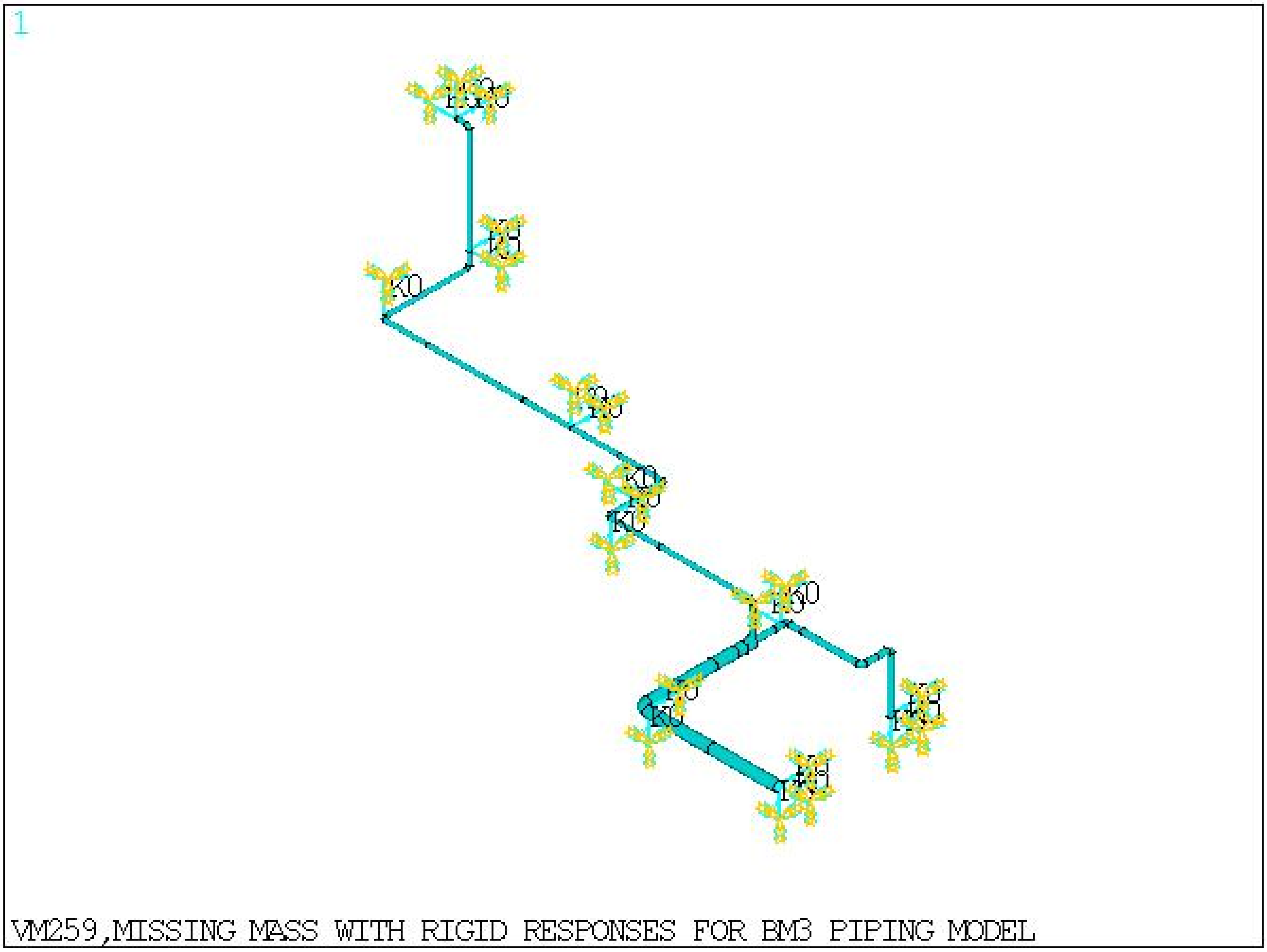
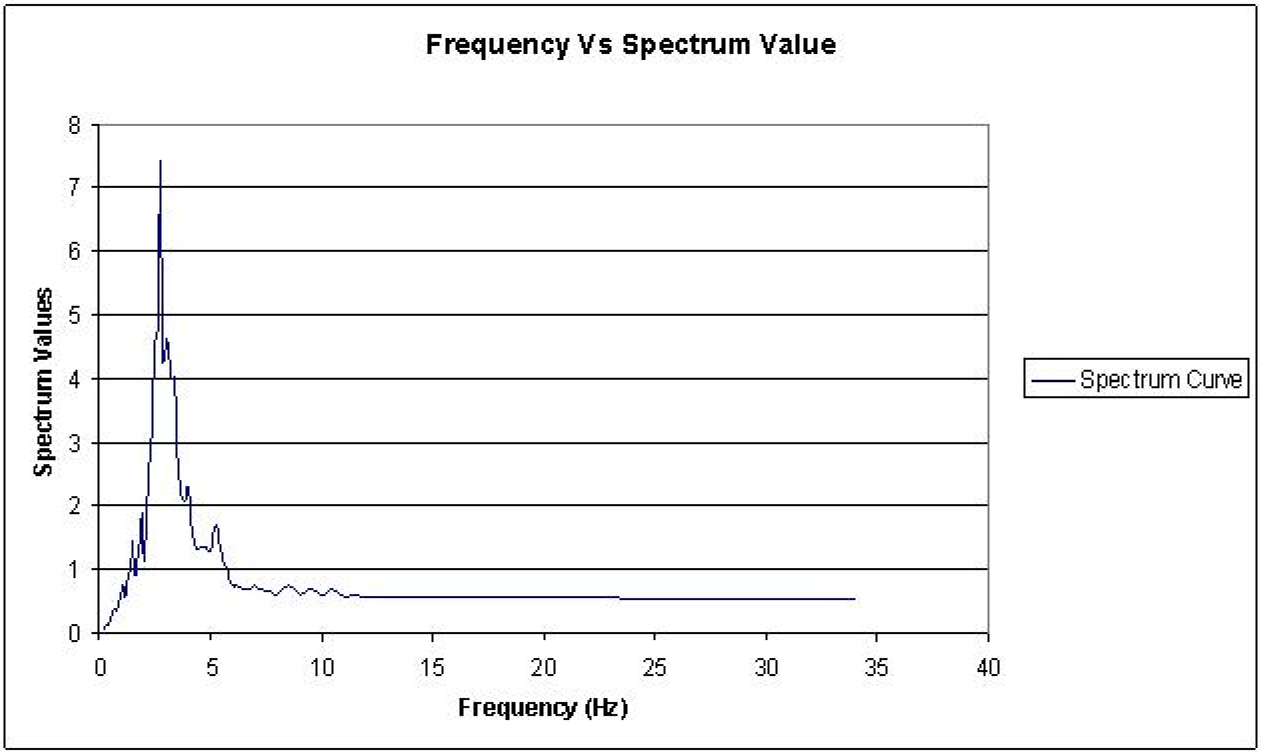


Table 259.1: Frequency versus Spectral values

Frequency (Hz)	Spectrum Values	Frequency (Hz)	Spectrum Values
0.2	0.06	2.1	1.18
0.3	0.13	2.2	2.65
0.4	0.13	2.3	2.85
0.5	0.2	2.4	3.26
0.6	0.35	2.5	4.47
0.7	0.39	2.6	4.75
0.8	0.37	2.7	5.29
0.9	0.41	2.8	7.44
1	0.76	2.9	4.27
1.1	0.64	3	4.61
1.2	0.59	3.15	4.13
1.3	0.91	3.3	3.96
1.4	1.03	3.45	4.05

1.5	1.46	3.6	2.44
1.6	0.95	3.8	2.09
1.7	0.91	4	2.29
1.8	1.61	4	2.29
1.9	1.92	4.2	1.52
2	1.57	4.4	1.34
4.6	1.37	10.5	0.7
4.8	1.36	11	0.59
5	1.31	11.5	0.61
5.25	1.69	12	0.56
5.5	1.27	12.5	0.59
5.75	1.04	13	0.59
6	0.76	13.5	0.59
6.25	0.76	14	0.58
6.5	0.69	14.5	0.59
6.75	0.7	15	0.58
7	0.74	16	0.55
7.25	0.7	17	0.56
7.5	0.67	18	0.55
7.75	0.66	20	0.55
8	0.61	22	0.55
8.5	0.75	25	0.54
9	0.6	28	0.54
9.5	0.69	31	0.54
10	0.61	34	0.54

Figure 259.2: Frequency Vs Spectrum Value



Material Properties	Geometric Properties	Loading
Straight Pipe: E = 2.9E+7 lb/inch^2 Nu = 0.3 DENS = 1.043e-03 lb-sec^2/in^4 Curved Pipe E = 2.9E+7 lb/inch^2 Nu = 0.3 DENS = 1.043e-03 lb-sec^2/in^4 Spring-damper element K = 1.0e5 lb/inch	Straight pipe: (PIPE16) Type 1, real 1 OD = 3.500 in. Wall Thickness = 0.2160 in. Type 2, real 2 OD = 4.5000 in. Wall Thickness = 0.2370 in. Type 3, real 3 OD = 8.625 in. Wall Thickness = 0.3220 in. Curved Pipe: (PIPE18) Type 4, real 4 OD = 3.500 in. Wall Thickness = 0.2160 in. Radius of Curvature = 4.500 in.	Spectrum curve Refer to the above defined (frequency versus spectrum values) table.

	Type 5, real 5 in. OD = 4.5000 in. Wall Thickness = 0.2370 in. Radius of Curvature = 6.000 in. Type 6, real 6 OD = 8.625 in. Wall Thickness = 0.3220 in. Radius of Curvature = 12.000 in.	

Analysis Assumptions and Modeling Notes

Node coordinates and element characteristics are given in appendix A of the reference document cited in the "Overview" (p. 737). The same mesh is used in the analysis.

Frequencies obtained from the modal analysis and reaction forces at supports obtained from the spectrum analyses are compared with the reference solutions.

The reaction moments are not compared since the rotational degrees of freedom for curved pipe elements (PIPE18) are not included in the lumped mass matrix formulation.

Results Comparison

	Target	Mechanical APDL	Ratio
Frequencies from the Modal Analysis			
Mode1	2.9100	2.9068	0.999
Mode2	4.3900	4.3837	0.999
Mode3	5.5200	5.5151	0.999
Mode4	5.7000	5.7018	1.000
Mode5	6.9800	6.9784	1.000
Mode6	7.3400	7.3427	1.000
Mode7	7.8800	7.8778	1.000
Mode8	10.3000	10.3961	1.009
Mode9	11.0600	11.0623	1.000
Mode10	11.2300	11.2323	1.000
Mode11	11.5000	11.5321	1.003
Mode12	12.4300	12.4550	1.002
Mode13	13.8800	13.9647	1.006
Mode14	16.1200	16.0920	0.998
Reaction forces at support (Spectrum analysis performed with missing mass)			
FX @ node 1	48.0810	48.1800	1.002

FY @ node 1	5.4936	5.1448	0.937
FZ @ node 1	7.5840	6.9158	0.912
FX @ node 31	50.6460	50.1255	0.990
FY @ node 31	24.7975	24.6392	0.994
FZ @ node 31	31.6776	30.9949	0.978
Reaction forces at support (Spectrum analysis performed with missing mass and rigid responses –Lindley method)			
FX @ node 1	46.3326	46.2160	0.997
FY @ node 1	3.7060	3.5776	0.965
FZ @ node 1	3.5360	3.2326	0.914
FX @ node 31	56.1510	56.6833	1.009
FY @ node 31	17.8542	17.8872	1.002
FZ @ node31	22.9944	22.4446	0.976
Reaction forces at support (Spectrum analysis performed with missing mass and rigid responses – Gupta method)			
FX @ node 1	45.4300	45.4499	1.000
FY @ node 1	3.0800	3.0720	0.997
FZ @ node 1	1.3400	1.3123	0.979
FX @ node 31	56.0600	55.9803	0.999
FY @ node 31	14.1900	14.3237	1.009
FZ @ node31	13.9500	13.8867	0.995

VM260: Two-Dimensional Consolidation Settlement Problem

Overview

Reference:	Schiffman, A. et al. "An Analysis of Consolidation Theories." *Journal of Solid Mechanics and Foundation Division*. (1969): 285-312.
Analysis Type:	Static (**ANTYPE**,0)
Element Type(s):	2-D 4-Node Coupled Pore-Pressure Mechanical Solid Element (CPT212) 2-D 8-Node Coupled Pore-Pressure Mechanical Solid Element (CPT213)
Input Listing:	vm260.dat

Test Case

An infinite rectangular half space plate is modeled with dimensions 12a by 9a. Pressure loading is applied on the center of the top surface (on one sixth of the total width). The top surface is made permeable and bottom surface is impermeable. Evolution of pore pressure computed with respect to depth and time are compared with reference values.

Nomenclature Used in This Problem

P = Pore pressure

Tv = $C_{Vc} t / a^2$

Tv = Time Factor

C_{Vc} = Consolidation coefficient

t = Time

Figure 260.1: Problem Sketch

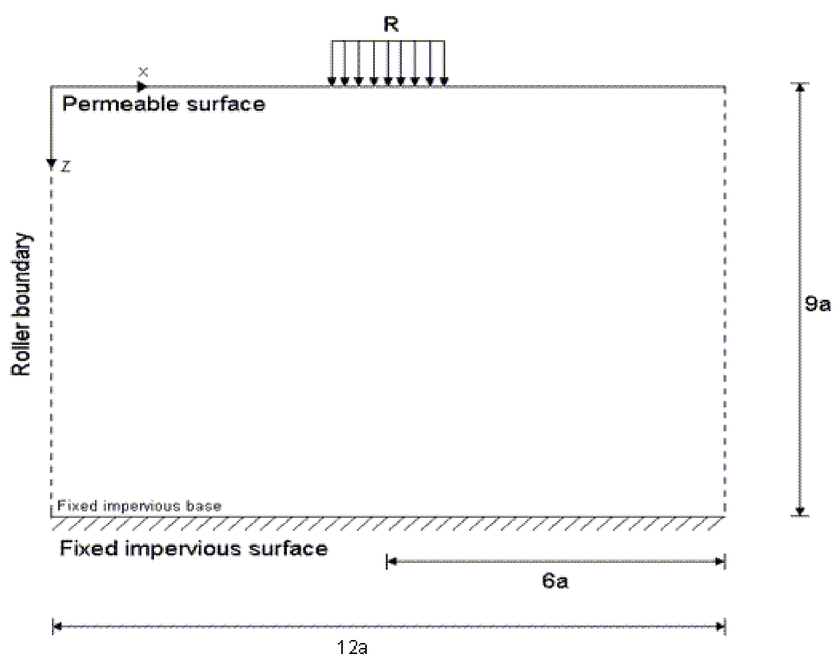
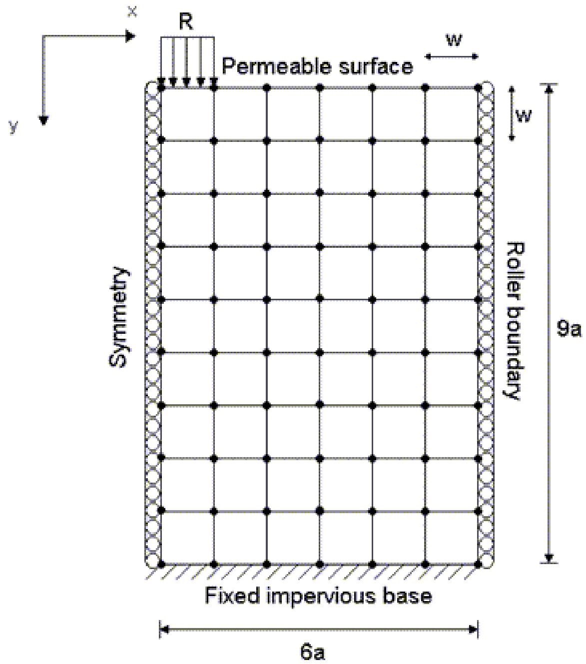


Figure 260.2: Two-Dimensional Consolidation Pore-Pressure Problem -- Representative Finite Element Model



Material Properties	Geometric Properties	Loading
E = 1000 Pa μ = 0.0 k = 0.267×10^{-4} t = 374530s	a = 1 m w = 1 m	R = 100 Pa

Analysis Assumptions and Modeling Notes

The plate is meshed using (CPT212) and (CPT213) elements with plane strain conditions. Permeability and Biot coefficients are defined to the material model using **TBDATA** command. Bottom surface is fixed in all directions and displacements along X directions are constrained on the right and left edges. Non-linear static analysis is then performed to compute the evolution of pore pressure with respect to time and depth.

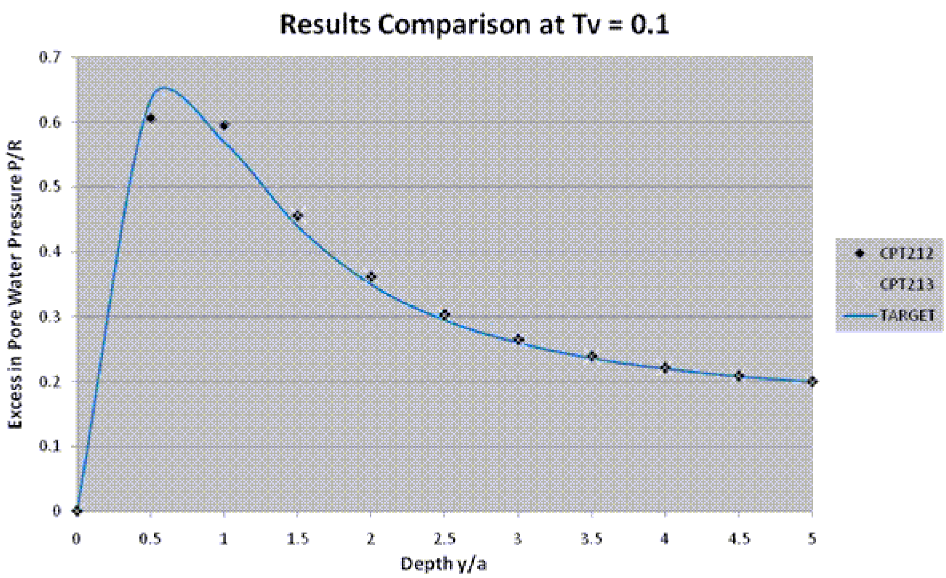
Results Comparison for the Evolution of P with Depth

	za	Target	Mechanical APDL	Ratio
P/R (*CPT212*)	0	0.0000	0.0000	1.000
	0.5	0.6350	0.6053	1.049
	1	0.5700	0.5962	0.956
	1.5	0.4400	0.4555	0.966
	2	0.3500	0.3615	0.968
	2.5	0.2950	0.3029	0.974
	3	0.2600	0.2648	0.982
	3.5	0.2360	0.2390	0.988

	4	0.2200	0.2211	0.995
	4.5	0.2080	0.2087	0.997
	5	0.2000	0.2000	1.000

	za	Target	Mechanical APDL	Ratio
P/R (*CPT213*)	0	0.0000	0.0000	1.000
	0.5	0.6350	0.5983	1.061
	1	0.5700	0.6031	0.945
	1.5	0.4400	0.4578	0.961
	2	0.3500	0.3625	0.965
	2.5	0.2950	0.3037	0.971
	3	0.2600	0.2653	0.980
	3.5	0.2360	0.2394	0.986
	4	0.2200	0.2214	0.994
	4.5	0.2080	0.2089	0.996
	5	0.2000	0.2001	0.999

Figure 260.3: Evolution of Excess Pore Water Pressure with Respect to Depth



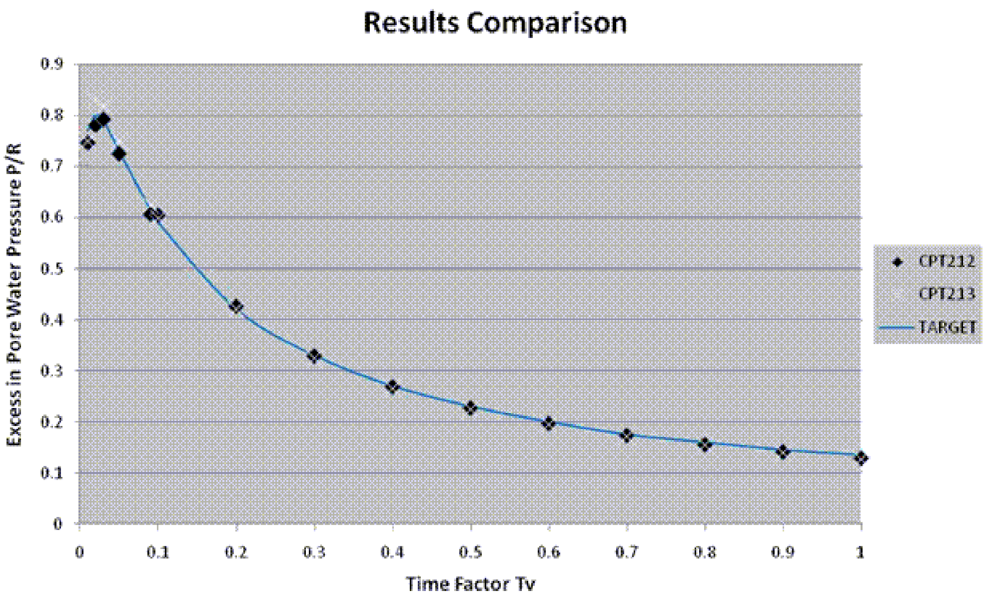
Results Comparison for the Evolution of P with Time

	Tv (za)	Target	Ansys	Ratio
P/R (CPT212)	0.01	0.7700	0.7466	1.031
	0.02	0.8000	0.7812	1.024
	0.03	0.7900	0.7928	0.996
	0.05	0.7300	0.7257	1.006
	0.09	0.6150	0.6072	1.013

	0.1	0.5900	0.6053	0.975
	0.2	0.4200	0.4267	0.984
	0.3	0.3300	0.3294	1.002
	0.4	0.2700	0.2687	1.005
	0.5	0.2300	0.2271	1.013
	0.6	0.2000	0.1969	1.016
	0.7	0.1750	0.1739	1.006
	0.8	0.1600	0.1558	1.027
	0.9	0.1450	0.1412	1.027
	1.0	0.1350	0.1291	1.046

	Tv (za)	**Target**	**Ansys**	**Ratio**
P/R (CPT213)	0.01	0.7700	0.7509	1.025
	0.02	0.8000	0.8298	0.964
	0.03	0.7900	0.8171	0.967
	0.05	0.7300	0.7497	0.974
	0.09	0.6150	0.6242	0.985
	0.1	0.5900	0.5983	0.986
	0.2	0.4200	0.4215	0.996
	0.3	0.3300	0.3258	1.013
	0.4	0.2700	0.2660	1.015
	0.5	0.2300	0.2251	1.022
	0.6	0.2000	0.1953	1.024
	0.7	0.1750	0.1725	1.014
	0.8	0.1600	0.1546	1.035
	0.9	0.1450	0.1402	1.034
	1.0	0.1350	0.1282	1.053

Figure 260.4: Evolution of Excess Pore Water Pressure with Respect to Time



VM261: Rotating Beam with Internal Viscous Damping

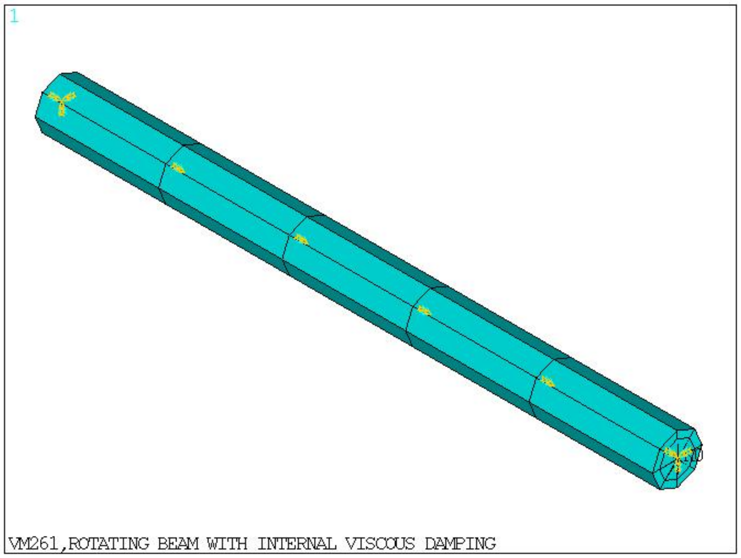
Overview

Reference:	E.S. Zorzi, H.D. Nelson, "Finite element simulation of rotor-bearing systems with internal damping", ASME Journal of Engineering for Power, Vol. 99, 1976, pg 71-76.
Analysis Type(s):	Modal Analysis (**ANTYPE** = 2)
Element Type(s):	3–D 2 node beam (BEAM188) 2–D spring damper elements (COMBI214)
Input Listing:	vm261.dat

Test Case

A beam with internal viscous damping is simply supported by means of two isotropic undamped bearings. Modal analysis is performed with multiple load steps to determine the critical speeds and logarithmic decrement of the system.

Figure 261.1: Rotating Beam With Internal Viscous Damping



Material Properties	**Geometric Properties**	**Loading**
Beam model E = 2.10E11 Pa GXY = 2.10E14 Pa DENS = 7800 Kg/m^3 Nu = 0.3	Beam length = 1.27m Beam diameter = 0.1016m	Rotational velocity 1^{st} load step = 0 rpm 2^{nd} load step = 1241.409 rpm 3^{rd} load step = 2492.366 rpm

Bearing stiffness Kyy = 1.75E+07 N/m Kzz = 1.75E+07 N/m		4th load step = 3743.324 rpm 5th load step = 5149.458 rpm 6th load step = 6245.240 rpm 7th load step = 7496.198 rpm 8th load step = 8747.156 rpm 9th load step = 9998.114 rpm 10th load step = 11249.071 rpm 11th load step = 12500.029 rpm 12th load step = 13789.184 rpm 13th load step = 14992.396 rpm

Analysis Assumptions and Modeling Notes

The beam is modeled as an assembly of five equal length finite elements and meshed with BEAM188 elements. Internal viscous damping is included in the model as a material property using **MP**,BETD command. Modal analysis is performed using QR Damp eigensolver. Axial motion and rotation are suppressed to avoid any torsion or traction related displacements.

Separate element material attribute pointer is assigned to bearing elements to avoid material property of beam being carried over to the bearing elements. Gyroscopic damping and rotating damping are activated by using **CORIOLIS** command turned on in a stationary reference frame.

The critical speeds for a synchronous excitation (slope = 1) and logarithmic decrements of the first two unstable frequencies after first and second critical speeds are determined and compared against reference values of case1 (a). The logarithmic decrement values are obtained from Figure 3.

Results Comparison

	Target	Mechanical APDL	Ratio
1st forward critical speed (rpm)	4950	5107.3538	1.032

	Target	Mechanical APDL	Ratio
2nd forward critical speed (rpm)	10500	10693.6863	1.018
Logarithmic decrement for 1st unstable frequency after critical speed	0.0010	0.0010	0.989
Logarithmic decrement for 2nd unstable frequency after critical speed	0.0103	0.0099	0.964

VM262: Two-Dimensional Fractural Problem under Thermal Loading

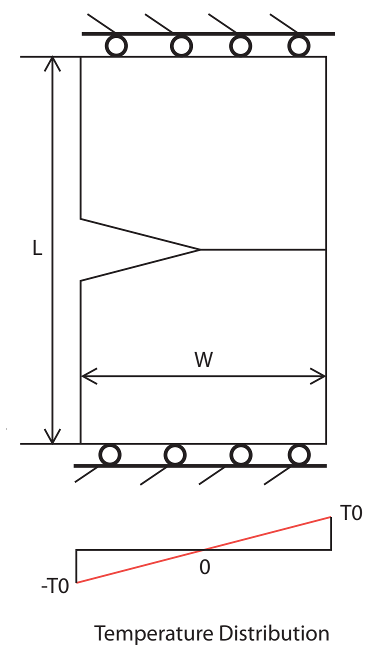
Overview

Reference:	Wilson, W.K. et al. "The Use of the J-integral in Thermal Stress Crack Problems." International Journal of Fracture. (1979): 377-387.
Analysis Type(s):	Static (**ANTYPE** = 0)
Element Type(s):	2-D Structural Solid Elements (PLANE182)
Input Listing:	vm262.dat

Test Case

The problem deals with an edge cracked strip with its ends constrained. The strip is subject to a linear temperature gradient through the thickness starting with zero at mid thickness and reaching its final value T0 at the right end edge. Stress intensity factor for the cracked strip is calculated and compared against analytical value.

Figure 262.1: Two-Dimensional Fractural Problem Sketch



Material Properties	Geometric Properties	Loading
E=1e5Pa μ=0.3 thermal expansion α=1e-4	Crack length = 1m L= 4m W= 2m	T0=10degree

Analysis Assumptions and Modeling Notes

The problem is solved using 2-D PLANE182 element with plain strain element behavior. A half plate is modeled and symmetry boundary conditions are considered. The crack tip nodes and the number of paths surrounding the crack tip nodes are defined using **CINT** command. The plate is subjected to linear temperature loading and the J integral values are computed for the crack tip node. From the J integral values the stress intensity factor KI is calculated.

Results Comparison

	Target	Mechanical APDL	Ratio
Stress intensity KI	126.604	128.633	1.016

VM263: Critical Speeds for a Rotor Bearing System with Axisymmetric Elements

Overview

Reference:	H.D. Nelson and J.M. McVaugh, "The dynamics of Rotor-Bearing System using Finite Elements", Journal of Engineering for industry, May 1976, pg: 593-600.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2)
Element Type(s):	General axisymmetric solid with 4 base nodes (SOLID272) General Axisymmetric Solid with 8 Base Nodes (SOLID273) 2D spring damper elements (COMBI214)
Input Listing:	vm263.dat

Test Case

A rotor-bearing system is analyzed to determine the whirl speeds. The distributed rotor was modeled as a configuration of six elements with each element composed of sub elements. See Table 263.1: Geometric data for rotor-bearing elements for a list of data for the elements. Two undamped linear bearings were located at positions four and six. A modal analysis is performed with multiple load steps to determine the critical speeds for the system.

Figure 263.1: Isometric view of rotor-bearing system without/ESHAPE (2D element plot)

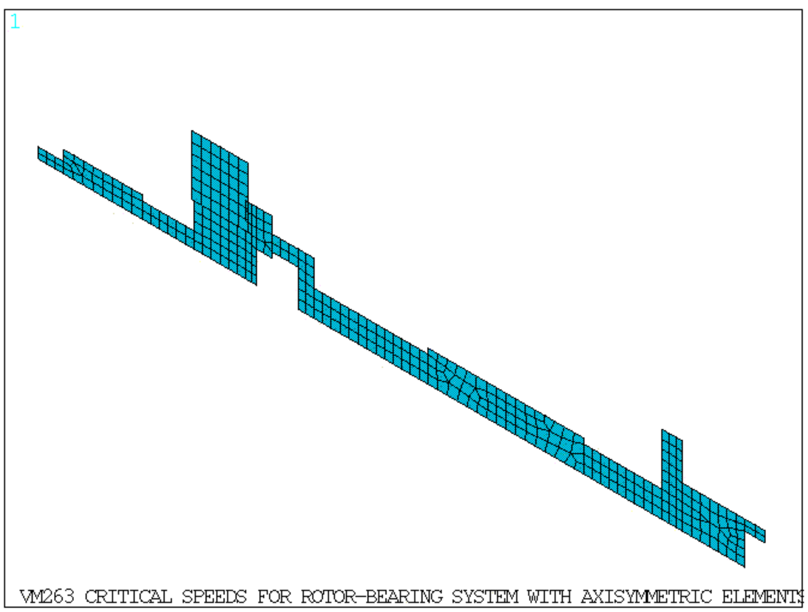


Figure 263.2: Isometric view of rotor-bearing system with /ESHAPE

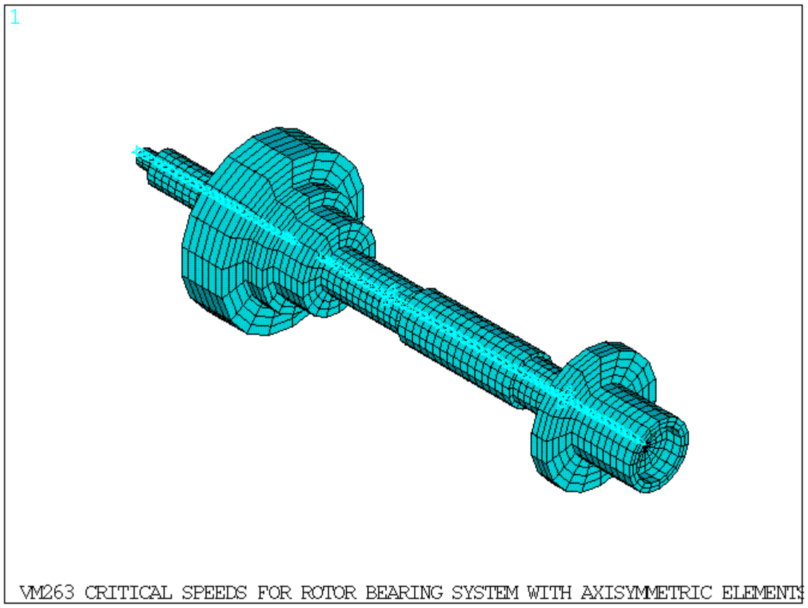


Table 263.1: Geometric Data of Rotor-Bearing Elements

Element No.	Subelement No.	Axial Distance to Subelement (cm)	Inner Diameter (cm)	Outer Diameter (cm)
1	1	0.00		0.51
	2	1.27		1.02
2	1	5.08		0.76
	2	7.62		2.03
3	1	8.89		2.03
	2	10.16		3.30
	3	10.67	1.52	3.30
	4	11.43	1.78	2.54
	5	12.70		2.54
	6	13.46		1.27
4	1	16.51		1.27
	2	19.05		1.52
5	1	22.86		1.52
	2	26.67		1.27
6	1	28.70		1.27
	2	30.48		3.81
	3	31.50		2.03
	4	34.54	1.52	203

Material Properties	Geometric Properties	Loading
Shaft and Disc:	Shaft:	Rotational velocity:

E = 2.078E11 Pa DENS = 7800 Kg/m^3 Nu = 0.3 Bearing stiffness: Kyy = 4.378E+07 N/m Kzz = 4.378E+07 N/m	Refer to Table 263.1 Disc: Thickness = 0.028 m Outer Radius = 0.0495 m Inner Radius = 0.0203 m	1st load step = 0 rpm 2nd load step = 10,000 rpm 3rd load step = 20,000 rpm 4th load step = 40,000 rpm 5th load step = 60,000 rpm 6th load step = 80,000 rpm 7th load step = 100,000 rpm

Analysis Assumptions and Modeling Notes

Both the shaft and the disc are modeled using SOLID272 and SOLID273 elements with 3 Fourier nodes in the circumferential direction. The thickness, outer radius and inner radius of the disc are adjusted to match the mass and moment of inertia of the mass element used in the reference. Two symmetric bearings along the global Y and Z directions are modeled using COMBIN14 elements.

A modal analysis is performed on the rotor-bearing system with multiple load steps using DAMP eigensolver to determine the whirl speeds and Campbell values. The translational displacements along X are constrained so that the system does not have axial motion. The gyroscopic effect is activated by turning the **CORIOLIS** command on in a stationary reference frame. The whirl speeds for slopes (excitation per revolution) 2.0 and 4.0 are determined and compared with analytical solutions.

Results Comparison

General Axisymmetric Solid with 4 Base Nodes SOLID272			
	Target	**Mechanical APDL**	**Ratio**
Whirl Speeds for slope = 2			
Mode 1	7929.000	7719.9497	0.974
Mode 2	8350.000	8146.1707	0.976
Mode 3	23760.000	23317.7264	0.981
Mode 4	24602.000	24165.6259	0.982
Mode 5	34820.000	33134.6333	0.952
Mode 6	42776.000	41781.0824	0.977
Whirl Speeds for slope = 4			
Mode 1	4015.000	3911.2392	0.974

General Axisymmetric Solid with 4 Base Nodes SOLID272			
	Target	**Mechanical APDL**	**Ratio**
Mode 2	4120.250	4017.7426	0.975
Mode 3	11989.250	11771.3739	0.982
Mode 4	12200.000	11982.9960	0.982
Mode 5	18184.250	17444.9128	0.959
Mode 6	20162.250	19649.5921	0.975

General Axisymmetric Solid with 8 Base Nodes SOLID273			
	Target	**Mechanical APDL**	**Ratio**
Whirl Speeds for slope = 2			
Mode 1	7929.000	7679.3371	0.969
Mode 2	8350.000	8110.3169	0.971
Mode 3	23760.000	23282.9012	0.980
Mode 4	24602.000	24161.7737	0.982
Mode 5	34820.000	33042.4881	0.949
Mode 6	42776.000	41441.8109	0.969
Whirl Speeds for slope = 4			
Mode 1	4015.000	3891.4540	0.969
Mode 2	4120.250	3999.1437	0.971
Mode 3	11989.250	11757.9809	0.981
Mode 4	12200.000	11977.3914	0.982
Mode 5	18184.250	17381.6411	0.956
Mode 6	20162.250	19527.4357	0.969

VM264: Terzaghi's One-Dimensional Consolidation Settlement Problem

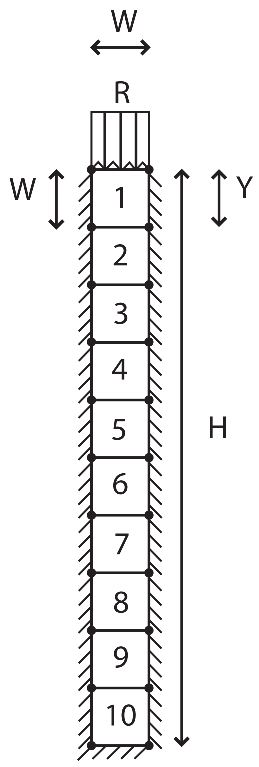
Overview

Reference:	K. Terzaghi, Theoretical Soil Mechanics, Wiley New York, 1942.
Analysis Type(s):	Static analysis (**ANTYPE** = 0)
Element Type(s):	2D 8-Node Coupled Pore-Pressure Element (CPT213) 3D 8-Node Coupled Pore-Pressure Element (CPT215) 3D 20-Node Coupled Pore-Pressure Element (CPT216) 3D 10-Node Coupled Pore-Pressure Element (CPT217)
Input Listing:	vm264.dat

Test Case

The problem deals with consolidation of an infinite half-space idealized as a one-dimensional situation. The top surface is permeable and the bottom surface is impermeable. Pressure is applied at the top of a vertically stacked element pile. The distribution of pressure along the depth is computed and compared against reference solution.

Figure 264.1: Problem Sketch



Material Properties	Geometric Properties	Loading
E = 5.8E5 Pa	Height H=10m	Pressure R =10 Pa
Nu = 0.0	Width W=1m	

Permeability k=8.62E-3 m/s		

Analysis Assumptions and Modeling Notes

The problem is modeled and solved with two dimensional (CPT213) and three dimensional (CPT215), (CPT216), (CPT217) coupled pore pressure elements. The UZ degrees of freedom in the 3-D model are constrained to make it behave like 2-D elements. Displacements along X direction are constrained on all nodes and displacements along Y direction are constrained at the bottom surface. The top edge is made pore pressure free (pressure=0). Static analysis is performed with unsymmetric Newton-Raphson option with an end time of 0.02s and the distribution of pore pressure along the depth is computed.

Results Comparison

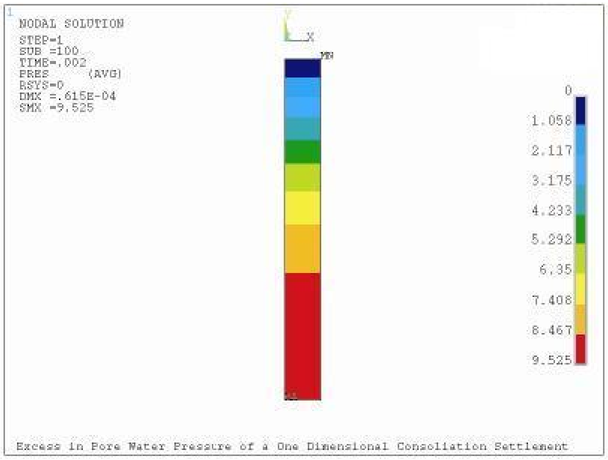
2D 8-Node Couple Pore-Pressure Element CPT213			
Y/H (Depth)	P/R (Pre Pressure)		
	Target	Mechanical APDL	Ratio
0. 1	0.180	0.176	0.982
0.2	0.350	0.345	0.986
0.3	0.500	0.497	0.996
0.4	0.630	0.629	0.999
0.5	0.740	0.737	0.996
0.6	0.820	0.820	1.001
0.7	0.890	0.881	0.991
0.8	0.930	0.922	0.992
0.9	0.940	0.945	1.006
1.0	0.950	0.952	1.003

3D 8-Node Couple Pore-Pressure Element CPT215			
Y/H (Depth)	P/R (Pre Pressure)		
	Target	Mechanical APDL	Ratio
0. 1	0.180	0.181	1.008
0.2	0.350	0.345	0.988
0.3	0.500	0.498	0.996
0.4	0.630	0.629	0.999
0.5	0.740	0.736	0.996
0.6	0.820	0.819	1.000
0.7	0.890	0.880	0.989
0.8	0.930	0.920	0.990
0.9	0.940	0.943	1.003
1.0	0.950	0.950	1.001

3D 8-Node Couple Pore-Pressure Element CPT216			
Y/H (Depth)	P/R (Pre Pressure)		
	Target	Mechanical APDL	Ratio
0. 1	0.180	0.176	0.982
0.2	0.350	0.345	0.986
0.3	0.500	0.497	0.996
0.4	0.630	0.629	0.999
0.5	0.740	0.737	0.996
0.6	0.820	0.820	1.001
0.7	0.890	0.881	0.991
0.8	0.930	0.922	0.992
0.9	0.940	0.945	1.006
1.0	0.950	0.952	1.003

3D 10-Node Couple Pore-Pressure Element CPT217			
Y/H (Depth)	P/R (Pre Pressure)		
	Target	Mechanical APDL	Ratio
0. 1	0.180	0.173	0.963
0.2	0.350	0.348	0.996
0.3	0.500	0.500	1.001
0.4	0.630	0.631	1.002
0.5	0.740	0.737	0.996
0.6	0.820	0.820	1.000
0.7	0.890	0.881	0.991
0.8	0.930	0.922	0.992
0.9	0.940	0.945	1.006
1.0	0.950	0.952	1.003

Figure 264.2: Pore pressure contour plot along the depth usingCPT213 element



VM265: Elastic Rod Impacting a Rigid Wall

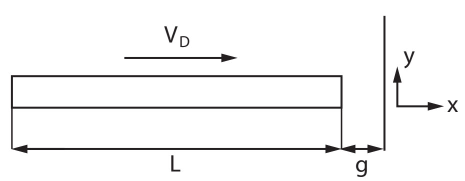
Overview

Reference:	N.J.Carpenter, R.L. Taylor and M.G. Katona, "Lagrange Constraints For Transient Finite Element Surface Contact", International Journal for Numerical Methods in Engineering, vol.32, 1991. pg 103-128.
Analysis Type(s):	Transient Analysis (**ANTYPE** = 4)
Element Type(s):	4-Node Structural Shell (SHELL181) 3-D Line-To-Surface Contact (CONTA177) 3-D Target Segment (TARGE170)
Input Listing:	vm265.dat

Test Case

A linear elastic prismatic rod is moving with an initial velocity and is impacting a rigid wall. The shock wave created from impact travels as a compression wave through the rod. During this time, the rod remains in contact with the rigid wall. The compression wave is then reflected as a dilatational wave upon reaching the free end of the rod and travels back to the contact surface. The rod gets separated from the rigid wall once the dilatational wave reaches the contact surface. The time at impact and at separation is determined from the analysis along with corresponding displacements, velocities and normal contact forces at the contact surface and compared to the solutions given in the reference. The time history plots are also compared to the reference plots.

Figure 265.1: Problem Sketch



Material Properties	Geometric Properties	Loading
E=3.0E+7 psi	L=10 in	V_0 = 202.2 in/sec^2
ν = 0.3	g = 0.01 in	
ρ = 0.73 lbf sec^2 / in^4	A = 1 in^2	

Analysis Assumptions and Modeling Notes

The elastic rod is modeled by 20 equal length SHELL181 elements with thickness of 1 in. All the DOF of the rod are constrained except for the axial one (allowing it to move in x direction) and an initial velocity in this direction is imposed on all nodes. A nonlinear transient dynamic analysis is performed using the full method with HHT algorithm and zero numerical damping. To model proper energy and momentum transfer between the rigid wall and the contact surface, impact constraints were enforced by using key option (7) = 4 for CONTA177.The final time and the uniform time step increment of 0.2226E-5 are chosen as mentioned in the reference. Displacements and normal contact forces at the upper right end contact node and center of mass velocities are obtained for time at impact and release and compared against the reference values.

Results Comparison

		Target	Mechanical APDL	Ratio
At Impact	Time, sec	0.00005	0.00005	1.001
	X displacement, in	0.01000	0.01000	1.000
	X velocity, in/sec	202.20000	202.20000	1.000
	Force, lb	0.00000	0.00000	1.000
At Release	Time, sec	0.00015	0.00015	0.987
	X displacement, in	0.01000	0.01009	1.009
	X velocity, in/sec	-202.20000	-197.78722	0.978
	Force, lb	0.00000	0.00000	1.000

Figure 265.2: Time history of contact surface displacement

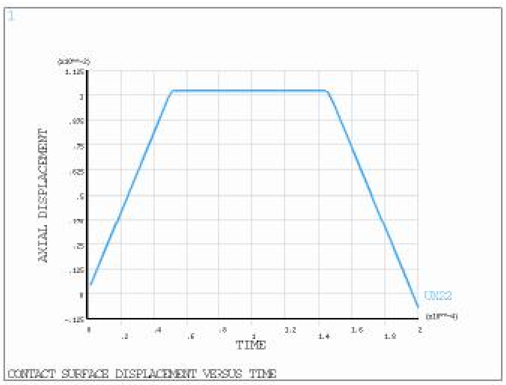


Figure 265.3: Time history of contact surface velocity

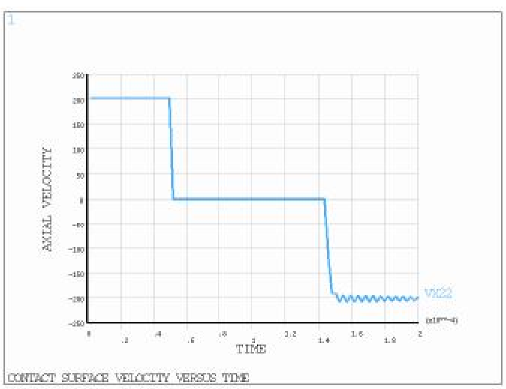


Figure 265.4: Time history of normal contact force

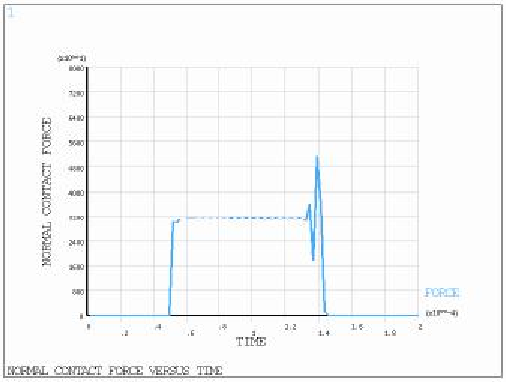
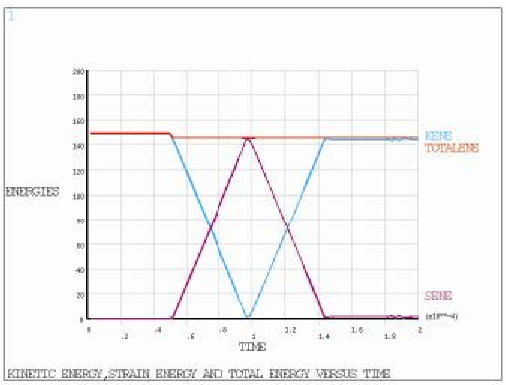


Figure 265.5: Time history of kinetic energy, strain energy and total energy



VM266: 3-D Crossing Beams in Contact with Friction

Overview

Reference:	G. Zavarise and P. Wriggers, " Contact with friction between beams in 3-D space", International Journal for Numerical Methods in Engineering, 2000, vol.49, pg: 977-1006.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D 2-Node Beam (BEAM188) 3-D Line-To-Line Contact (CONTA176) 3-D Target Segment (TARGE170)
Input Listing:	vm266.dat

Test Case

Two orthogonal beams with similar cross section and with an initial out-of-plane displacement are brought into contact by undergoing large displacements in 3-D space. Normal and frictional contact forces are calculated at 0.5, 0.66, 0.83, and 1 second, and then compared against reference values.

Figure 266.1: Front view and lateral view of the crossing beams

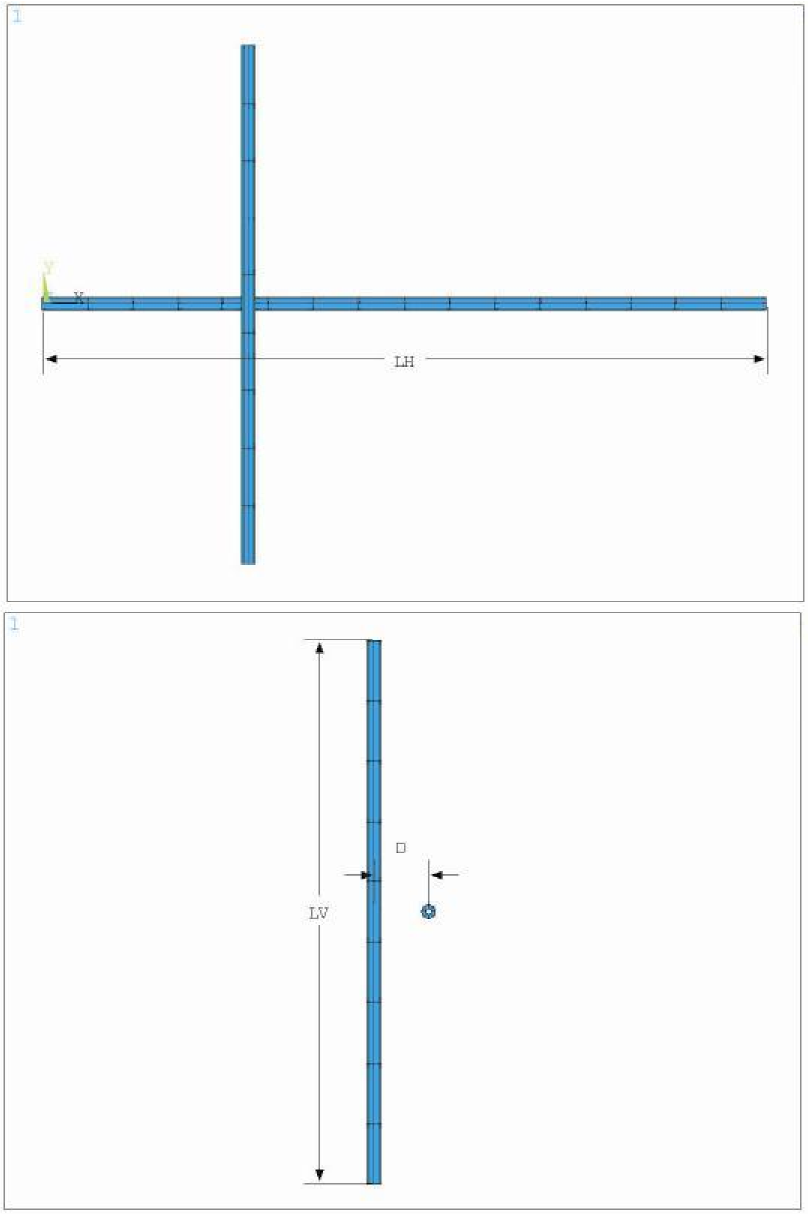
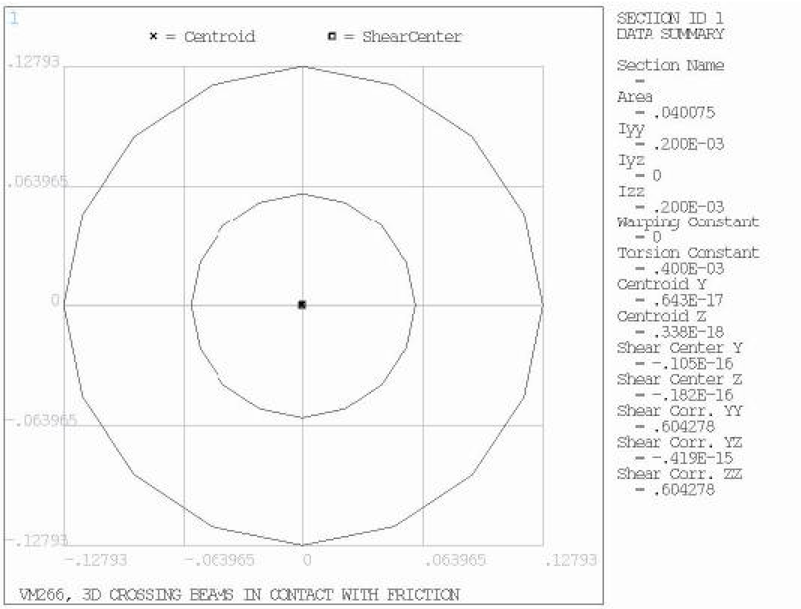


Figure 266.2: Geometry and properties of the cross sections



Material Properties	Geometric Properties	Loading
E=1.0 E+8 psi ν = 0.0 μ = 0.1	LH=14 in LV=10 in D = 1 in Cross-Section properties: Ri = 0.06 in Ro = 0.12793 in A = 4.0 E-2 in^2 I_{yy} = I_{zz} =2.0 E-4 in^4	U_x = 0.18 in U_z = 1.8 in

Analysis Assumptions and Modeling Notes

The beams are modeled using quadratic shape functions with 16 equal length elements for the horizontal beam and 9 equal length elements for the vertical beam. The vertical beam is clamped at both ends and the horizontal beam has the left end free and restrained in all DOF at the right end except for the translational and out of plane directions. Displacement loading is applied at the right end of the horizontal beam to bring both the beams into contact. Target elements (TARGE170) are defined on the vertical beam and the contact elements (CONTA176) are defined on the horizontal beam with penalty algorithm. A friction coefficient of 0.1 and penalty values for normal and tangential contact of 1.0E+4 are chosen according to the reference data. The normal and frictional contact force are then calculated at different time steps and compared against reference.

The model is solved again using traction based crossing beam contact: KEYOPT (3) = 3. An area factor, A = 5.71425 is used to scale the traction-based contact definition from the force-based contact definition.

It has units m^{-2} and is determined from the contact radius and element length (l): A = 1/(rl). This factor is used to scale the penalty values and results so that they use proper units.

Results Comparison

		Target	Mechanical APDL	Ratio
Normal Contact Force	NFORCE3 (t = 0.5s)	17.000	17.177	1.010
	NFORCE4 (t = 0.66s)	33.800	34.030	1.007
	NFORCE5 (t = 0.83s)	50.400	50.440	1.001
	NFORCE6 (t= 1s)	67.000	66.295	0.989
Frictional Contact Force	TFORCE3 (t = 0.5s)	1.700	1.717	1.010
	TFORCE4 (t = 0.66s)	3.380	3.403	1.007
	TFORCE5 (t = 0.83s)	5.040	5.044	1.001
	TFORCE6 (t= 1s)	6.700	6.629	0.989
Traction Based Contact – Normal Pressure	NPRES3 (t = 0.5s)	97.1422	98.1578	1.010
	NPRES4 (t = 0.66s)	193.1416	194.4582	1.008
	NPRES5 (t = 0.83s)	287.9982	288.2287	1.001
	NPRES6 (t= 1s)	382.8547	378.8312	0.989
Traction Based Contact - Frictional Pressure	TPRES3 (t = 0.5s)	9.7142	9.8158	1.010
	TPRES4 (t = 0.66s)	19.3142	19.4458	1.008
	TPRES5 (t = 0.83s)	28.7998	28.8229	1.001
	TPRES6 (t= 1s)	38.2855	37.8831	0.989

VM267: Inclined Crack in 2-D Plate under Uniform Tension Loading

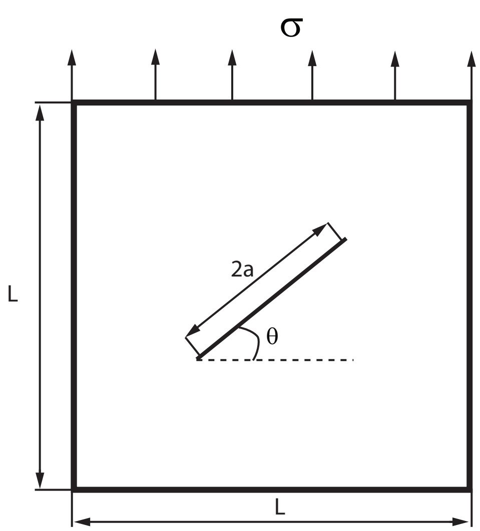
Overview

Reference:	T.L. Anderson, Fracture Mechanics: Fundamentals and applications, CRC Press, Boca Raton, FL, 1995.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4 node structural solid (PLANE182)
Input Listing:	vm267.dat

Test Case

A 2D plate with length L is subjected to uniform tension loading. An inclined crack of length 2a is modeled with an angle of (30° - θ) between the crack surface and loading direction. Stress intensity factors are computed using **CINT**, SINF command.

Figure 267.1: Problem sketch for 2-D inclined crack

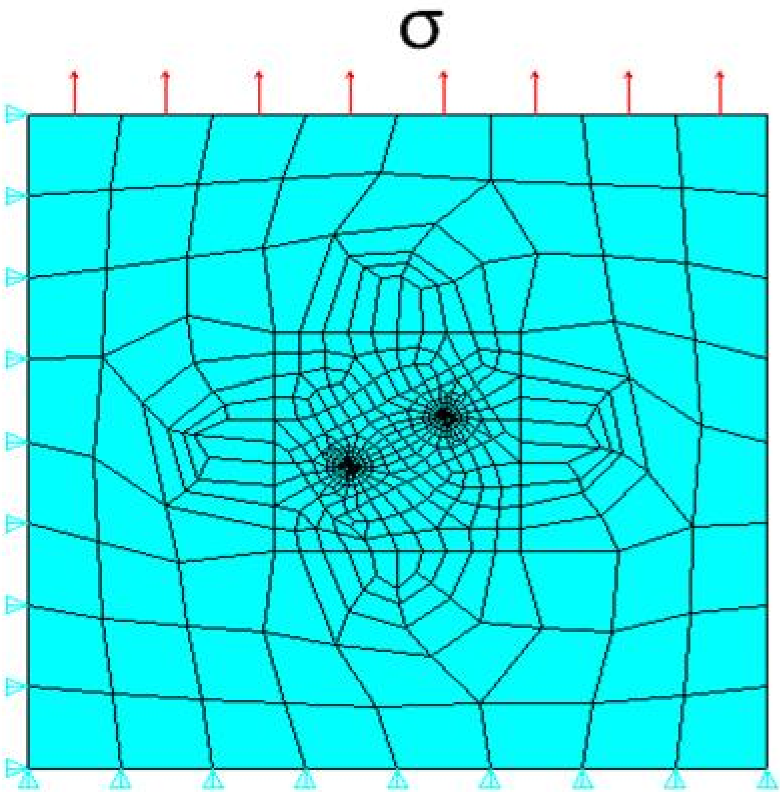


Material Properties	Geometric Properties	Loading
E = 210G Pa Nu = 0.3	L = 0.3m Crack length 2a = 0.09m θ = 30°	σ = 10MPa

Analysis Assumptions and Modeling Notes

The problem is solved using 2-D PLANE182 element with plain strain element behavior (Figure 267.2: Finite element model of 2D inclined crack (p. 772)). The plate is constrained along X direction at X=0 and along Y direction at Y=0. The crack tip node components and the number of paths surrounding the crack tip are defined using **CINT** command. Mode 1 and Mode 2 stress intensity factors obtained from contours 2, 3, 4, and 5 are then averaged and compared against the reference solution.

Figure 267.2: Finite element model of 2D inclined crack



Results Comparison

	Target	Mechanical APDL	Ratio
KI_Right tip (Mode1)	2819957	2839964	1.007
KII_Right tip (Mode2)	1628103	1646529	1.011

VM268: Mullins Effect on a Rubber Tube Model Subjected to Tension Loading

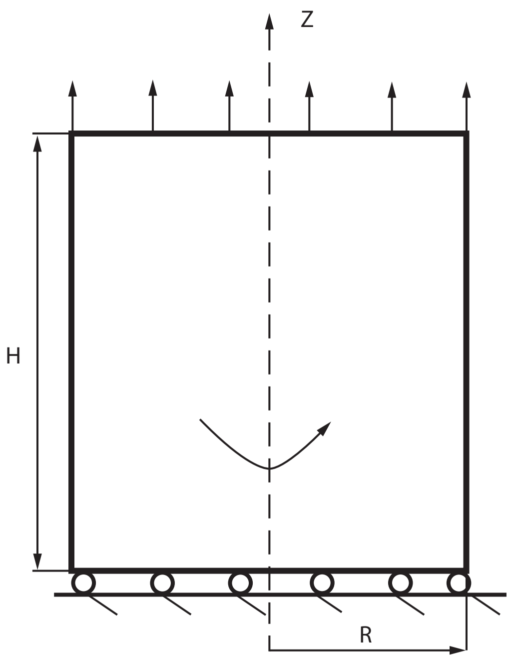
Overview

Reference:	R.W.Ogden, et al., "A Pseudo-elastic Model for the Mullins Effect in Filled Rubber", Royal Society of London Proceedings Series A., (1989), pg: 2861-2877.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2D 4 node structural solid (PLANE182)
Input Listing:	vm268.dat

Test Case

An axisymmetric rubber plate made of Neo-Hookean material is modeled with radius R and height H. The model is subjected to cyclic displacement loading on the top surface. The axial stress obtained at different load steps is compared against reference solution.

Figure 268.1: Problem sketch



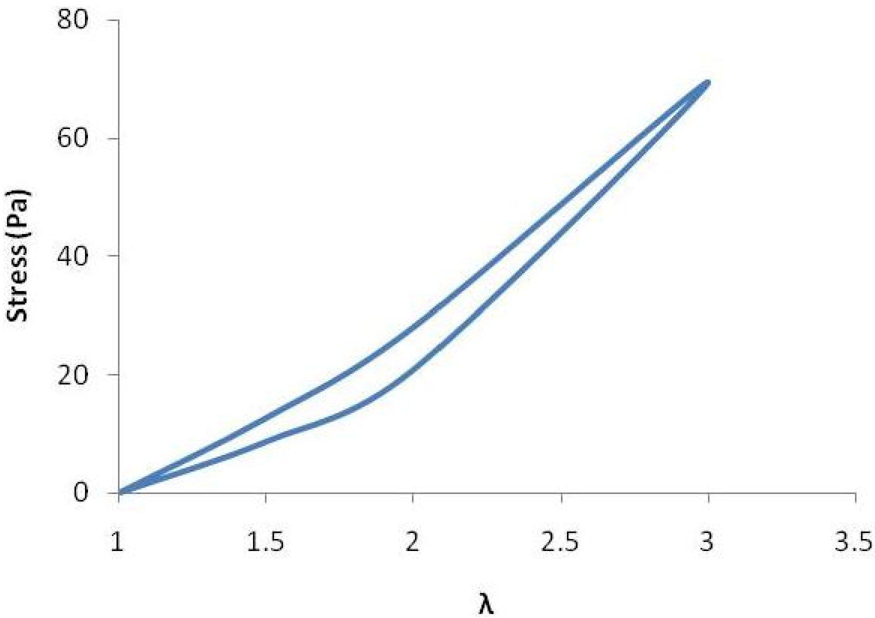
Material Properties	Geometric Properties	Displacement Loading
Neo-Hookean Constants: μ = 8 MPa **Ogden-Roxburgh Mullins Constants:** r=2.104	R=0.5m H=1m	One cycle of loading Step 1: λ=1.5 Step 2: λ=2.0 Step 3: λ=3.0 Step 4: λ=2.0 Step 5: λ=1.5

m=30.45 β=0.2		Step 6: λ=1.0

Analysis Assumptions and Modeling Notes

The rubber tube is modeled using axisymmetric PLANE182 elements. Modified Ogden-Roxburgh Mullins effect was applied to model stress softening of hyper elastic material during unloading stage. Symmetric boundary conditions are applied to the model and the axial stress for element 1 obtained at different stretch is compared with reference solution.

Figure 268.2: Variation of axial stresses with stretch λ in one loading cycle



Results Comparison

Stretch λ	Axial stress (Pa)		
	Target	**Mechanical APDL**	**Ratio**
1.5	12.666	12.666	1.000
2.0	28.000	28.000	1.000
3.0	69.333	69.333	1.000
2.0	20.819	20.822	1.000
1.5	8.660	8.670	1.001
1.0	0.000	0.000	1.000

VM269: Deformation of Tube and Sphere Modeled with Neo-Hookean Material Model

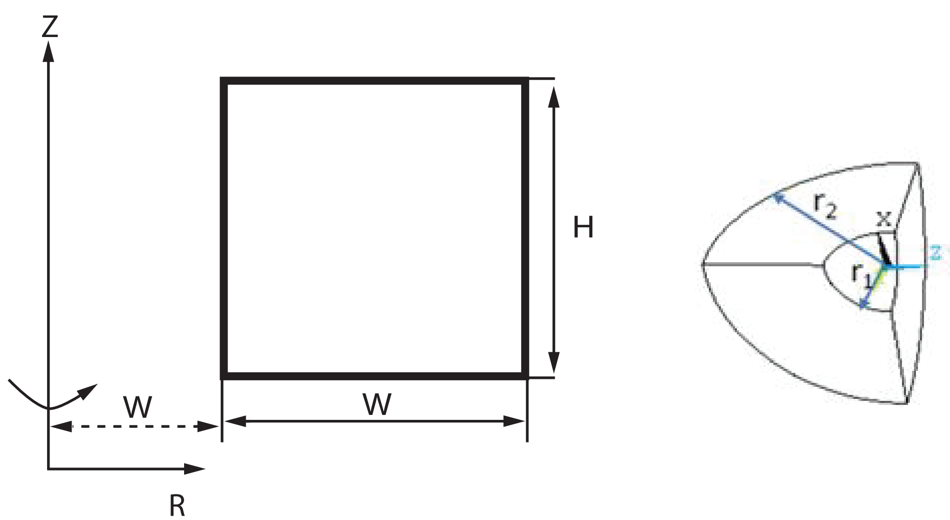
Overview

Reference:	Z. Yosibash, " Axisymmetric Pressure Boundary Loading for Finite Deformation Analysis Using p-FEM", Computer Methods in Applied Mechanics and Engineering, 196(2007): 1261-1277.
Analysis Type(s):	Static analysis (**ANTYPE** = 0)
Element Type(s):	2D 4 node structural solid (PLANE182) 3D 8 node structural solid (SOLID185)
Input Listing:	vm269.dat

Test Case

The tube is modeled with width W and height H and the sphere is modeled with inner radius r1 and outer radius r2. Both the models are made up of neo-hookean material. Stresses are computed at the outer edge nodes for both the models and compared with reference values.

Figure 269.1: Problem sketch



Tube (axisymmetric)

Sphere 1/8

Material Properties	Geometric Properties	Loading
Neo-Hookean Constants: μ=1 Mpa d=1e-3	Tube W=1m H=1m Sphere r1=0.01m r2=0.03m	Deformation (u) in radial direction (R) u = (A-1)*R , A=2

Analysis Assumptions and Modeling Notes

The tube is modeled with axisymmetric PLANE182 elements and 1/8 of sphere is modeled with SOLID185 elements. Displacements are constrained in all directions except for the radial ones. Deformation which is proportional to the radius is then applied along radial direction on all the nodes and static analysis with large deformation is performed to compute the stresses.

Results Comparison

		Target	**Mechanical APDL**	**Ratio**
Tube	S_RR	6000.0992	6000.0992	1.000
	S_ZZ	5999.8016	5999.8016	1.000
Sphere	S_RR	14000.0000	14000.0000	1.000

VM270: Forces in Permanent Magnets

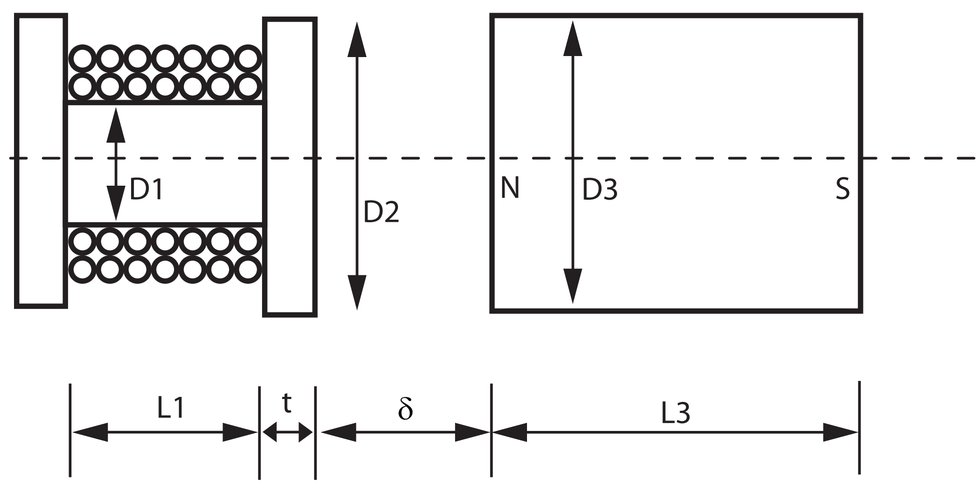
Overview

Reference:	N.Ida, J.P.A Bastos, "Forces in permanent magnets: Team workshop problem 23", Proceedings of the Team Workshop in the Sixth Round, Okayama (1996), pp. 49-56.
Analysis Type(s):	Static analysis (**ANTYPE** = 0)
Element Type(s):	2-D Infinite Solid (INFIN110) 2-D 8 node Electromagnetic Solid (PLANE233)
Input Listing:	vm270.dat

Test Case

Axial force is calculated between the coaxial magnet and coil shown in Figure 270.1: Coil and Magnet Configuration (p. 777). The magnet is made up of Samarium-Cobalt and the coil is wound on a nonmagnetic form (brass). The magnitude of the DC-current energizing the coil is 50mA. The forces are computed at an axial distance of 0.234mm between the magnet and coil.

Figure 270.1: Coil and Magnet Configuration



Material Properties	Geometric Properties	Loading
Air: Magnetic relative permeability (MURX) = 1 Copper: Magnetic relative permeability (MURX) = 1 **Magnet (Samarium-Cobalt):** Remanence (BR) = 1.02T	Spool inner diameter (D1) = 3.048mm Spool outer diameter (D2) = 3.9624mm Inner length (L1) = 1.524mm Spool thickness (t) = 0.127mm	Coil: Total current (I) = 50mA Resistance (R) = 57Ohm Number of turns (N) = 280

Magnetic relative permeability (MURX) = 1.126894 Magnetic coercive force (HC) = 720000A/m Magnetic relative permeability (MURX) = BR/(HC*MUZRO) = 1.126894 where MUZRO = 4πe-7H/m **Infinite elements (air):** Magnetic relative permeability (MURX) = 1	Axial displacement (δ) = 0.234mm Diameter of magnet (D3) = 2.9972mm Length of magnet (L3) = 1.6mm	Current density (JS) = N*I/(D2/2-D1/2)/L1A/m^2

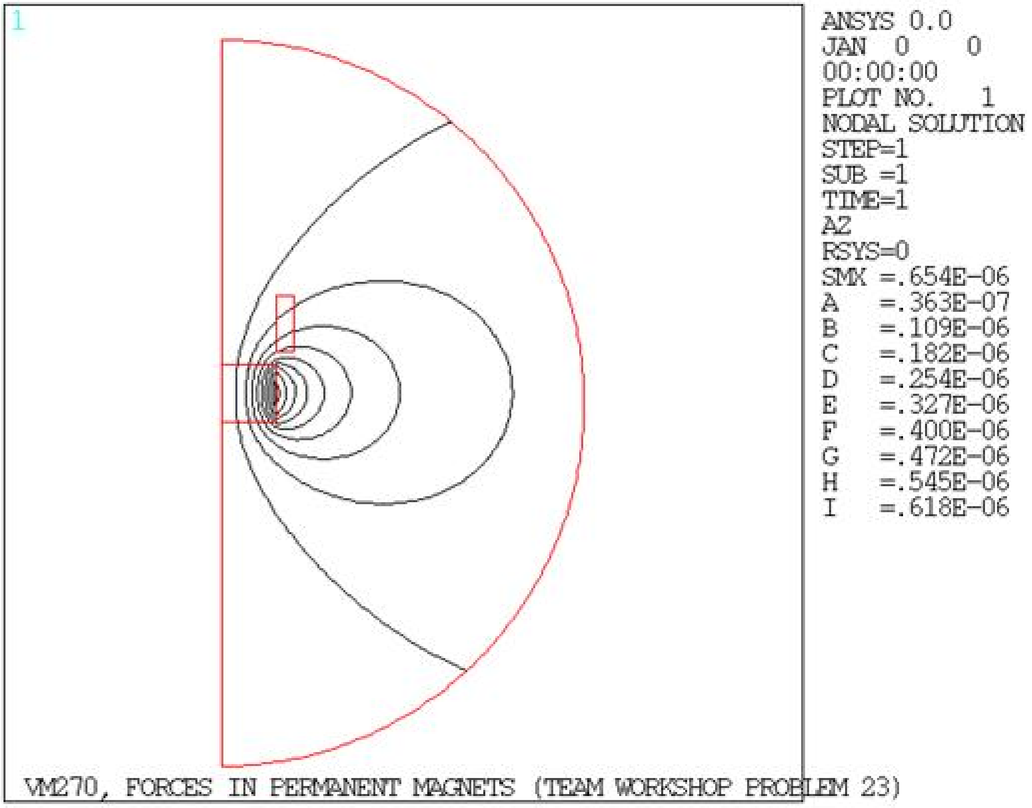
Analysis Assumptions and Modeling Notes

Two axisymmetric magnetostatic analyses are performed to determine the axial force (Fy) acting on the magnet and the coil respectively. The magnet, the coil, and the surrounding air are modeled with 2-D PLANE233 elements. Open magnetic boundaries (see Figure 270.2: Flux Lines (p. 779)) are modeled with 2-D INFIN110 quadratic elements. The coil is loaded with constant current density JS (**BFE**,,JS) derived from the total current I = 50 mA and the coil parameters.

The first analysis calculates the total axial force acting on the magnet as a sum of Maxwell forces in the magnet and in the surrounding air. To obtain a more accurate total force, the option to condense magnetic forces at the element corner nodes (KEYOPT(7) = 1) is activated on the PLANE233 element type. Element forces are summed up using the **EMFT** command. Note that when Maxwell forces are summed up, all the nodes in the region of interest and all the elements attached to these nodes should be selected.

The second analysis determines the axial force acting on the coil using the Lorentz force element option (KEYOPT(8) = 1). This option is applicable to conducting solids only and can be used as an alternative to the Maxwell force option. When summing up Lorentz forces using **EMFT**, only the nodes in the conducting region need to be selected.

Figure 270.2: Flux Lines



Results Comparison

Axial displacement δ = 0.234 mm	Target	Mechanical APDL	Ratio
Magnetic (Maxwell) force (FY_M) acting on the magnet, N	0.0113	0.0112	0.994
Magnetic (Lorentz) force (FY_L) acting on the coil, N	-0.0113	-0.0112	0.994

VM271: Convection Treatment Problem for a Hollow Cylinder with Fluid Flow

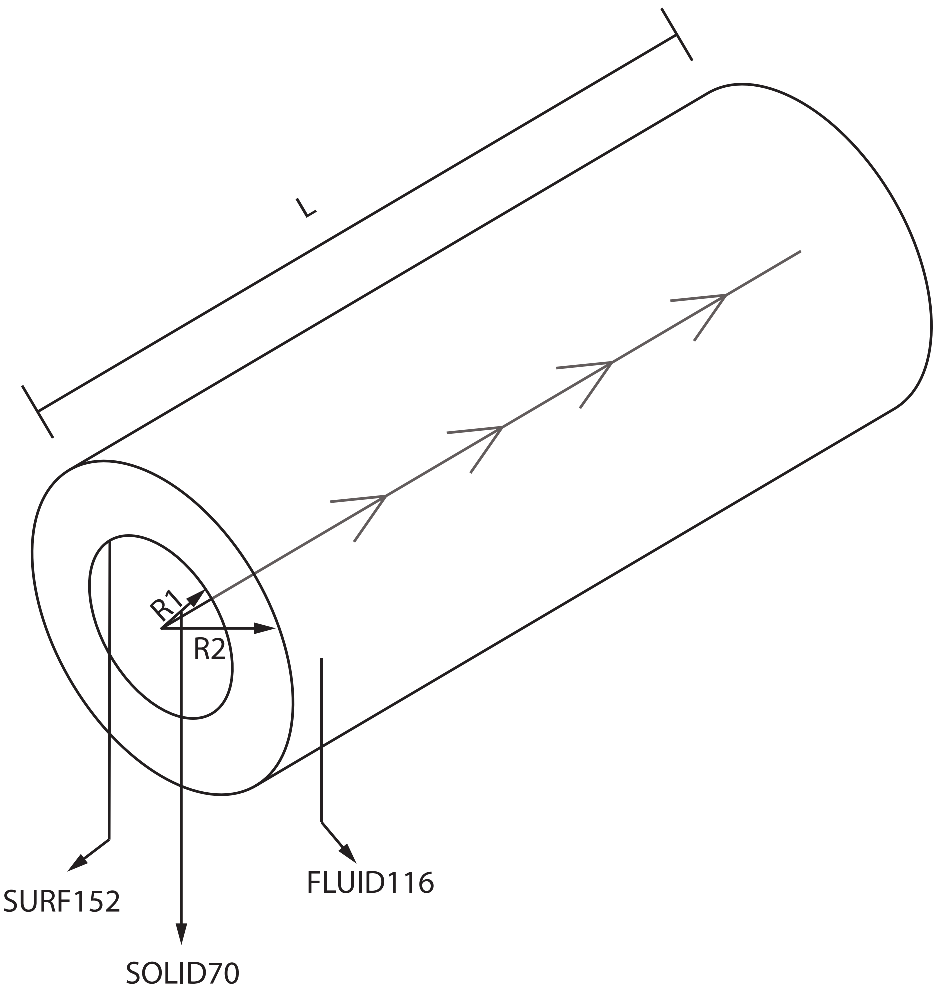
Overview

Reference:	Vedat S.Arpaci, Ahmet Selamet, Shu-Hsin Kao, "Introduction to Heat Transfer", 2000, pg. 90-100.
Analysis Type(s):	Static analysis (**ANTYPE** = 0)
Element Type(s):	Coupled thermal fluid pipe (FLUID116) 3D Thermal surface effect (SURF152) 3D Thermal solid (SOLID70)
Input Listing:	vm271.dat

Test Case

A hollow cylinder is modeled with an inner radius of 0.01105m, an outer radius of 0.02m and a length of 0.1m. Fluid is made to flow through a hollow cylinder to simulate the convection problem. Surface effect elements with film coefficients are used in between the fluid and cylinder to include the convection loads. The inlet temperature of the fluid, mass flow rate of the fluid, and the bulk temperature at the outer cylinder surface are defined. A static analysis is performed on the model to determine the nodal temperature of the fluid elements.

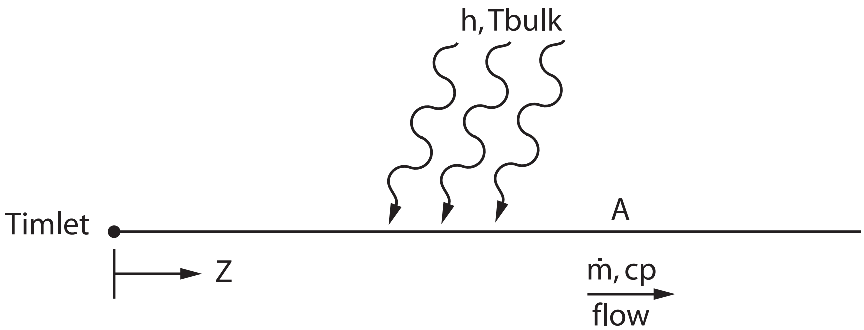
Figure 271.1: Problem Sketch



Material Properties	Geometric Properties	Loading
Fluid: Specific heat for fluid = 0.5474 J/Kg C Thermal conductivity for fluid = 1.0e-16 W/m C Cylinder: Thermal conductivity for cylinder = 1000 W/m C	Inner radius (R1) = 0.01105 m Outer radius (R2) = 0.02 m Length (L) = 0.1 m	Inlet temperature of fluid (TINLET) = 700 ° C Temperature at the outer cylinder (TBULK) = 2000 ° C Film coefficients for surface element = 300 W/m^2 C Mass flow rate for fluid = 7.2 (Kg/sec)

Analysis Assumptions and Modeling Notes

FLUID116 elements with temperature degrees of freedom only and with exponential upwind difference shape function are used to model the fluid flowing through the cylinder. SOLID70 elements are used to model the hollow cylinder, and SURF152 elements are used to model surface elements for specifying convection loads. The **MSTOLE** command is used to map the FLUID116 elements with SURF152 elements by adding two extra nodes from fluid to the surface elements. This is achieved by setting KEYOPT 5 =2 for SURF152 elements after the **ESURF** command and before issuing the **MSTOLE** command. The outer surface of the cylinder is held at a fixed temperature of 2000° C. The solid thermal conductivity is set very high so that the fluid experiences a bulk temperature of 2000° C . The inlet temperature and outer temperature of the cylinder are specified using the **D** command. The mass flow rate for the fluid element and film coefficient for surface element is defined using the **SFE** command. Static solve is performed and nodal temperature for FLUID116 elements are computed and compared with analytical solutions. The analytical solution is obtained using the equation below as defined in the reference book.



Where:

$\dot{m} = \rho A V$

$$\text{Temperature at } Z = (\text{Tinlet} - \text{Tbulk}) * \exp\left(\frac{-h\ A}{\dot{m}\ cp} * \frac{Z}{L}\right) + \text{Tbulk}$$

Where:

$\dot{m}$ = main flow rate of the fluid

h = film coefficient

A = convection area

cp = specific heat for fluid

Results Comparison

Node	Location (Z)	Temperatures		
		Target	**Mechanical APDL**	**Ratio**
1	0.000	700	700.000	1.000
3	0.333	913.537	913.360	1.000
4	0.667	1091.999	1091.703	1.000
2	1.000	1241.147	1240.775	1.000

VM272: 2-D and 3-D Frictional Hertz Contact

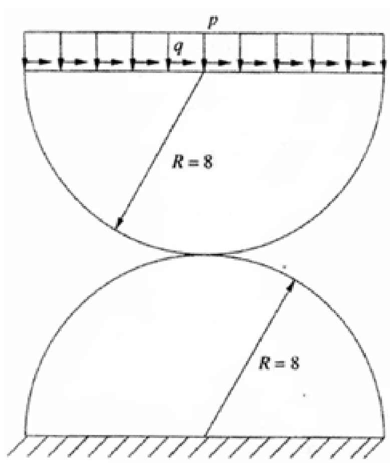
Overview

Reference:	Two Dimensional Mortar Contact Methods for Large Deformation Frictional Sliding, International Journal for Numerical Methods in Engineering Vol.62, pp 1183-1225.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4-Node Structural Solid (PLANE182) 2-D 2-Node Surface-to-Surface Contact (CONTA171) 2-D Target Segment (TARGE169) 2-D Structural Surface Effect (SURF153) 3-D 8-Node Structural Solid (SOLID185) 3-D 4-Node Surface-to-Surface Contact (CONTA173) 3-D Target Segment (TARGE170) 3-D Structural Surface Effect (SURF154)
Input Listing:	vm272.dat

Test Case

Two parallel linear elastic half cylinders of radius R are pressed by a small distributed pressure p. A tangential pressure, q, is then applied to cause friction at the contact interface. The bottom of the lower cylinder is fixed in all directions. Determine the contact pressure and friction results across the contact interface.

Figure 272.1: Hertzian Contact Problem Sketch



Material Properties	Geometric Properties	Loading
E=200.0 N/mm^2 v=0.3	R = 8.0 mm	p=0.625 N/mm q= 0.05851 N/mm

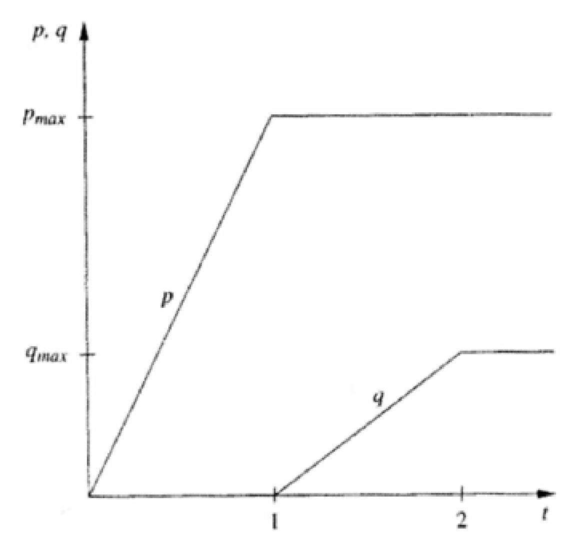
Analysis Assumptions and Modeling Notes

This problem is solved in two ways:

- 2-D lower order elements CONTA171, PLANE182
- 3-D lower order elements CONTA173, SOLID185

In the first analysis, the cylinders are modeled and meshed with plane elements with plane strain behavior. The problem is solved using 2-D surface to surface contact elements with surface-projection definition (KEYOPT(4)=3) and updating contact stiffness based on stresses of underlying elements (KEYOPT(10)=2). Contact Damping (0.01) is used for contact elements to avoid rigid body motion in the initial sub step. In the second analysis, the cylinders are modeled with 3-D solid elements with unit thickness in the Z direction. The same element options and contact damping used in 2-D analysis are applied to 3-D analysis. The simulations use two load steps; the first is a ramped normal pressure of 10 N, applied on the top surface of the upper cylinder, and the second is a ramped tangential pressure of 0.93622 N, also applied to the top surface of the upper cylinder.

Figure 272.2: Load History Diagram



Analytic results approach zero more rapidly than computed results toward the end of the contact interface. These small differences are due to mesh discretization and are considered acceptable.

The plots below show contact pressure and friction with respect to distance along X from the center for both cases.

Figure 272.3: Plot of the First Case

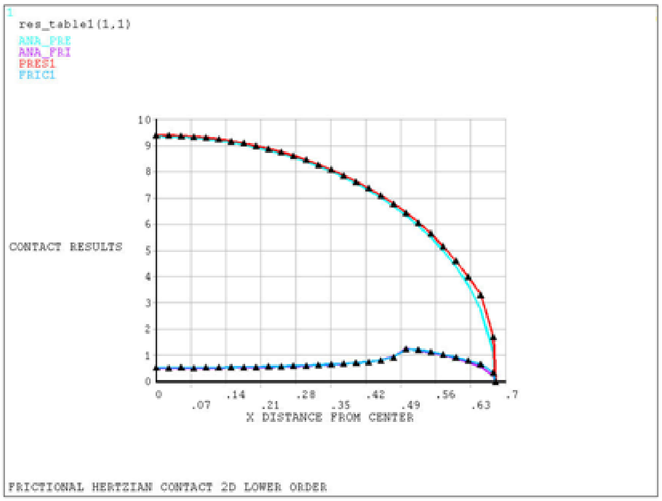
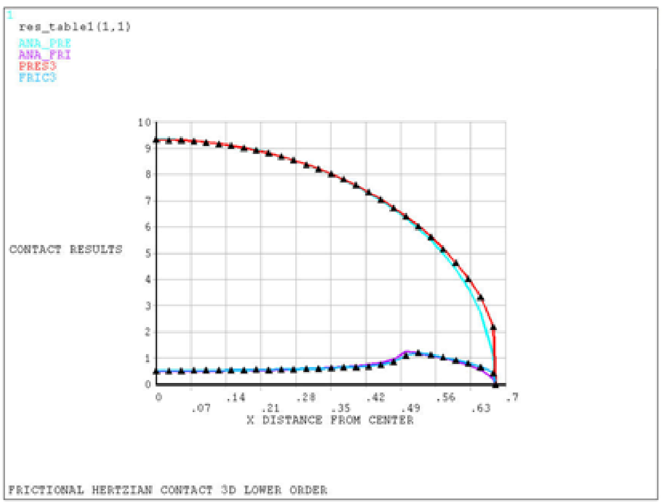


Figure 272.4: Plot of the Second Case



Results Comparison

Table 272.1: Contact Pressure 2-D

Location (mm)	Target	Mechanical APDL	Ratio
0.000	9.3514	9.4102	1.006
0.100	9.2494	9.3084	1.006
0.201	8.9366	8.9983	1.007
0.301	8.3896	8.4581	1.008
0.401	7.5581	7.6409	1.011
0.501	6.3317	6.4508	1.019

Location (mm)	Target	Mechanical APDL	Ratio
0.601	4.3924	4.6080	1.049

Table 272.2: Contact Friction 2-D

Location (mm)	Target	Mechanical APDL	Ratio
0.000	0.5063	0.5321	1.051
0.100	0.5140	0.5368	1.044
0.201	0.5395	0.5521	1.023
0.301	0.5926	0.6053	1.021
0.401	0.7069	0.7178	1.015
0.501	1.2663	1.2305	0.972
0.601	0.8785	0.9216	1.049

Table 272.3: Contact Pressure 3-D

Location (mm)	Target	Mechanical APDL	Ratio
0.000	9.3514	9.3347	0.998
0.100	9.2494	9.2372	0.999
0.201	8.9366	8.9296	0.999
0.301	8.3896	8.3946	1.001
0.401	7.5581	7.5879	1.004
0.501	6.3317	6.4077	1.012
0.601	4.3924	4.6424	1.057

Table 272.4: Contact Friction 3-D

Location (mm)	Target	Mechanical APDL	Ratio
0.000	0.5063	0.5192	1.025
0.100	0.5140	0.5252	1.022
0.201	0.5395	0.5673	1.052
0.301	0.5926	0.6038	1.019
0.401	0.7069	0.6519	0.922
0.501	1.2663	1.2559	0.992
0.601	0.8785	0.9285	1.057

VM273: Shape Memory Alloy with thermal effect under uniaxial loading

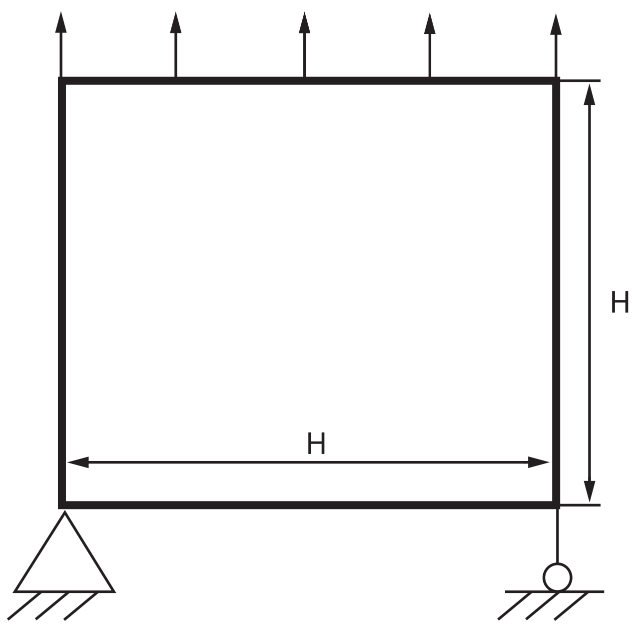
Overview

Reference:	Auricchio, F. et al. "*Improvements and algorithmeical considerations on a recent three-dimensional model descrbing stress-induced solid phase transformation*". *International Journal for Numerical Methods in Engineering*, 55. 1225-1284. 2002
Analysis Type(s):	Static Analysis (**ANTYPE**=0)
Element Type(s):	3-D Structural Solid Elements (SOLID185)
Input Listing:	vm273.dat

Test Case

A block is made of shape memory alloy material. One cycle of uniaxial displacement loading is applied in vertical direction (Figure 273.1: Uniaxial Loading Problem Sketch (p. 789)). The whole process includes tension, unload, compression, and unload. The whole loading history repeats with body temperature 285.15K and 253.15K respectively. The stress history is obtained and compared against the reference solution.

Figure 273.1: Uniaxial Loading Problem Sketch



Material Properties	Geometric Properties	Loading
Material properties for Austenite phase: E=70,000 MPa μ=0.33	H=10 mm	1. Uniaxial tension to 0.35 mm in Y, then unload back to zero. 2. Uniaxial compression to -0.35 mm, then unload back to zero.

Material Properties	Geometric Properties	Loading
Material properties for Martensite phase: Em=70,000MPa Parameters for phase transformation: h=500 MPa R=45 MPa β=7.5MPa.K^{-1} T_0=253.15K m=0		In the above loading process, the body temperature is maintained at 285.15K and 253.15K respectively.

Analysis Assumptions and Modeling Notes

The problem is solved using 3-D SOLID185 elements. The shape memory thermal effect is defined by **TB**, SMA. The block is subjected to one cycle of uniaxial tension and compression with body temperature held at 285.15K and 253.15K, respectively. History of stresses in loading direction is acquired in POST26.

Results Comparison

	Target	Mechanical APDL	Ratio
T= 285.15K			
S_SAS	345.0	349.508	1.013
S_FAS	367.0	367.168	1.000
S_SSA	258.0	257.071	0.996
S_FSA	236.0	238.891	1.012
T=253.15K			
S_SAS	54.6	55.568	1.018
S_FAS	74.1	73.229	0.988
S_SSA	-37.1	-36.868	0.994

VM274: Stabilizing Squeal Damping

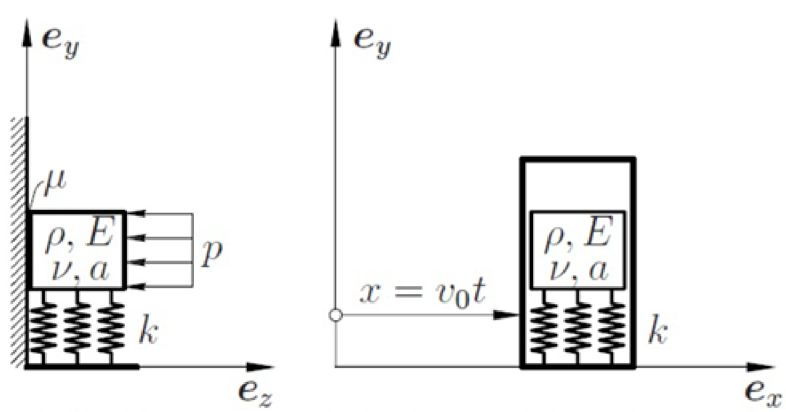
Overview

Reference:	Any Dynamics Textbook
Analysis Type(s):	Static Analysis (**ANTYPE**=0) Modal Analysis (**ANTYPE**=2)
Element Type(s):	3-D 8-Node Structural Solid (SOLID185) 3-D 4-Node Structural Surface-to-Surface Contact (CONTA173) 3-D Target Segment (TARGE170) Spring-Damper (COMBIN14) Structural Mass (MASS21)
Input Listing:	vm274.dat

Test Case

A rigid block (Young's modulus E, Poisson ratio ν, density ρ, length of edge a, area A) is elastically supported by a spring-damper element and guided by a rail with a velocity υ. The whole assembly is sliding on the rough e_x-e_y-plane (coefficient of friction μ, normal pressure p). Linear perturbation modal analysis is performed using the DAMP eigensolver to determine the damped frequency and modal damping ratio, which is then compared against analytical results.

Figure 274.1: Stabilizing Squeal Damping Problem Sketch



Material Properties	Geometric Properties	Loading
E = 21 x 10^{10} N/m^2	a = 0.1m	υ = 10 m/s
ν = 0.3	A = 0.01m	k = 315 N/m
μ = 0.5		p = 100 Pa
ρ = 8000 kg/m^3		
m = 8kg		

Analysis Assumptions and Modeling Notes

The rigid block is modeled and meshed with SOLID185 elements. The block is constrained on all degrees of freedom at location y=0. The pilot node is created using TARGE170 elements. Mass is defined on the pilot node using MASS21 elements. A spring element with stiffness 'k' is created using COMBIN14 elements to support the block. One end of the spring element is connected to the pilot node and the other end is fixed. Stabilizing squeal damping is activated using real constant FDMS of the contact elements. Remote force is applied on the block using the pilot node and contact elements. A non-linear static analysis is performed with two load steps. In the first load step, the remote force is applied. In the second load step, the velocity is applied through the **CMROTATE** command. A linear perturbation modal analysis is performed from the base non-linear static solve using the DAMP eigensolver to determine the damped modes and modal damping ratio. The damped frequency originating from friction is calculated using the following formula:

$$\lambda_{1,2} = \frac{-N_0\mu \pm \sqrt{-4cm\upsilon_0^2 + N_0^2\mu^2}}{2m\upsilon_0} \quad (274.1)$$

Where:

- N_o (force) = 1N
- μ (friction) = 0.5
- c (spring stiffness) = 315 N/m
- m (mass) = 8 Kg
- υ_o (velocity) = 10 m/s

Substituting these parameters in the above equation yields:

$\lambda_{1,2}$ = 0.003125±6.274949i

Converting radians/seconds to hertz:

$(1/2\pi)\lambda_{1,2}$ = 0.000497±0.998287i

Damping ratio = 0.0004980

Results Comparison

	Target	Mechanical APDL	Ratio
Modal Damping Ratio	0.0004980	0.00049751	0.999

VM275: Mode lock-in and friction induced vibrations of a Pin-Disc model

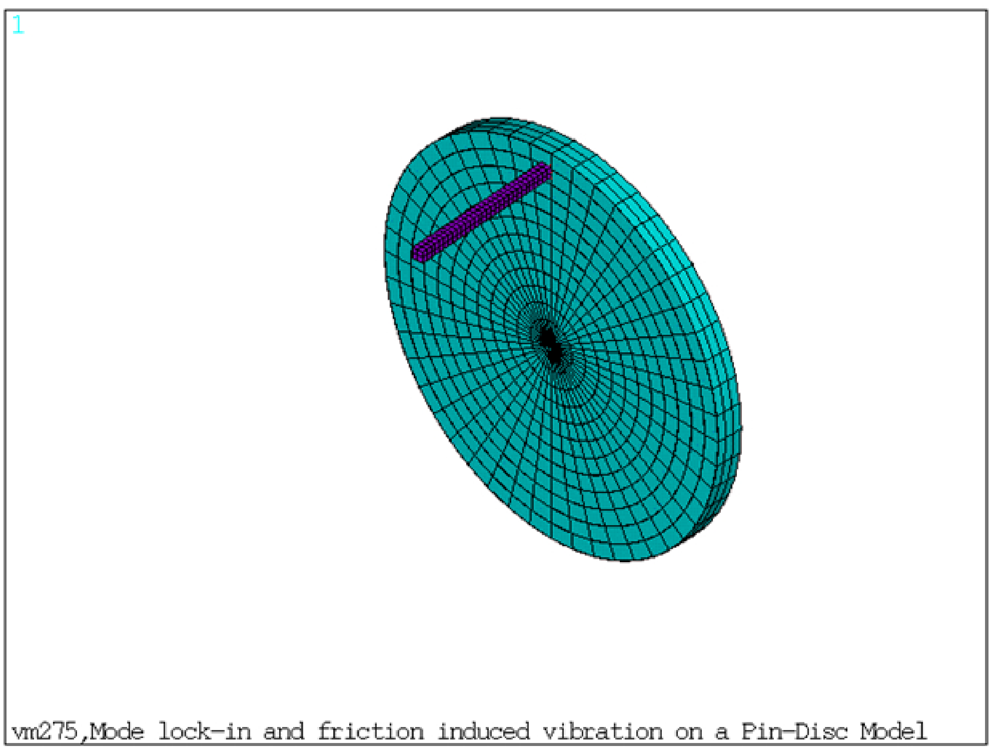
Overview

Reference:	Allgaier, R., Gaul, L., Keiper, W., Willner, K., Mode Lock-In and Friction Modeling, Computational Methods in Contact Mechanics IV, ed. By L. Gaul and C.A. Brebbia, WIT Press, Southampton (1999), pg 35-47.
Analysis Type(s):	Static Analysis (**ANTYPE**=0) Modal Analysis (**ANTYPE**=2)
Element Type(s):	3-D 20-Node Structural Solid (SOLID186) 2-D/3-D Node Surface-to-Surface Contact (CONTA175) 3-D Target Segment (TARGE170)
Input Listing:	vm275.dat

Test Case

A brake squeal analysis is performed on a pin-disc model using three different procedures to highlight the mode coupling phenomenon caused by friction induced vibrations. The unstable frequency is obtained in each procedure using the unsymmetric eigensolver (**MODOPT**,UNSYM) and compared against the target value of the reference.

Figure 275.1: Stabilizing Squeal Damping Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 70000\ N/mm^2$ $\nu = 0.33$ μ (coefficient of friction) = 0.152 $\rho = 2.7e\text{-}09\ kg/mm^3$	Disc outer diameter = 358 mm Disc inner diameter = 8 mm Disc thickness = 25 mm Pin length = 149 mm Pin width = 10 mm Pin height = 10 mm	Displacement at the free end of the pin = 0.1 mm Rotational velocity (**CMROTATE** command) = 2.0 rad/sec

Analysis Assumptions and Modeling Notes

The disc-pin is modeled with an aluminum material model and meshed with SOLID186 elements. The inner radius of the disc is constrained along all directions. The pin is clamped at one end and in contact with the disc at the other end at an angle of 4 degrees inclination. A standard frictional contact pair with CONTA175 and TARGE170 elements is used to model the contact region.

The unsymmetric full Newton-Raphson option is used to solve the modal analysis for all three procedures. For full non-linear perturbed modal analysis and partial non-linear perturbed modal analysis, the prestress load is the displacement load applied on the free end of the pin to bring both the pin and disc components into contact. The **CMROTATE** command is used to rotate the nodes of the disc and to generate sliding frictional contact between the disc and pin. The pin length is adjusted so that the third bending mode of the disc (2246Hz) and second bending mode of the pin (2279Hz) can couple to produce unstable squealing modes.

Results Comparison

	Target	Mechanical APDL	Ratio
Full Nonlinear Perturbed Modal Analysis			
Mode (Hz)	2215.000	2262.237	0.979
Partial Nonlinear Perturbed Modal Analysis			
Mode (Hz)	2215.000	2259.521	0.980
Linear Non-prestressed Modal Analysis			
Mode (Hz)	2215.000	2269.878	0.976

VM276: Moisture Diffusion in a Plate Under Constant Flux

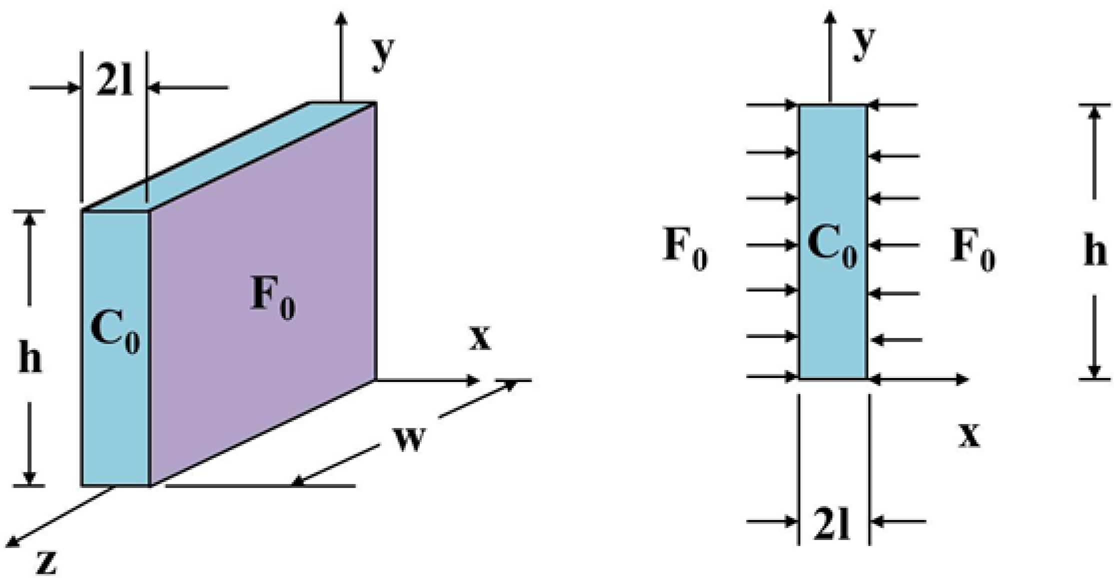
Overview

Reference:	Crank, J. *The Mathematics of Diffusion*. 2nd Printing, Bristol: Oxford University Press, 1975 pp. 61-62.
Analysis Type(s):	Transient Analysis (**ANTYPE**=4)
Element Type(s):	3-D 20-Node Diffusion Solid (SOLID239)
Input Listing:	vm276.dat

Test Case

A plate of thickness 2l at an initial concentration C_0 is subjected to an applied diffusion flux F_0 at its surface (x = ± l). A time transient analysis (**ANTYPE** = 4) is performed at a run time of t=129600s and at a run time of t=90720s to determine the moisture concentration in the plate at location x=l/2. The total moisture weight gain is also determined at time t=90720s.

Figure 276.1: Plate with Constant Diffusion Flux Sketch



Material Properties	Geometric Properties	Loading
Diffusivity coefficient: D = 4e-5 mm^2/s Saturated concentration: C_{sat} = 3e-8 kg/mm^3	l = 2 mm w = 50 mm h = 50 mm	$C_0 = \frac{1e-10\ kg/mm^3}{C_{sat}}$ F_0 = 5e-14 $kg/s*mm^2$

Analysis Assumptions and Modeling Notes

Constant diffusion flux F_0 is applied as a surface load using the **SF**,,DFLUX command. The F_0 is selected such that the concentration results will not exceed the saturated concentration C_{sat}.

The normalized concentration approach is used for the analysis. Normalized initial concentration C_0 is applied using the IC command. The saturated concentration C_{sat} is defined as a material property (**MP**,,CSAT).

To calculate the moisture weight gain, the actual concentration (**ETABLE**,,SMISC,1) of each element is multiplied by the element's volume. These individual element weight gains are then summed to give the total weight gain.

The target concentration solution is obtained from Eq. 4.55 given in the reference. The equation is truncated to five terms for target result calculation.

$$C = C_{IC} + \frac{F_0 l}{D}\left\{\frac{Dt}{l^2} + \frac{3x^2 - l^2}{6l^2} - \frac{2}{\pi^2}\sum_{n=1}^{\infty}\frac{(-1)^n \exp\{\frac{-Dn^2\pi^2 t}{l^2}\}\cos\{\frac{n\text{À}x}{l}\}}{n^2}\right\}$$

Where:

C_{IC} = The initial actual concentration of the plate, which is equal to C_0*C_{sat}.
x = X-location in plate. The value l/2 is used for target results calculations.

The target total moisture weight gain solution is obtained by adding the initial moisture weight of the sheet to the below listed weight gain equation given in the reference.

M_t=M_0+twh

Where:

M_0 = the initial moisture weight at time t=0s, which is equal to 2*l*h*w*C_0*C_{sat}.

Results Comparison

	Target	Mechanical APDL	Ratio
Concentration, kg/mm^3 (x = l/2, t = 90720s)	0.22638e-08	0.22314e-08	0.986
Moisture Weight Gain, kg (t = 90720s)	0.23680e-04	0.23096e-04	0.975

Figure 276.2: Concentration in Plate over Time

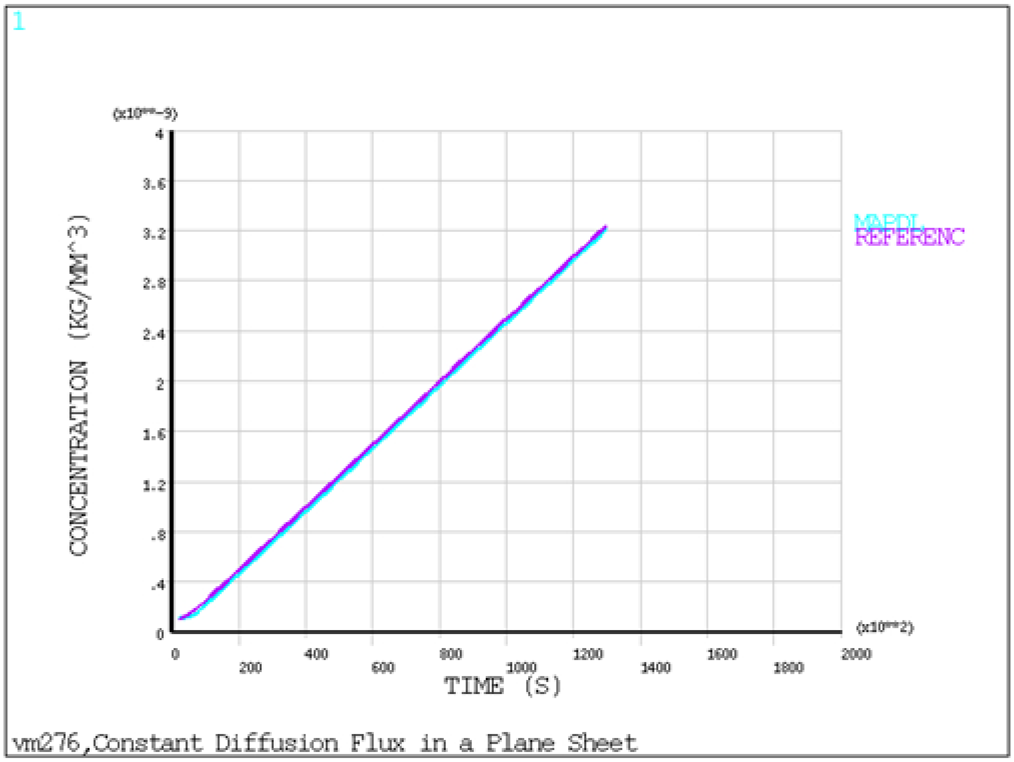
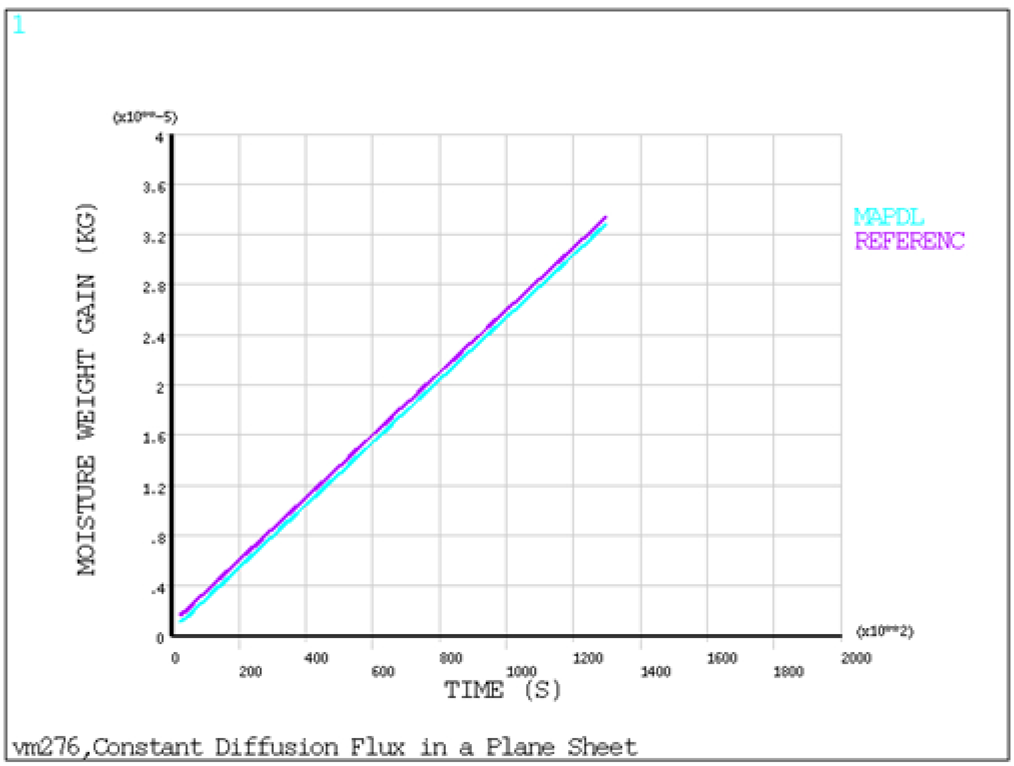


Figure 276.3: Moisture Weight Gain over Time



VM277: Hall Plate in a Uniform Magnetic Field

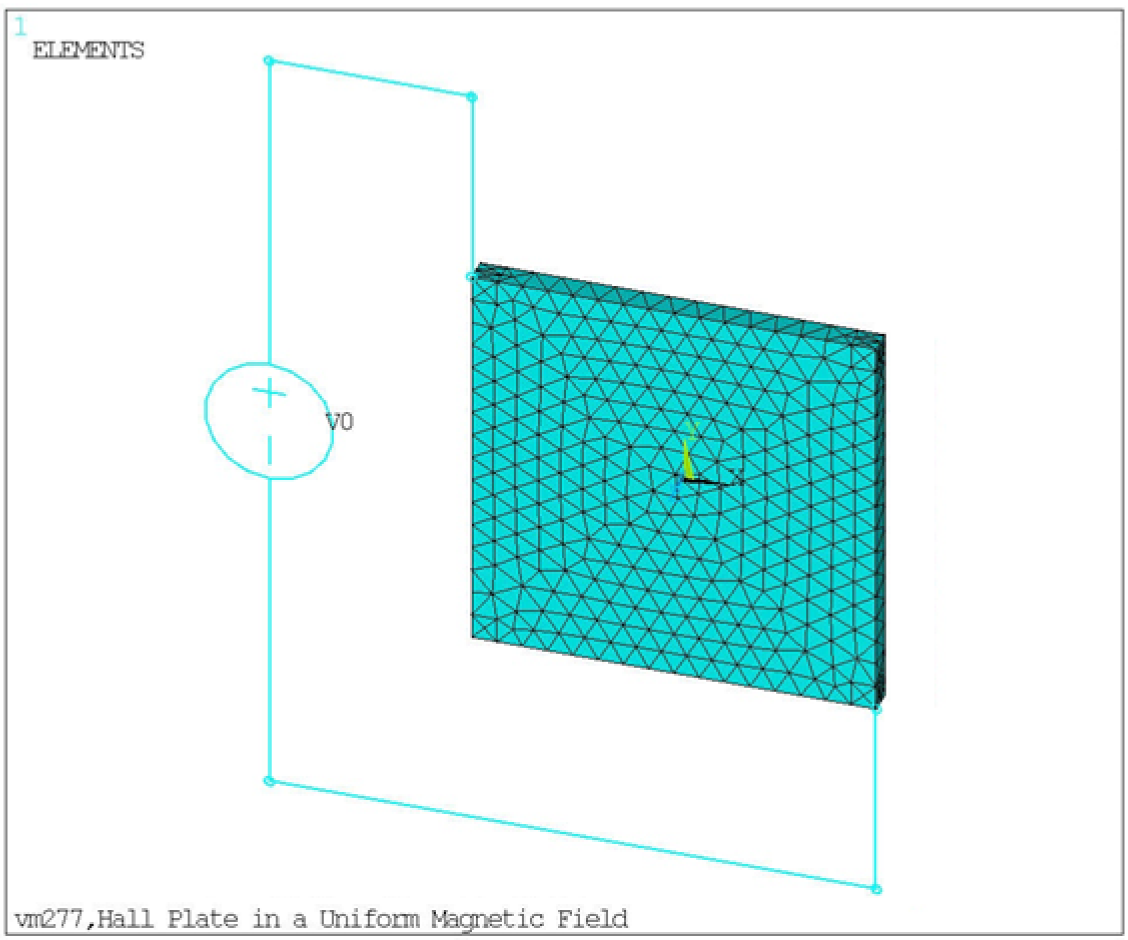
Overview

Reference:	Meijer, G. *Smart Sensor Systems*. John Wiley & Sons, Ltd. 2008, p. 252.
Analysis Type(s):	Static Analysis (**ANTYPE**=0)
Element Type(s):	3-D 20-Node Electromagnetic Solid Elements (SOLID236) Electric Circuit Elements (CIRCU124) Meshing Facet (MESH200)
Input Listing:	vm277.dat

Test Case

A series of static electromagnetic analyses is performed on a plate with length 2a, height 2b, and thickness c to determine the Hall voltage produced by a uniform magnetic field B perpendicular to the plate surfaces.

Figure 277.1: Hall Plate in a Uniform Magnetic Field Element Plot



Material Properties	Geometric Properties	Loading
Hall constant Rh = -0.0001 m^3/C Electrical resistivity = 1.6e-3 Ω*m Relative magnetic permeability μ = 1	a = 3e-3 m b = 3e-3 m c = 0.4e-3 m	V0 = 3 V B = 0.8 T

Analysis Assumptions and Modeling Notes

The initial electric potential distribution in the plate is created by a voltage V0 applied across a pair of contacts as shown in Figure 277.1: Hall Plate in a Uniform Magnetic Field Element Plot (p. 799).

Electrical contacts are made by coupling the voltage of the nodes (**CP**, VOLT) located within a small volume at each corner of the Hall plate. The voltage load V0 was applied by coupling the voltage (**CP**, VOLT) of the independent voltage source (**CIRCU124**) (KEYOPT (1) = 4) with the corresponding electrical contacts on the plate. A ground is created by setting the voltage of one electrical contact to zero (**D**,,VOLT).

Meshing facet elements are used to depict the presence of wires.

The first analysis is performed without any applied magnetic field to determine the offset voltage. The output voltage should be zero in the absence of a magnetic field; however, due to non-uniform meshing, the current distribution is not symmetrical, resulting in a small potential difference (offset voltage) across the output pair of contacts. In a real application, the offset voltage may be caused by various factors, such as mechanical stresses, material inhomogenities, or temperature variations.

For the second static analysis, the output voltage is calculated when there is an applied magnetic field (B) perpendicular to the Hall plate (Figure 277.2: Vector Plot of Applied Magnetic Field on Hall Plate (p. 801)). The offset voltage is subtracted from this output voltage to determine the Hall voltage.

The target Hall voltage is obtained using Eq. 9.14 in the reference:

$$V_H = \frac{IB}{c} Rh$$

Where:

I = the current through the plate. This value is retrieved using ***GET**.

Results Comparison

	Target	Mechanical APDL	Ratio
Hall Voltage, V (B = 0.8 T)	0.42761e-01	0.42761E-01	0.985

Figure 277.2: Vector Plot of Applied Magnetic Field on Hall Plate

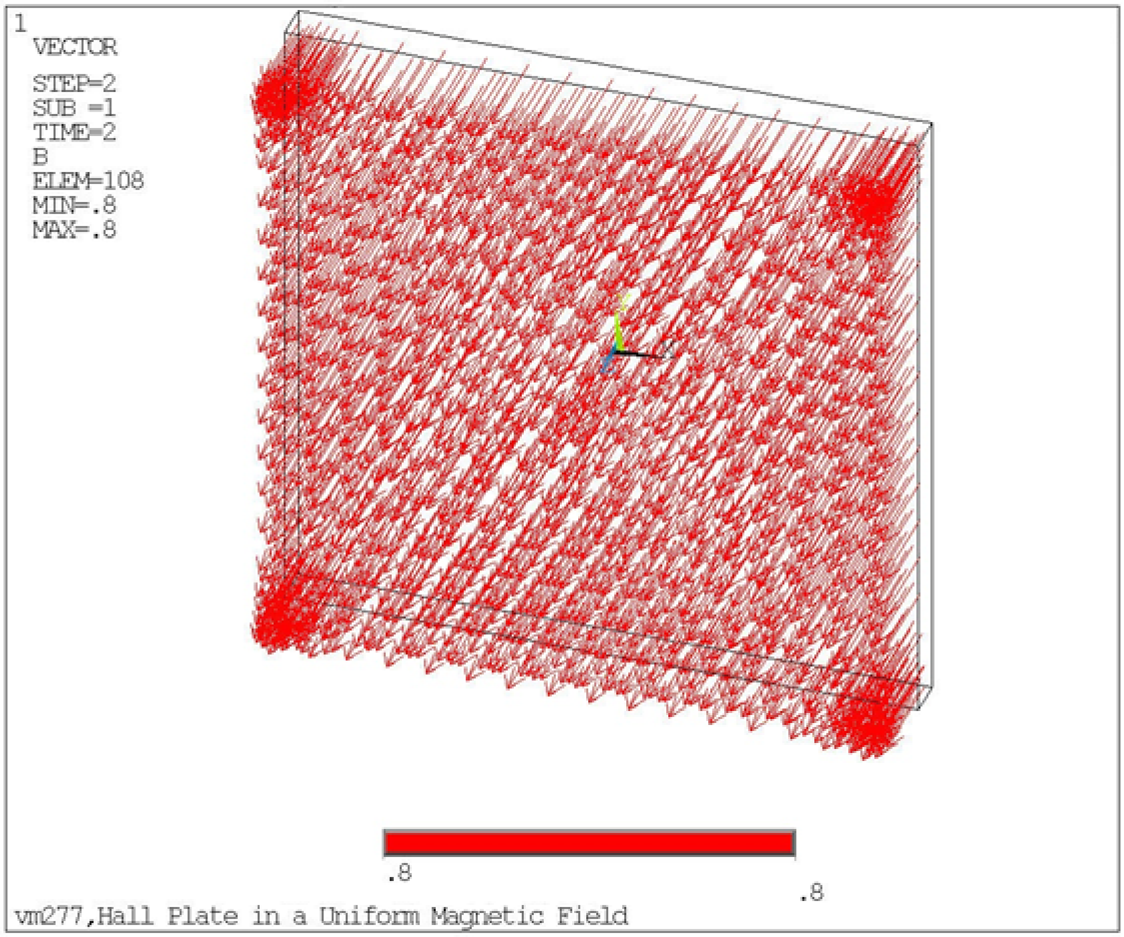
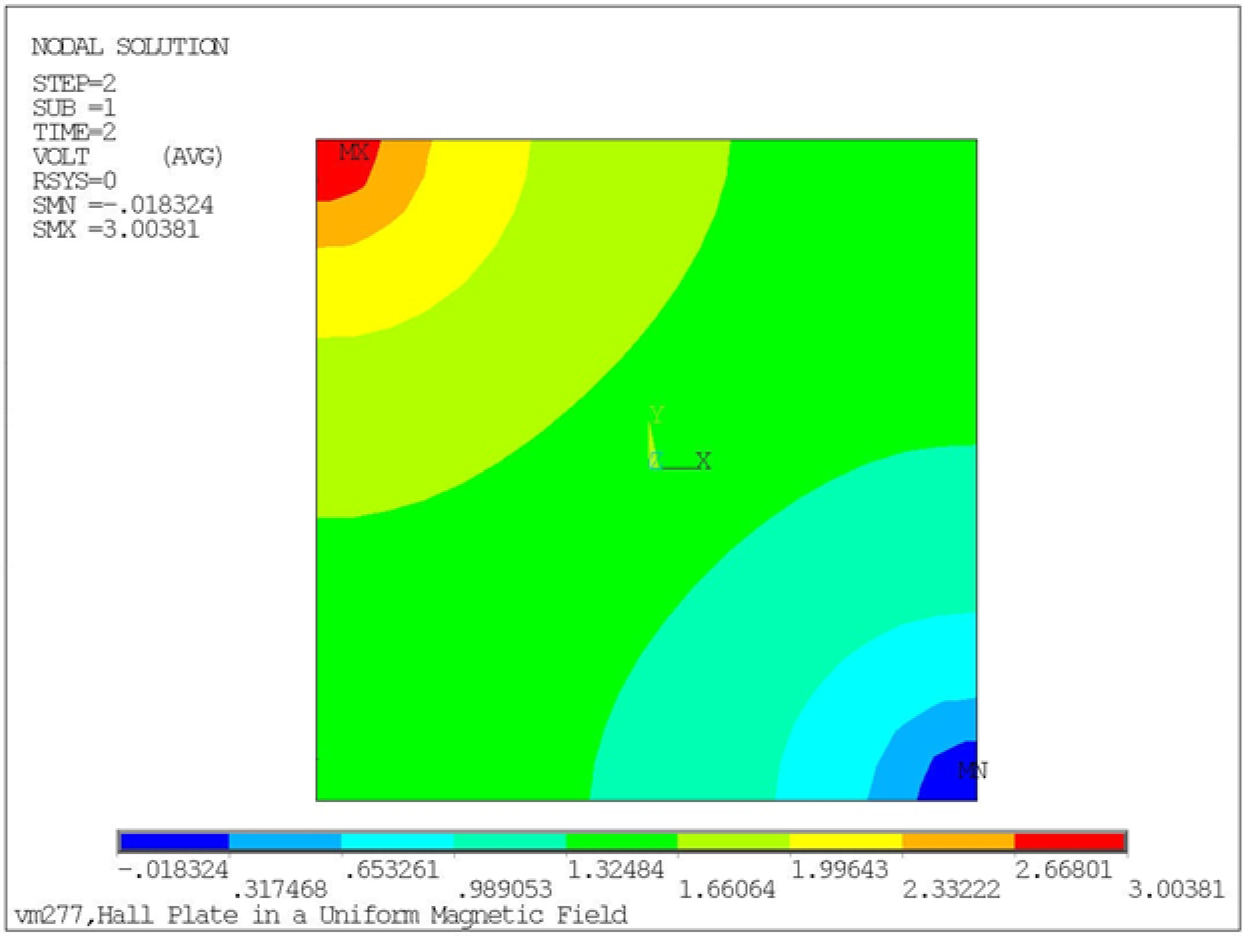


Figure 277.3: Electric Potential Distributions in the Hall Plate



VM278: Effect of a Pipe Lying on the Ground under Gravity Loading

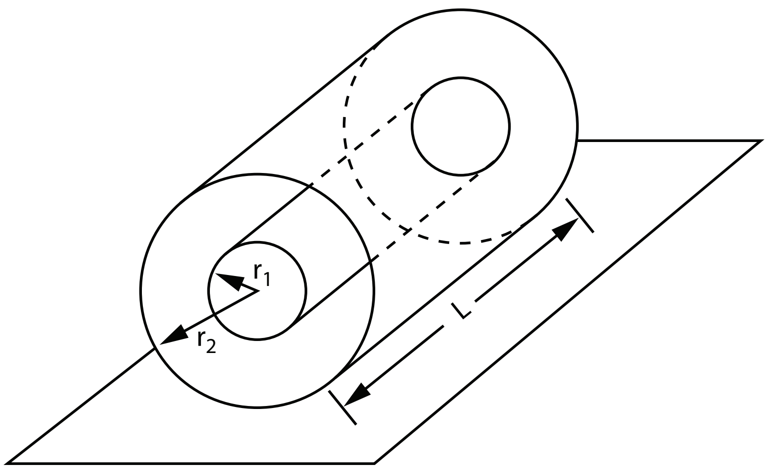
Overview

Reference:	Any Basic Mechanics Text
Analysis Type(s):	Static Analysis (**ANTYPE**=0)
Element Type(s):	3-D 3-Node Pipe (PIPE289) 3-D Line-to-Surface Contact (CONTA177) 3-D Target Segment (TARGE170)
Input Listing:	vm278.dat

Test Case

A straight pipe lies on the ground. Once gravity is applied, the weight of the pipe creates pressure and a penetration of the ground surface. These quantities are determined from the contact output.

Figure 278.1: Pipe on Ground Problem Sketch



Material Properties	Geometric Properties	Loading
Young's Modulus (E) = 2.0E11 pa Poisson ratio (υ) = 0.3 Density (ρ) = 7850 kg/m^3 Coefficient of friction (μ) = 0.2	Length (L) = 100 m Inner radius (r_1) = 0.25m Outer radius (r_2) = 0.24m	Acceleration = 9.81 m/sec^2

Analysis Assumptions and Modeling Notes

PIPE289 elements are used to model the pipe of length L = 100m, outer radius r_1 = 0.25m, and inner radius r_2 = 0.24m. Density is ρ = 7850 kg/m^3. Based on this data, the weight of the cylinder can be calculated as $W = mg = \rho L\pi(r_1-r_2)^2 g$ = 11845.45N. The contact pressure is calculated by dividing the weight by the area factor used in traction contact formulation. This area is the product of the contact length and the outer radius of the pipe section: $A = Lr_2$ = 25m^2. The resulting contact pressure is P = W/A = 4741.8 N/m^2. The contact element is traction-based (KEYOPT(3) = 1), so its stiffness (k = 1E6) is in units of force/length^3. The formula for penetration is: D = P/k = 4.7418E-3.

Results Comparison

Contact Result	Target	Mechanical APDL	Ratio
PRESSURE (N/m^2)	4737	4742	1.001
PENETRATION (m)	4.737 x 10^{-3}	4.742 x ^{10}-3	1.001
AREA (m^2)	25	25	1.000

VM279: T-Stress for a Crack in a Plate Using the CINT Command

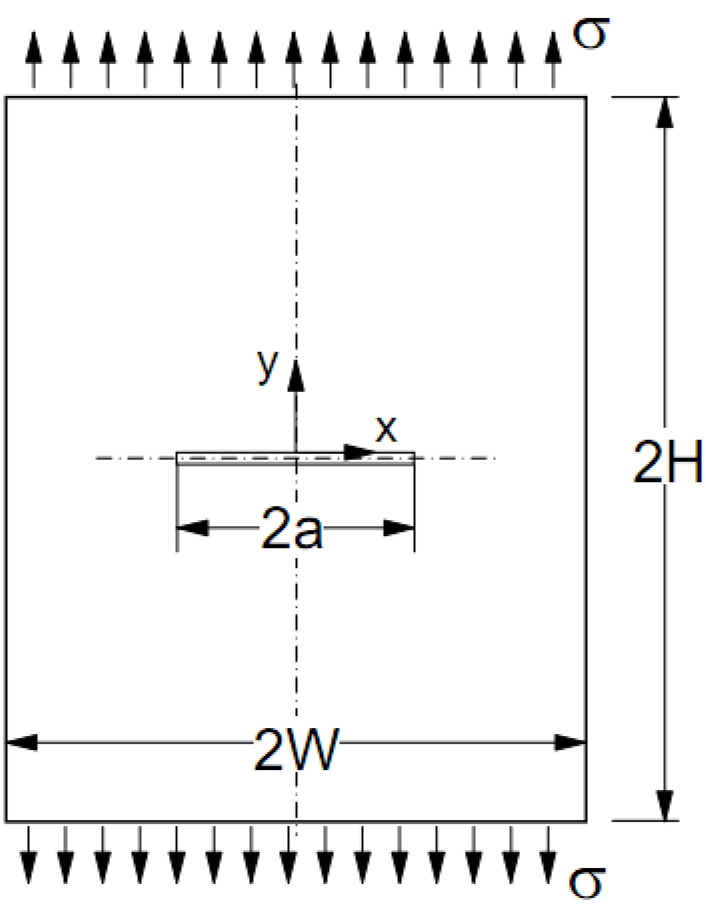
Overview

Reference:	Fett, T., *Stress Intensity Factors, T-Stresses, Weight Functions*, Institute of Ceramics in Mechanical Engineering, University of Karlsruhe, 2008, pp. 151-152
Analysis Type(s):	Static Analysis (**ANTYPE**=0)
Element Type(s):	2-D 8-Node Structural Solid Element (PLANE183) 3-D 8-Node Structural Solid Element (SOLID185) 3-D 20-Node Structural Solid Element (SOLID186)
Input Listing:	vm279.dat

Test Case

A rectangular plate with a center crack is subjected to an end tensile stress σ as shown in Figure 279.1. Symmetry boundary conditions are considered and T-Stress is determined using the **CINT** command.

Figure 279.1: Two-Dimensional Fractural Problem Sketch



Material Properties	Geometric Properties	Loading
Young's Modulus (E) = 207000 MPa Coefficient of friction (μ) = 0.3	a = 10 mm a / W = 0.2 H / W = 0.75	Tensile stress (σ) = 100 MPa

Analysis Assumptions and Modeling Notes

The problem is solved using a 2-D PLANE183 element with plane strain element behavior and 3-D solid elements (SOLID185 and SOLID186). A one-quarter plate is modeled and symmetry boundary conditions are considered. The crack tip nodes and the number of paths surrounding the crack tip nodes are defined using the **CINT** command. The plate is subjected to a tensile stress and the T-Stress is computed for the crack tip nodes. In the 3-D analysis, a plane strain condition is achieved by constraining UZ degrees of freedom of all nodes (displacement in the Z-direction). The crack front and the path surrounding the crack front are defined using the **CINT** command.

Results Comparison

Analysis	Target	Mechanical APDL	Ratio
T-STRESS Using PLANE183 Elements (2-D Analysis)	-110.0000	-110.7618	1.007
T-STRESS Using SOLID185 Elements (3-D Analysis)	-110.0000	-110.4708	1.004
T-STRESS Using SOLID186 Elements (3-D Analysis)	-110.0000	-110.5179	1.005

VM280: Conduction in a Doubly Insulated Pipe Carrying Steam

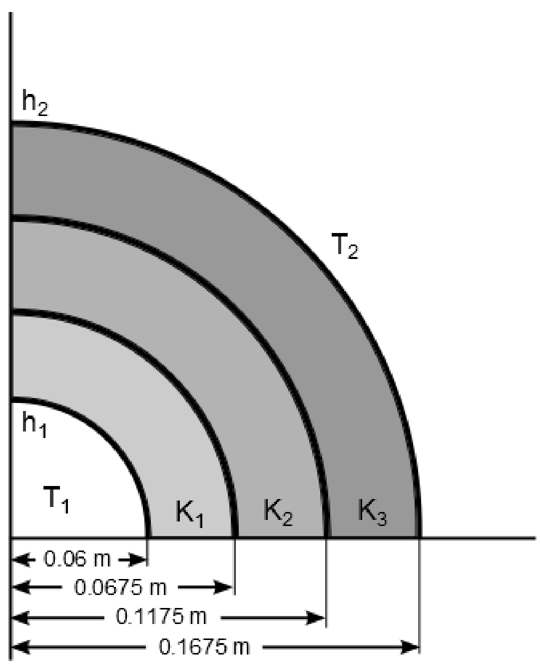
Overview

Reference:	Kothandaraman, C.P., *Fundamentals of Heat and Mass Transfer*, 2006, p. 35
Analysis Type(s):	Steady-State Thermal Analysis (**ANTYPE**=0)
Element Type(s):	3-D 8-Node Thermal Solid Element (SOLID278) 3-D 20-Node Thermal Solid Element (SOLID279)
Input Listing:	vm280.dat

Test Case

A pipe carrying steam at 230 °C has an internal diameter of 0.12 m and a thickness of 0.0075 m. The thermal conductivity of the pipe material, K_1, is 49 W/m·K and the convective heat transfer coefficient on the inside, h_1, is 85 W/m^{2}K. The pipe is insulated by two layers of insulation, one with 0.05 m thickness with thermal conductivity, K_2, of 0.15 W/m·K and over it another layer with 0.05 m thickness with thermal conductivity, K_3, of 0.48 W/m·K. The outside is exposed to air at 35 °C with a convection coefficient, h_2, of 18 W/m^{2}K. Determine the interface temperatures at locations x = 0.06 m, 0.0675 m, 0.1175 m, and 0.1675 m.

Figure 280.1: Pipe Carrying Steam with Insulation Layers Problem Sketch, One-Quarter Cross-Section



Material Properties	Geometric Properties	Loading
Thermal conductivity of pipe material, K_1 = 49 W/m·K Thermal conductivity of the 1st insulation layer, K_2 = 0.15 W/m·K Thermal conductivity of the 2nd insulation layer, K_3 = 0.48 W/m·K	Internal radius of the pipe = 0.06 m Thickness of the pipe = 0.0075 m Thickness of the 1st insulation layer = 0.05 m Thickness of the 2nd insulation layer = 0.05 m	Bulk temperature at pipe inner radius, T_1 = 230 °C Convective film coefficient at pipe inner radius, h_1 = 85 W/m^{2}K Bulk temperature at the outside radius of the 2nd insulation layer, T_2 = 35 °C Convective film coefficient at the outer radius of the 2nd insulation layer, h_2 = 18 W/m^{2}K

Analysis Assumptions and Modeling Notes

The problem is solved twice: first using 3-D 8-node thermal solid elements (SOLID278) and then using 3-D 20-node thermal solid elements (SOLID279). The pipe and the insulation layers are modeled as separate volumes. The bulk temperatures and convective film coefficients at the inside radius of the pipe and the outside radius of the 2nd insulation layer are defined using the **SFE**,,,CONV command. Steady-state (static) thermal analysis is then performed to determine the interface temperature at various locations.

Results Comparison

	Target (°C)	Mechanical APDL (°C)	Ratio
Temperatures at the interface (SOLID278)			
X = 0.06 m	222.300	222.236	1.000
X = 0.0675 m	222.200	222.141	1.000
X = 0.1175 m	77.040	76.207	0.989
X = 0.1675 m	48.030	50.068	1.042
Temperatures at the interface (SOLID279)			
X = 0.06 m	222.300	222.258	1.000
X = 0.0675 m	222.200	222.163	1.000
X = 0.1175 m	77.040	76.508	0.993

	Target (°C)	Mechanical APDL (°C)	Ratio
X = 0.1675 m	48.030	50.133	1.044

VM281: Effect of Stress Stiffening and Spin Softening on a Rotating Plate

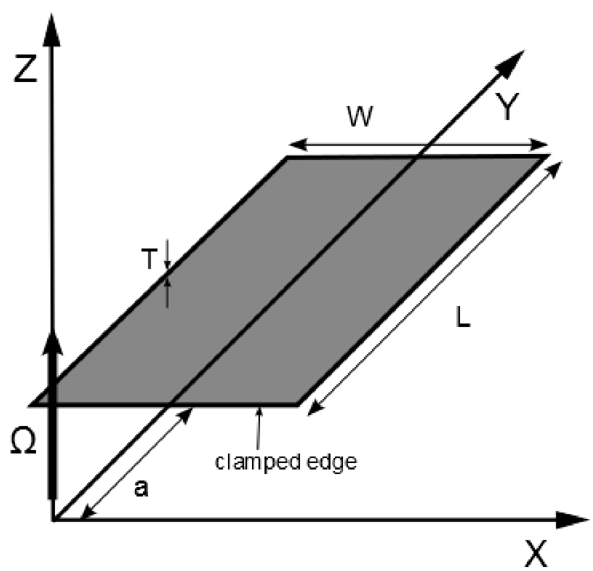
Overview

Reference:	Lawrence, C., Aiello, R. A., Ernst, M. A., McGee, O. G., "A NASTRAN Primer for the Analysis of Rotating Flexible Blades", *NASA Technical Memorandum 89861*, 1987, p. 14
Analysis Type(s):	Static Analysis (**ANTYPE** = 0) Linear Perturbation Modal Analysis (**ANTYPE** = 2)
Element Type(s):	4-Node Structural Shell Element (SHELL181) 8-Node Structural Solid Element (SOLID185)
Input Listing:	vm281.dat

Test Case

A steel plate, clamped on one edge and free on the other edges, is rotating about an offset axis. The first bending frequency is determined as a function of the rotational velocity. The analysis is done for two cases: rotation about the Z-axis (as shown in Figure 281.1: Problem Sketch of a Rotating Plate (p. 811)) and about the X-axis.

Figure 281.1: Problem Sketch of a Rotating Plate



Material Properties	Geometric Properties	Loading
Young's Modulus, E = 2.0 x 10^{11} Pa Poisson's Ratio, ν = 0.3 Density, ρ = 7850 kg/m^3	Length, L = 0.1524 m Width, W = 0.0508 m Thickness, T = 0.00254 m Offset[a], a = 0.1 m	Rotational velocities, Ω = 0, 3200, 9600 RPM

[a]The offset value is not specified in the reference. It was determined based on the frequency value at 9600 RPM along the Z-axis for the shell model.

Analysis Assumptions and Modeling Notes

The problem is solved for two cases. In the first case, the plate is modeled using 4-node structural shell elements (SHELL181). In the second case, the plate is modeled using 8-node structural solid elements (SOLID185). All degrees of freedom are constrained at the plane edge nearest the origin.

The rotational velocity is defined with **CMOMEGA** applied to all elements. The rotation is around the global X-axis (parallel to the plate width) or along the global Z-axis (perpendicular to the plate). For rotation about the X-axis, both the spin softening and stress stiffening affect the bending modes. For rotation about the Z-axis, the spin softening is negligible.

A nonlinear static analysis is performed, followed by a linear perturbation modal analysis to predict the bending modes using the Block-Lanczos eigensolver.

Results Comparison

		Bending Frequency (Hz)		
SHELL181 Elements				
Rotational Velocity Axis	**Ω (RPM)**	**Target**	**Mechanical APDL**	**Ratio**
none	0	90.000	90.831	0.991
X	3200	108.000	108.273	0.997
X	9600	195.000	195.119	0.999
Z	3200	121.000	120.589	1.003
Z	9600	250.000	252.245	0.991
SOLID185 Elements				
Rotational Velocity Axis	**Ω (RPM)**	**Target**	**Mechanical APDL**	**Ratio**
none	0	90.000	90.875	0.990
X	3200	108.000	108.324	0.997
X	9600	195.000	195.234	0.999
Z	3200	121.000	120.602	1.003
Z	9600	250.000	252.303	0.991

VM282: Mode Superposition Response Analysis of a Piston-Fluid System

Overview

Reference:	Axisa, F., Antunes, J., *Modelling Mechanical Systems: Fluid-Structure Interaction*, 2006, p. 486
Analysis Type(s):	Modal Analysis (**ANTYPE** = 2) Mode Superposition Harmonic Analysis (**ANTYPE** = 3)
Element Type(s):	3-D Acoustic Fluid Element (FLUID30) Structural Mass (MASS21) Spring-Damper Element (COMBIN14) 3-D 8-Node Surface-to-Surface Contact Element (CONTA174) 3-D Target Segment Element (TARGE170)
Input Listing:	vm282.dat

Test Case

A simple piston-fluid system is modeled using a spring damper element (COMBIN14) for the piston, fluid elements (FLUID30) for the fluid column, and a mass element (MASS21) for the mass of the piston, as shown in Figure 282.1: Schematic Representation of a Spring-Mass Damper System Coupled to a Compressible Fluid Column in a Tube (p. 813). The contact between the piston and the fluid column is established using the surface-to-surface contact element (CONTA174).

The piston is driven by a harmonic force $F_0 e^{i\omega t}$ along the axial direction. A mode superposition (MSUP) harmonic analysis is performed to investigate the displacement of the piston and the pressure amplitude at mid-column.

Figure 282.1: Schematic Representation of a Spring-Mass Damper System Coupled to a Compressible Fluid Column in a Tube

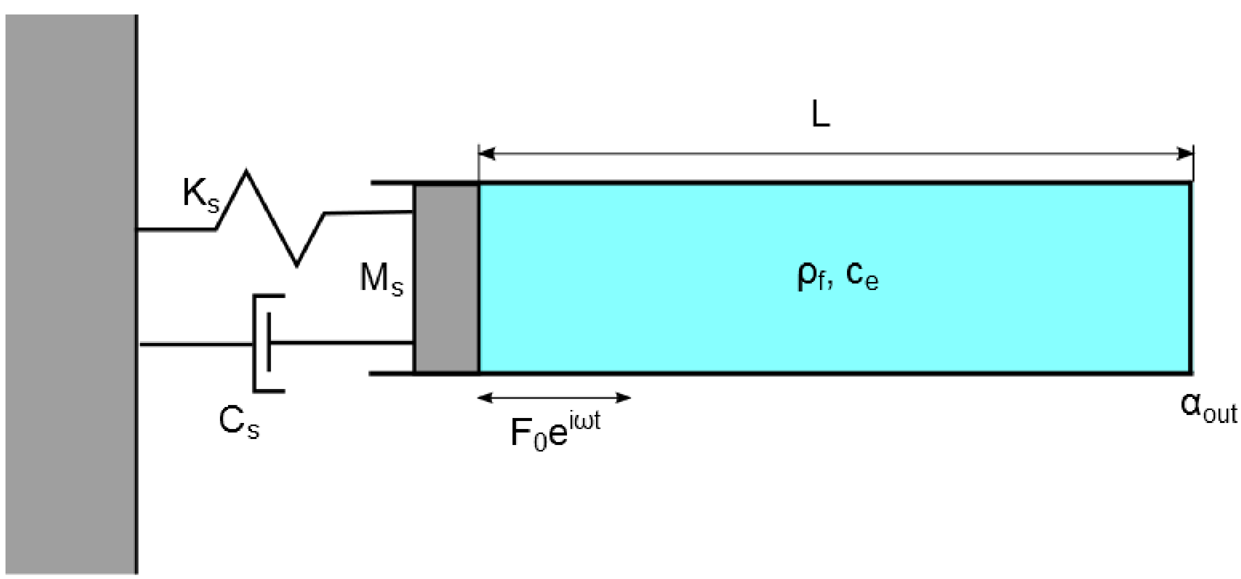
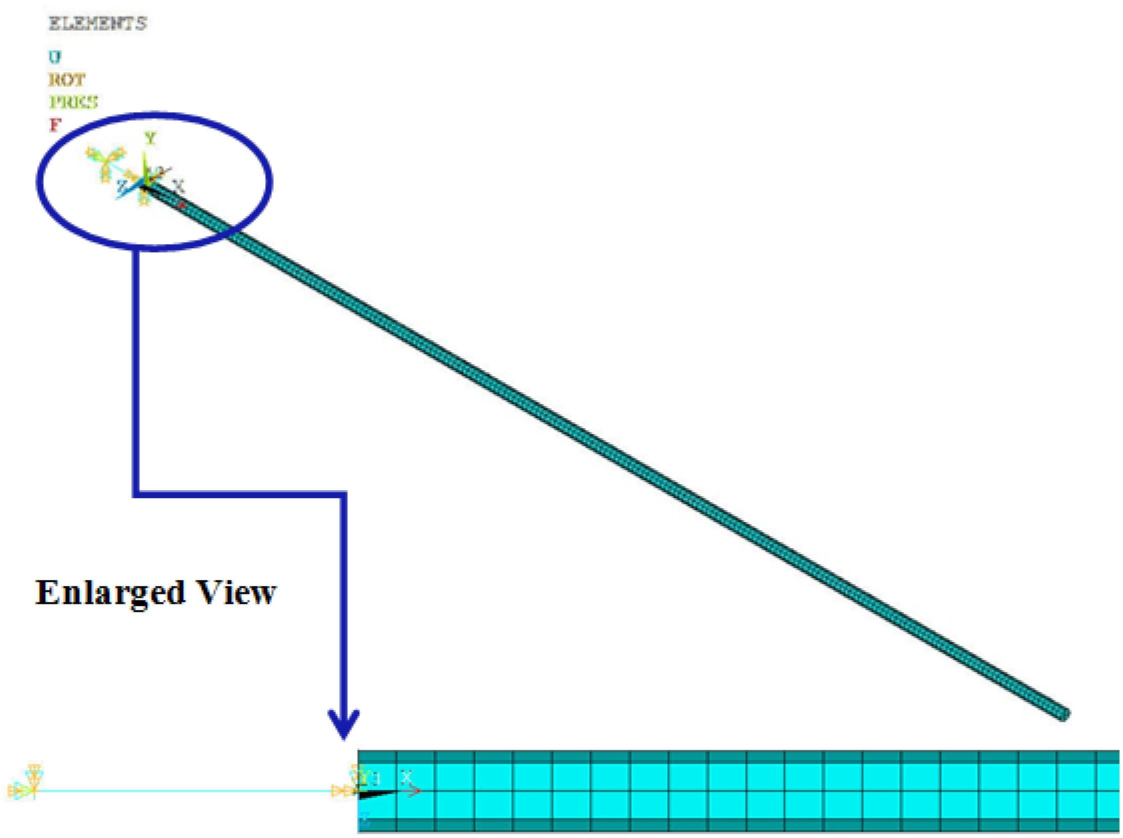


Figure 282.2: Finite Element Representation of a Spring-Mass Damper System Coupled to a Compressible Fluid Column in a Tube



Material Properties	Geometric Properties	Loading
Fluid Properties Density, ρ_f = 1000 kg/m^3	Tube radius, R = 12.5 cm	F_0 = 1000 N

Material Properties	Geometric Properties	Loading
Effective speed of sound, c_e = 1000 m/s Scaling factor of the stiffness of the fluid column, $K_f = 2 \times 10^6$ N/m Mass, M_f = 1178 kg **Structural Properties** Mass, $M_s = M_f/2$ Stiffness, $K_s = K_f$ Modal damping ratios[a] corresponding to $\xi_0 = \dfrac{C_s}{2\sqrt{M_s K_s}} = 0.04$: 2.0453×10^{-2}, 3.6948×10^{-3}, 7.0040×10^{-4}, 2.2468×10^{-4}, 9.8247×10^{-5}	Tube length, L = 24 m	f = 0-100 Hz

[a]The modal damping ratios were obtained in a separate modal analysis using the damped eigensolver.

Analysis Assumptions and Modeling Notes

The piston is modeled as a 1-D spring-mass system with one end fixed. The fluid column is modeled as a straight tube of constant cross-sectional area filled with a compressible fluid. The tube is closed at the outlet.

The MPC-based contact pairs are established using CONTA174 elements (KEYOPT(2) = 2) between the piston and the fluid column. The fluid-structure interaction (FSI) condition is defined using the **SF**,,FSI command at the interface between the piston and the fluid column.

A modal analysis of the piston-fluid system is performed using the unsymmetric eigensolver. The frequencies obtained from this simulation are compared with the analytical solution.

After performing the modal solve, the response of the piston-fluid system is evaluated using a mode-superposition harmonic analysis for a frequency range of excitation between 0-100 Hz. The damping in the piston is considered by specifying modal damping ratios (**MDAMP**). These results are then compared with the analytical solution.

Results Comparison

Modal Frequency	Target	Mechanical APDL	Ratio
f_1, Hz	9.916	9.877	0.996
f_2, Hz	24.583	24.305	0.989
f_3, Hz	43.729	43.526	0.995

Modal Frequency	Target	Mechanical APDL	Ratio
f_4, Hz	63.895	63.760	0.998
f_5, Hz	84.395	84.292	0.999

	Target	Mechanical APDL	Ratio
Piston displacement amplitude at 1.0 Hz, m	0.00025	0.00026	1.052
Piston displacement amplitude at f_1, m	0.00576	0.00575	0.998
Fluid pressure amplitude at 1.0 Hz, MPa	10300.000	10881.003	1.056
Fluid pressure amplitude at f_1, MPa	264000.000	263403.917	0.998

The nodal solution plot (**NSOL**) shows the response with respect to the frequency of excitation.

Figure 282.3: Piston Displacement Response

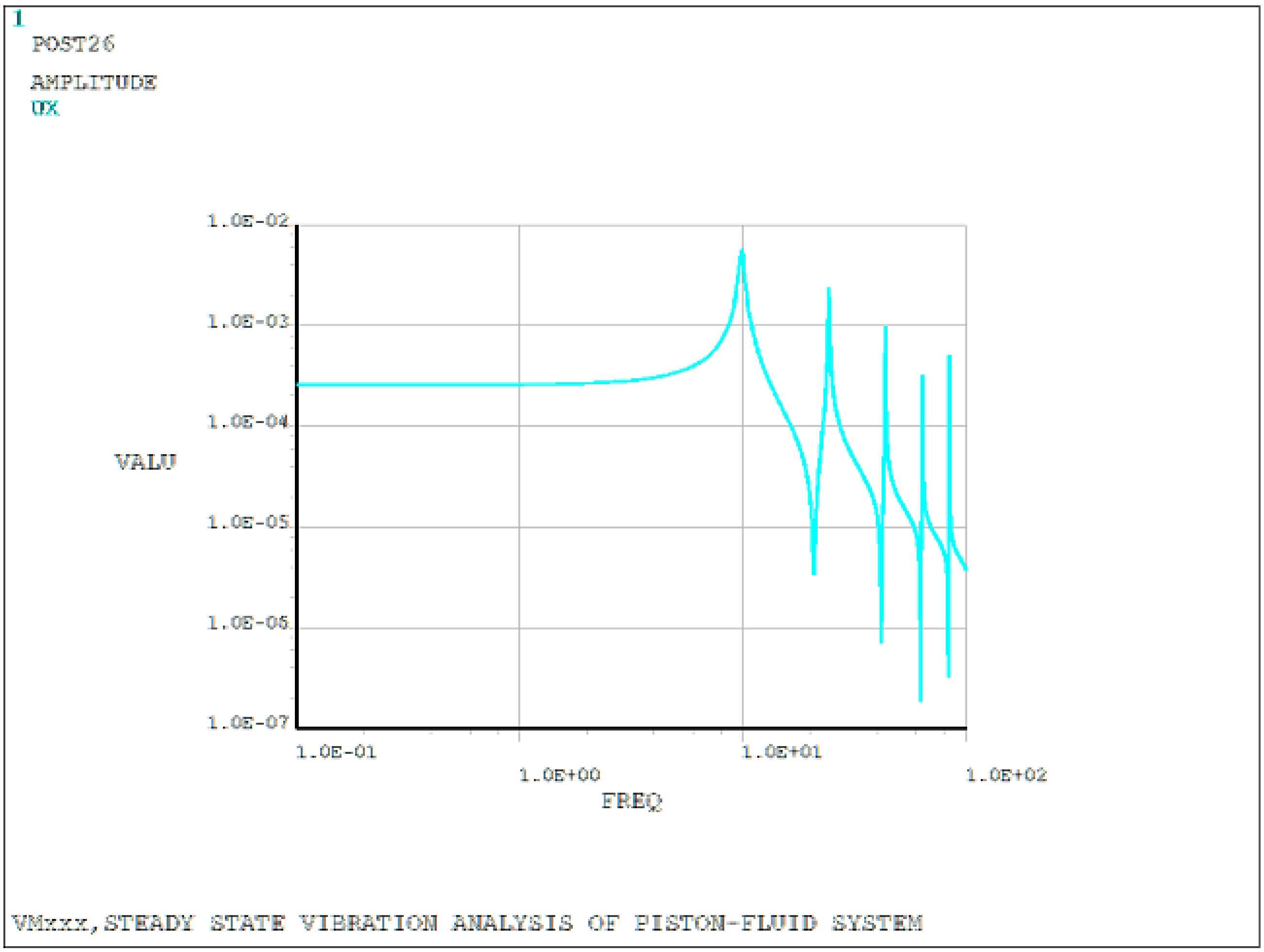
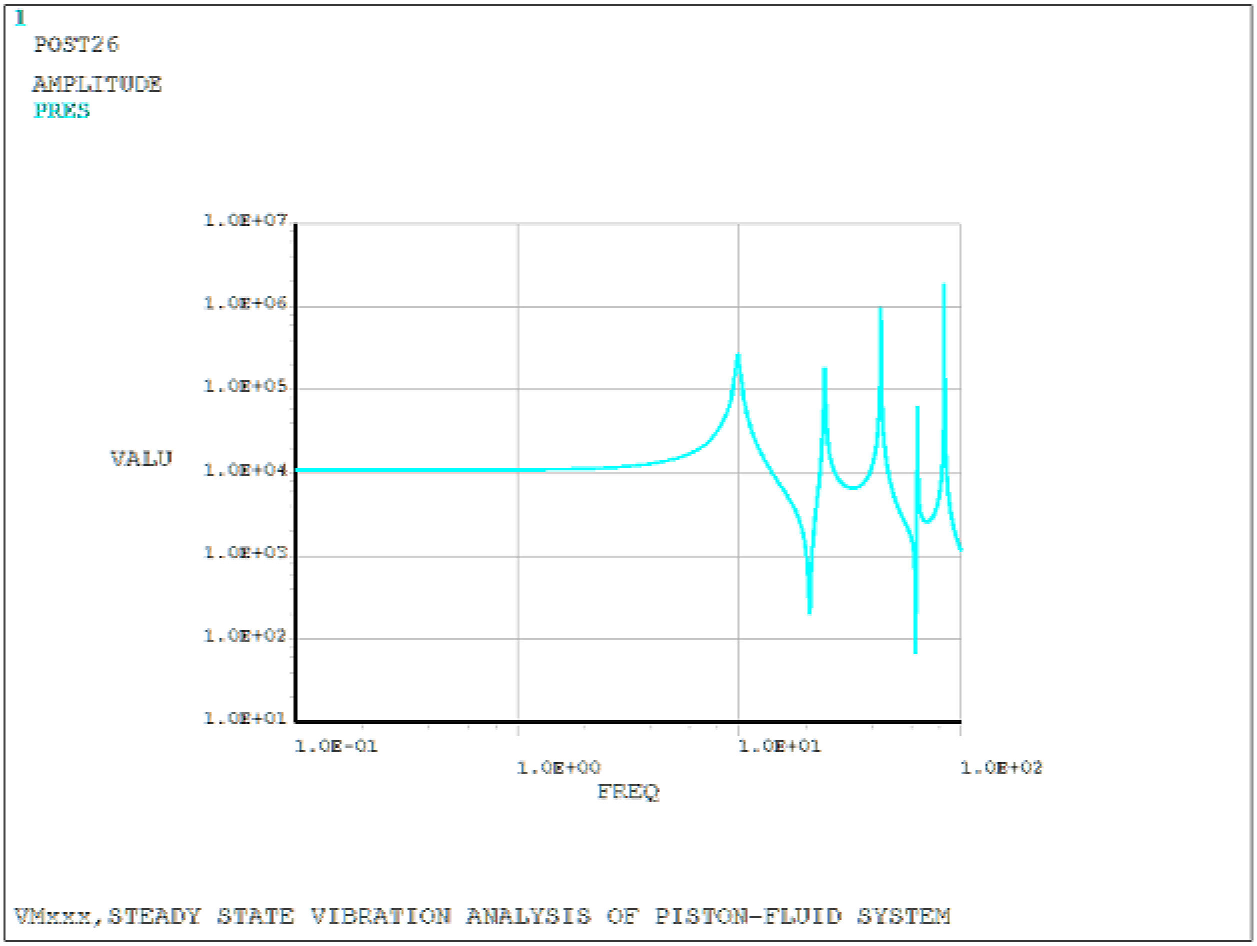


Figure 282.4: Fluid Pressure Response at Mid-Column



VM283: Low Reduced Frequency Model for Visco-thermal Fluid with Thin Structure

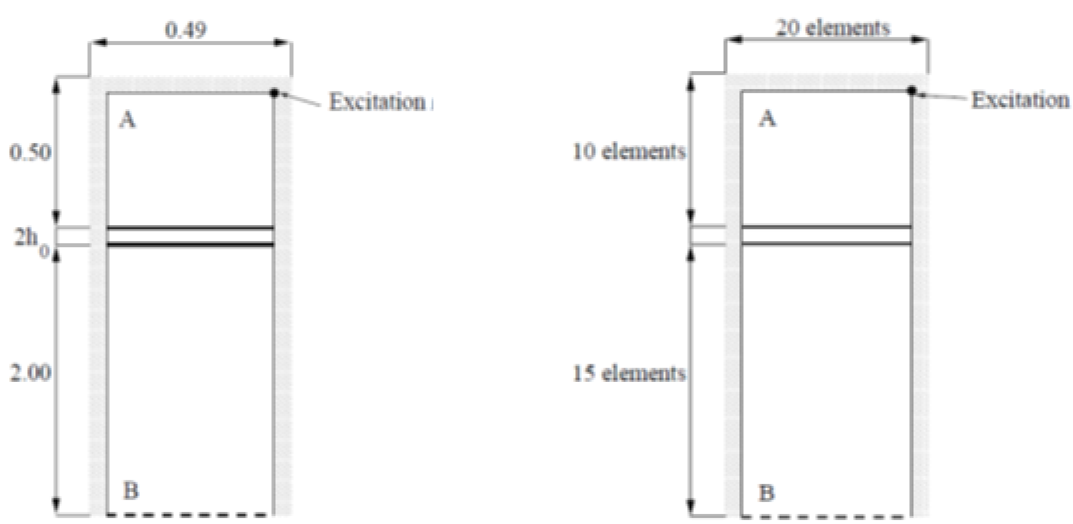
Overview

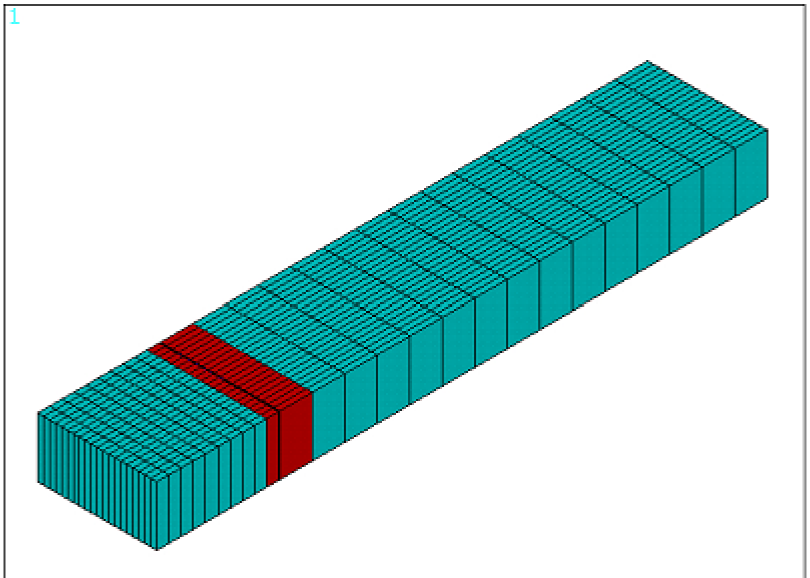
Reference:	Beltman, W.M, "Viscothermal Wave Propagation Including Acousto-Elastic Interaction", PhD Thesis, University of Twente, Mechanical Engineering Department, 1998, pp. 128-136
Analysis Type(s):	Full Harmonic Analysis (**ANTYPE** = 3)
Element Type(s):	3-D Acoustic Fluid 8-Node Solid Elements (FLUID30) 3-D 8-Node Structural Solid Shell (SOLSH190)
Input Listing:	vm283.dat

Test Case

The acoustic transmission loss between two rooms separated by a double-wall aluminum panel is calculated in a frequency range from 10 to 300 Hz. An excitation source in room A generates a pressure field, and the panel transmits a part of the incident energy into room B. All transmitted energy will be absorbed at the impedance boundary at the far end of room B. The walls of room A and B are hard, except for the sides coupled to the double wall panel and the impedance boundary.

Figure 283.1: Double Wall Configuration and Finite Element Model





Material Properties	Geometric Properties
For air: Speed of sound = 340 m/s Density = 1.2 kg/m^3 Dynamic viscosity = 18.2 x 10^{-6} Pa·s Thermal conductivity = 25.6 x 10^{-3} W/m·K Specific heat = 1004 J/kg·K Heat coefficient at constant volume per unit of mass = 1004/1.4 J/kg·K **For aluminum plates:** Density = 2710 kg/m^3 Elastic modulus = 70 x 10^9 N/m^2 Poisson's ratio = 0.3	Thickness of visco-thermal thin layer = 2 mm Thickness of aluminum plates = 1 mm and 2 mm Height of room A = 0.5 m Height of room B = 2.0 m Width = 0.49 m Depth = 0.245 m

Analysis Assumptions and Modeling Notes

The lengths of room A and room B along the Z-direction are meshed with 10 and 15 FLUID30 elements, respectively. The width is meshed with 20 FLUID30 elements. The aluminum plates are meshed using structural solid shell elements (SOLSH190). The visco-thermal layer between the aluminum plates and the volumes of room A and B are all meshed using pure acoustic elements, except for interfaces with structural solid shell elements. On these interfaces, coupled acoustic elements with fluid-structure interaction (FSI) are applied. Loading is not considered in this model, because transmission loss is calculated from the ratio of average pressures. The infinite radiation impedance boundary condition is specified to absorb waves reflected out of the system.

Results Comparison

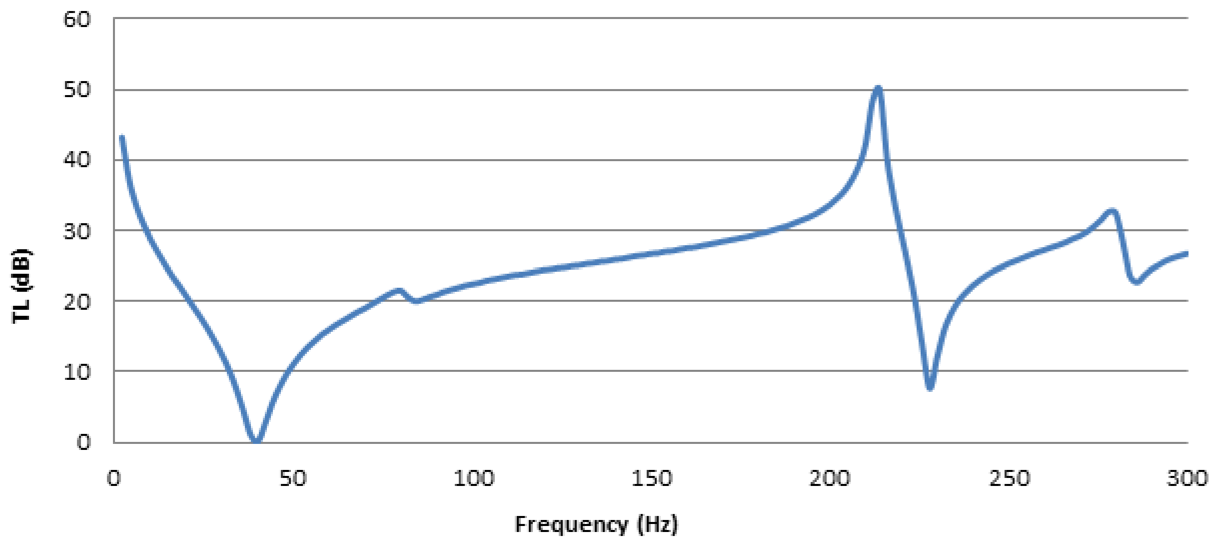
The transmission loss (TL) is calculated using the average nodal pressures in room A and across the absorbing boundary of room B, respectively.

$$TL = 20 \log \frac{P_A}{P_B}$$

The TL value obtained from Mechanical APDL shows the same variation trend versus frequency as depicted in Figure 6.31 in the reference material. The computed TL values at the peaks and troughs are listed with target values obtained from the reference figure.

Frequency (Hz)	Target (dB)	Mechanical APDL	Ratio
10	29.000	28.708	1.007
40	0.000	0.071	1.000
80	22.000	21.544	1.000
84	20.000	20.000	1.000
214	51.500	49.984	0.971
228	8.000	7.642	0.950
278	34.000	32.576	0.988
286	24.000	22.696	0.908
300	28.500	26.685	0.921

Figure 283.2: Transmission Loss Versus Frequency for the Double Wall Configuration Obtained from Mechanical APDL



Part II: Benchmark Study Descriptions

Chapter 1: Overview

This manual also provides information on the applicability, selection and performance of Mechanical APDL finite elements, meshing algorithms, and solution algorithms by a series of benchmark test cases. The benchmark studies are designed to illustrate both proper, and in some cases, improper application of finite element techniques in various modeling situations. Improper use may take the form of inappropriate element selection or mesh discretization. The results presented here for some test cases may appear in error, but are in fact the "expected" solutions for the chosen element, discretization, and loading condition. By providing the results for such test cases, we hope to provide guidance in the selection of appropriate analysis options.

While ANSYS, Inc. cannot provide an exhaustive set of benchmark studies, we have included the most commonly-used elements and analysis types. Using these benchmark studies as a guideline, you can extend the applicability to other element types or solution methods. In many instances, existing benchmark standards were used as the basis of the test case construction.

The following benchmark topics are available:

1.1. Description of the Benchmark Studies

The benchmark test cases are designed to test element performance, meshing algorithm's effect on solution performance, alternative solution algorithms (for modal analysis), and element energy error norm performance.

Element performance (accuracy) is checked for a subset of some of the more frequently used solid and shell elements including PLANE35, PLANE182, PLANE183, SHELL63, SHELL181, SHELL281, SOLID70, PLANE77, PLANE55, SOLID186, and SOLID187. The tests are designed to check the element performance under various load conditions and element shapes. Solution accuracy and convergence rates are also presented for the elements.

The effect of alternative meshing schemes on solution accuracy is studied for several test cases. The meshing schemes include quadrilateral and triangle meshing for areas, and brick and tetrahedral meshing for volumes. Solution accuracy is based on the energy error norm and/or localized stress and displacement evaluation.

For benchmark test cases using 2-D and 3-D solid elements in a static analysis, results are in part expressed in terms of an energy error norm. Energy error norms can be used as a guide in evaluating the mesh discretization used in a finite element analysis. See Energy Norm (p. 827) for more information.

The benchmarks are categorized into VMD*XX* test cases and VMC*XX* test cases (where *XX is the problem number). The VMD series is specifically designed to test individual finite element performance under distorted, or irregular shapes. The VMC series is designed to test solution accuracy and convergence for a series of test* *cases that undergo increasing mesh refinement or use alternate element types. The benchmark studies follow the documentation of the VM test cases in this manual.*

Three types of analyses are included in the benchmark tests:

- Static analysis (ANTYPE = 0)
- Mode frequency analysis (ANTYPE = 2)
- Transient analysis (ANTYPE = 4)

The benchmark test cases are drawn from a variety of resources, such as NAFEMS (National Agency for Finite Element Methods and Standards) based in the United Kingdom, proposed benchmarks in the literature, and textbook problems. Where applicable, test cases that conform to published benchmark specifications are identified.

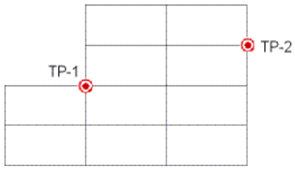
1.2. Benchmark Test Case Content and Nomenclature

Format and content for the benchmark test cases are as follows:

- **Overview**--a list of the major reference for the problem, the analysis type, the element type(s), and the name of the test case file (in the printed manual) or a link to the test case file (in the online version).
- **Test Case**--a brief description of the problem and desired solution output. Also included are necessary material properties, geometric properties, loadings, boundary conditions, and parameter definitions. The parameters listed in the parameter definition area are used to define model variables that distinguish each test case run. Each test case is uniquely defined by these parameters and noted in the Results Comparison section.
- **Representative Mesh Options**--a graphics display of a sampling of the finite element meshes created by the test. Parameters defined in the Test Case section are used to specify the finite element mesh patterns shown.
- **Target Solution**--solution used for comparison purposes. The target solution is obtained from the problem reference unless specifically mentioned otherwise in the Assumptions, Modeling Notes, and Solution Comments section.
- **Results Comparison**--results from the Mechanical APDL solution compared with the target solution. Where applicable, the Mechanical APDL results are normalized with respect to the target solution and presented as the ratio of the Mechanical APDL results divided by the target results.
- **Graphical Results** (optional)--results displayed in graphical form.
- **Assumptions, Modeling Notes, and Solution Comments**--general comments on the test case modeling, assumptions, and results interpretation.

In addition to the abbreviations, symbols, and units defined in Abbreviation and Symbol List (p. 8), one additional symbol is used throughout the benchmark studies to identify the location of a target point where a solution comparison is made. The target point symbol is a bull's-eye: ◉

Several target points may be used in a test case, so each is identified separately as Target Point*xx* (or TP-*XX*). The example below shows two target points on a simple 2-D finite element mesh.



Solution comparisons between the target solution and the Mechanical APDL solution at target points are listed in the Results Comparison section.

1.3. Running the Benchmark Test Cases

The benchmark test cases are contained on the installation media. Each test case input file is designed to be executed in one of two ways:

- Execute the single documented test case input (as shown in the Data Input Listing section for the problem in this manual; see Appendix B (p. 1805))
- Execute all test cases for the problem. The single test case executions are designed to run quickly, with run times comparable to the larger tests in Overview (p. 825). Executing all test cases is, in many instances, very time consuming and may require extremely large amounts of disk space and memory.

1.4. Energy Norm

The finite element solution is an approximation to the true solution of a mathematical problem. From an analyst's standpoint, it is important to know the magnitude of error involved in the solution. The Mechanical APDL program offers a method for a posteriori estimation of the solution error due to mesh discretization. The method involves calculating the energy error within each finite element and expressing this error in terms of a global error energy norm.

The error energy within each finite element is calculated as

$$e_i = 1/2\int_V \{\Delta\sigma\}^T [D]^{-1} \{\Delta\sigma\}\, dV$$

where:

e_i = error energy in element i
$\{\Delta\sigma\}$ = nodal stress error vector
$[D]$ = stress-strain matrix

The nodal stress error vector $\{\Delta\sigma\}$ is the averaged nodal stresses minus the unaveraged nodal stresses.

By summing all element error energies e, the global energy error in the model, e, can be determined. This can be normalized against the total energy (u + e), where u is the strain energy, and expressed as a percent error in energy norm, E:

The percent error in energy norm E is a good overall global estimate of the discretization or mesh accuracy. Several VMD and VMC tests use this error norm to illustrate its behavior as a function of known displacement or stress error. It should be recognized that the correlation of the error energy norm to displacements or stress error is problem-dependent, and therefore this norm should only be viewed as a relative measure of accuracy.

1.5. Benchmark Test Case Coverage Index

Table 1.1: Structural Plane Elements

Test Case No.	Element Number			
	42	**82**	**182**	**183**
C2	X	X	X	X
C5				
C8	X	X		X
D1	X	X		X
D3	X	X		X

Table 1.2: Structural Solid Elements

Test Case No.	Element Number					
	45	**92**	**95**	**185**	**186**	**187**
C1	X	X	X	X	X	X
C2						
C5	X	X				
C8	X		X			
D1	X	X	X			
D3	X	X	X			

Table 1.3: Structural Shell Elements

Test Case No.	Element Number				
	43	**63**	**93**	**181**	**281**
C3	X	X	X	X	
C4	X	X	X		X
D2	X	X	X	X	

Table 1.4: Thermal Solid Elements

Test Case No.	Element Number		
	35	**55**	**77**
C6	X	X	X
C7	X	X	X

Table 1.5: Analysis Type Coverage

Test Case No.	ANTYPE Analysis Type		
	0	**2**	**4**
C1	X		
C2	X		
C3	X		

Test Case No.	ANTYPE Analysis Type		
	0	2	4
C4		X	
C5		X	
C6	X		
C7	X		
C8			X
D1	X		
D2	X		
D3		X	

VMC1: Built-In Plate Under Uniformly Distributed Load

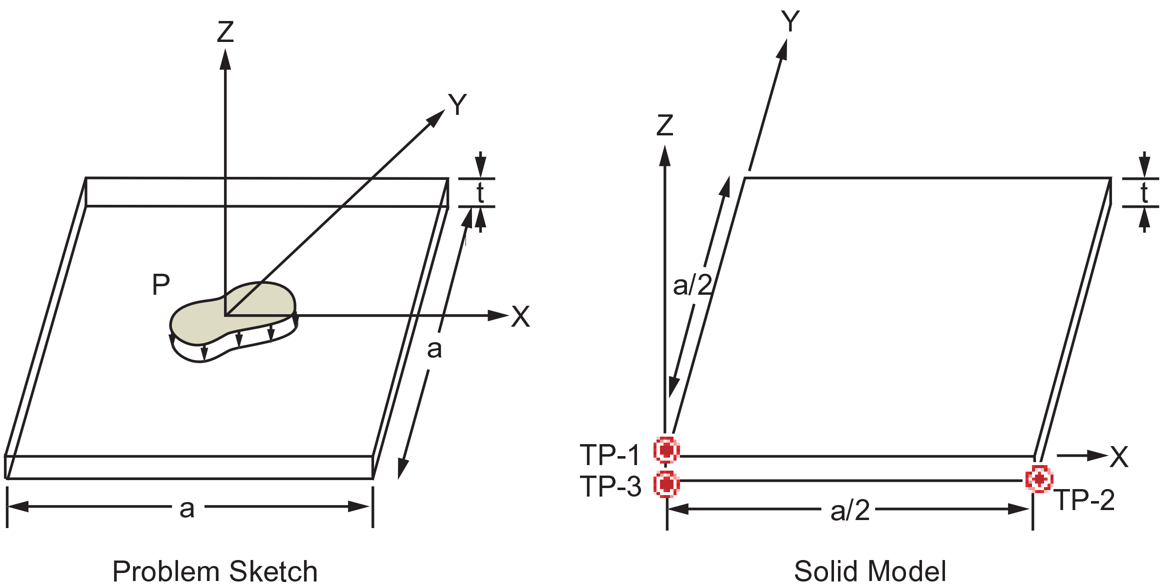
Overview

Reference:	S. Timoshenko, S, Woinowsky-Knieger, *Theory of Plates and Shells*, McGraw-Hill Book Co., Inc., New York, NY, 1959, pg. 202, Approximate Solution
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	3-D Structural Solid Elements (SOLID45) 3-D 8-Node Structural Solid Elements (SOLID185) 3-D 10-Node Tetrahedral Structural Solid Elements (SOLID92, SOLID187) 3-D 20-Node Structural Solid Elements (SOLID95, SOLID186)
Input Listing:	vmc1.dat

Test Case

A rectangular plate with built-in edges is subjected to a uniform pressure load on the top and bottom surface. Monitor displacement and stress results at three target points for a series of mesh refinements for different elements. Compare the effect of increased mesh refinement on the percent energy error norm.

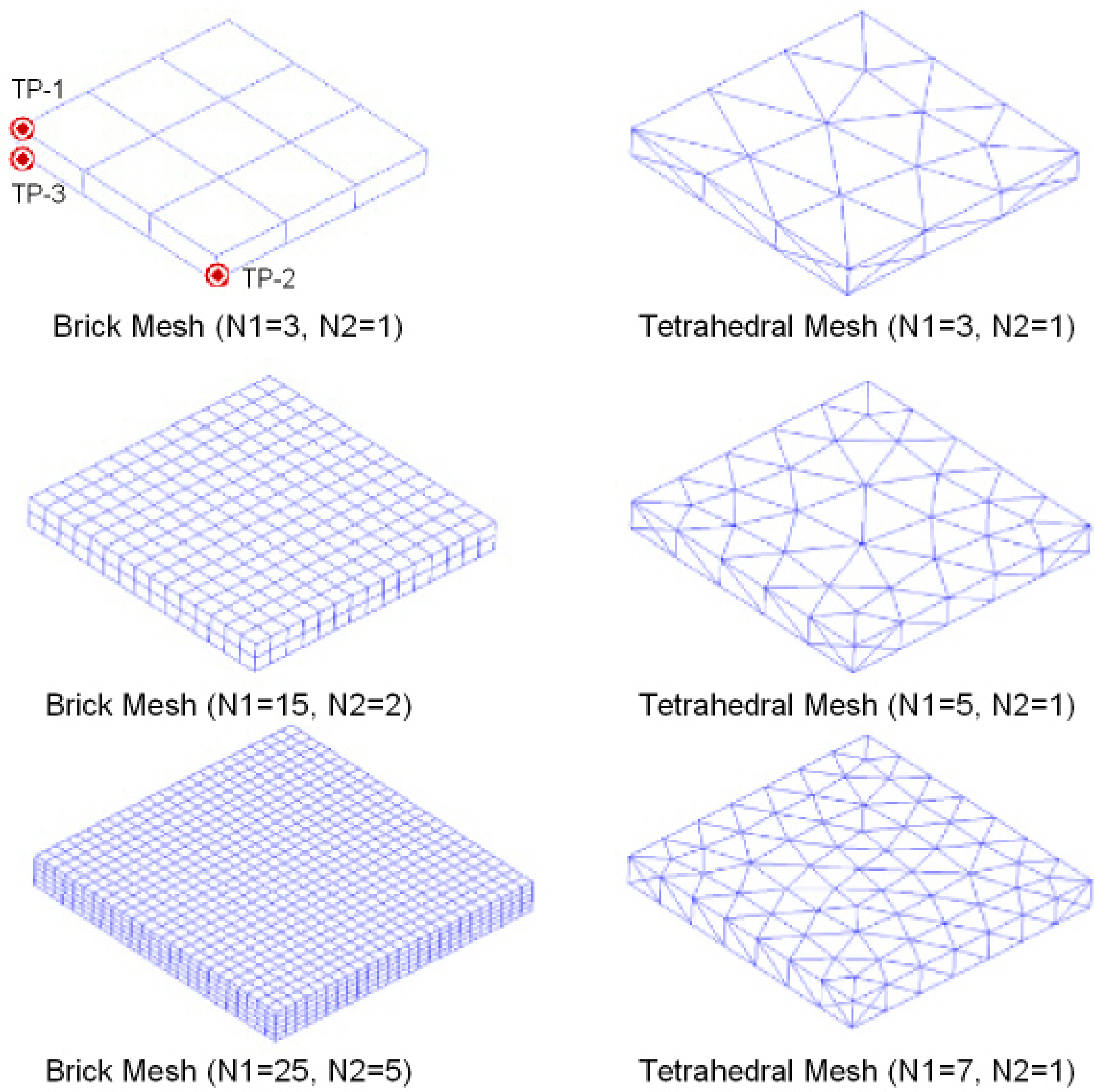
Figure C1.1: Built-in Plate Problem Sketch



Material Properties	Geometric Properties	Loading and Boundary Conditions for Mechanical APDL Model
$E = 1 \times 10^7$ psi $\upsilon = 0.3$	a = 10 in t = 1 in **Parameter Definitions**	Loading: Pressure = 1000 psi Boundary Conditions: At X = a/2, UX = 0 At x = a/2 and Z = 0, UZ = 0

Material Properties	Geometric Properties	Loading and Boundary Conditions for Mechanical APDL Model
	N1 = no. elements along each horizontal edge N2 = no. elements through thickness	At Y = a/2, UY = 0 At Y = a/2 and Z = 0, UZ = 0 At X = 0, UX = 0 At Y = 0, UY = 0 At Z = 0, UX = UY = 0 At Z = -t/2, P = -500

Figure C1.2: Representative Mesh Options



Solution Information

Table C1.1: Target Solution

ETYP	N1	N2	DOF	% Error Norm	UZ(1), in	SX(2), ksi	SX(3), ksi
95	25	10	45708	10	-.0172	-32.124	14.465

Table C1.2: Results Comparison

ETYP	N1	N2	DOF	% Error Norm	Ratio UZ(1)	Ratio SX(2)	Ratio SX(3)
45	3	1	96	56.559	.925	.461	.983
45	6	1	294	33.354	.961	.663	.985
45	15	2	2304	19.077	.980	.851	.992
45	20	4	6615	14.575	.987	.913	.996
45	25	5	12168	13.194	.990	.936	.997
95	3	1	288	8.365	.958	.829	1.037
95	6	1	945	7.725	.978	.955	1.006
95	15	2	8160	10.25	.991	.961	.999
95	20	4	24507	10.16	.997	1.000	1.000
92	3	1	741	37.573	0.957	0.822	0.977
92	5	1	1377	27.360	0.974	.934	1.001
92	7	1	2493	23.100	0.98	0.960	1.000
92	10	1	4629	20.425	.984	0.966	1.00
185	3	1	96	56.946	0.928	0.434	0.935
185	6	1	294	34.017	0.962	0.653	0.973
185	15	2	2304	19.154	0.980	0.850	0.991
185	20	4	6615	14.591	0.987	0.913	0.996
185	25	5	12168	13.202	0.990	0.936	0.997
186	3	1	288	8.365	0.958	0.829	1.037
186	6	1	945	7.725	0.978	0.955	1.006
186	15	2	8160	10.250	0.991	0.961	0.999
186	20	4	24507	10.160	0.997	1.001	1.000
187	3	1	741	37.573	0.957	0.822	0.977
187	5	1	1377	27.360	0.974	0.934	1.001
187	7	1	2493	23. 100	0.979	0.960	1.000

ETYP	N1	N2	DOF	% Error Norm	Ratio UZ(1)	SX(2)	SX(3)
187	10	2	4629	20.425	0.984	0.966	1

Table C1.3: Results Comparison - Shell Element and Analytical Solution

ETYP	N1	N2	DOF	% Error Norm	UZ(1), in	SX(2), ksi	SX(3), ksi
35	5	1	576	NA	-.0165	-29.580	14.303
Approximate Analytical Solution (neglecting shear deflection)					-.0138	-30.780	13.860

Assumptions, Modeling Notes, and Solution Comments

1. The problem exhibits symmetry about the midplane of the plate, and about the X and Y axes. This symmetry allows for a 1/8 symmetry sector to be modeled.

2. The approximate analytical solution neglects shear deflection. Shear deflection is accounted for in the finite element solutions.

3. The target solution is obtained from a fine mesh solution using SOLID95.

4. The 8-node isoparametric shell (SHELL281), subjected to the same loading, has results in line with the target solution. The SHELL281 element takes into account shear deflection effects.

5. Deflection and bending stresses converge quickly to the target solution at the center of the plate (target points 1 and 3) for the solid element test cases.

6. Bending-stresses are maximum at the built-in edges, peaking at the midspan of the plate (target point 2). It can be seen that a significant number of elements through the plate thickness are required to accurately predict the bending stresses at the built-in edge for the solid elements.

7. The percent error in energy norm remains relatively high as the mesh is refined, with most of the error energy located at the built-in edges. This behavior is expected at built-in edges where point-wise inaccuracies in the solution occur. The displacement and stress results for which the refinement was targeted are quite good, despite the high energy error.

VMC2: Elliptic Membrane Under a Uniformly Load

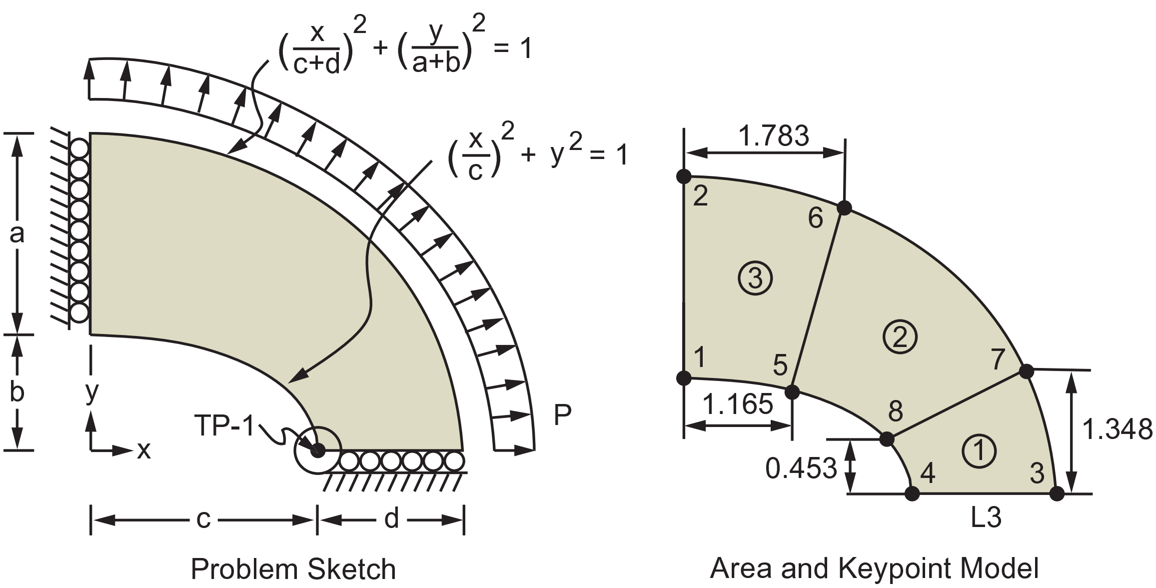
Overview

Reference:	J. Barlow, G. A. O. Davis, "Selected FE Benchmarks in Structural and Thermal Analysis", *NAFEMS Rept. FEBSTA*, Rev. 1, October 1986, Test No. LE1 (modified)
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D Structural Solid Elements (PLANE42) 2-D 4-Node Structural Solid Elements (PLANE182) 2-D 8-Node Structural Solid Elements (PLANE82, PLANE183)
Input Listing:	vmc2.dat

Test Case

An elliptic membrane structure of thickness t is subjected to a uniformly distributed outward pressure P. Monitor the tangential edge stress σ_y at target point 1 for a series of uniform mesh refinements using quadrilateral and triangular elements. Compare the effect of increased mesh refinement with the percent energy error norm.

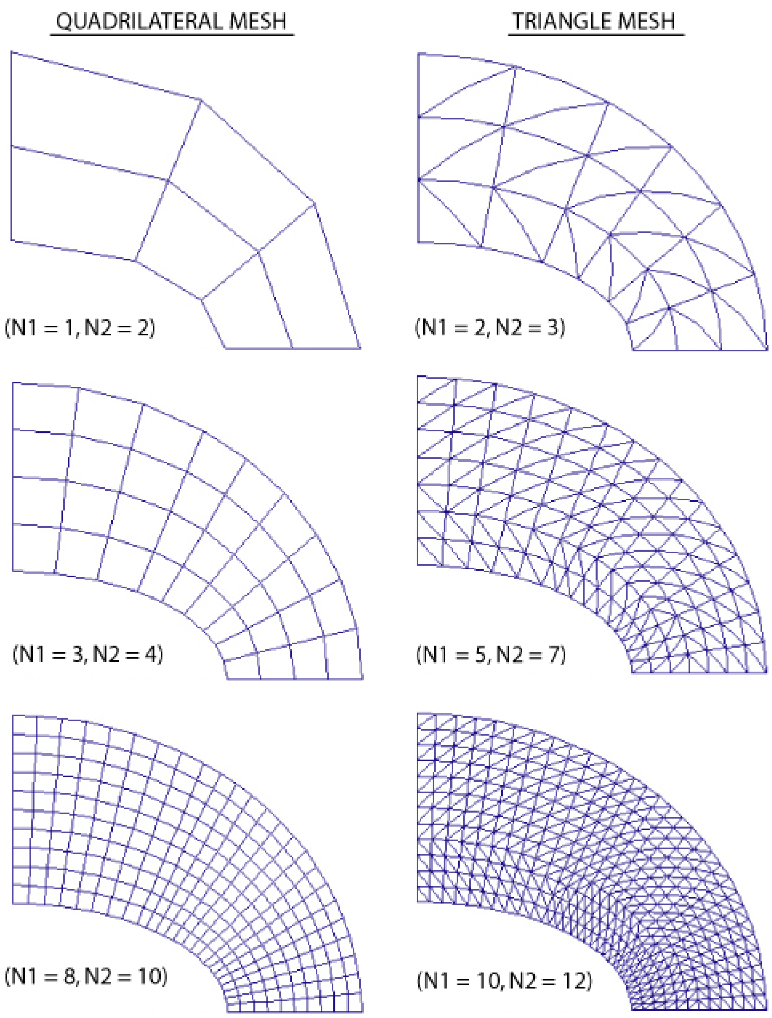
Figure C2.1: Elliptic Membrane Problem Sketch



Material Properties	Geometric Properties	Loading and Boundary Conditions
$E = 210 \times 10^3$ MPa $\upsilon = 0.3$	a = 1.75 m b = 1.0 m c = 2.0 m d = 1.25 m t = 0.1 m **Parameter Definitions**	At x = 0 UX = 0 At y = 0 UY = 0 Along outer edge P = -10 MPa

Material Properties	Geometric Properties	Loading and Boundary Conditions
	N1 = no. elements in circumferential direction, per area N2 = no. elements in radial direction per area	

Figure C2.2: Representative Mesh Options



Results Tables

Target Solution: SY = 92.7 MPa Results Comparison - Quadrilateral Meshing

ETYP	N1	N2	DOF	% Error Norm	SY Ratio
42	1	2	24	36.452	0.634
42	2	3	56	22.545	0.809
42	3	4	100	16.549	0.885
42	5	7	256	10.781	.960
42	8	10	550	7.513	0.987

ETYP	N1	N2	DOF	% Error Norm	SY Ratio
42	10	12	806	6.306	0.994
82	1	2	58	15.914	0.844
82	2	3	146	5.764	0.899
82	3	4	270	3.157	0.924
82	5	7	720	0.981	0.963
82	8	10	1578	0.422	0.977
82	10	12	2330	0.270	0.982
182	1	2	24	33.020	0.720
182	2	3	56	26.575	0.861
182	3	4	100	20.817	0.923
182	5	7	256	14.197	0.987
182	8	10	550	9.906	1.007
182	10	12	806	8.290	1.012
183	1	2	58	15.914	0.844
183	2	3	146	5.764	0.899
183	3	4	270	3.157	0.924
183	5	7	720	0.981	0.963
183	8	10	1578	0.422	0.977
183	10	12	2330.	0.270	0.982

Results Comparison - Triangular Meshing

ETYP	N1	N2	DOF	% Error Norm	Normalized SY
2	1	2	70	22.484	0.737
2	2	3	182	10.657	0.837
2	3	4	342	6.612	0.882
2	5	7	930	2.665	0.942
2	8	10	2058	1.480	0.965
2	10	12	3050	1.159	0.973

Assumptions, Modeling Notes, and Solution Comments

1. From an element performance standpoint, the problem is designed to test membrane elements for accurate modeling of the strain variation, nodal stress extrapolation, and curved boundary modeling (of higher order elements).

2. From a modeling standpoint, the problem is designed to test quadrilateral and triangular meshes for solution accuracy with various element types. For the areas modeled, all exterior line segment specifications for mesh density are made equal for the various mesh options.

3. For quadrilateral and triangle element meshes under uniform mesh refinement (parameters N1 and N2 varied), the calculated percent error in energy norm follows a log-log linear relationship to the number of degrees of freedom in the model. The higher order element (PLANE82) exhibits nearly identical log-

log slopes while the lower order element (PLANE42) exhibits a more gradual slope. These results illustrate that the PLANE82 solutions converge at nearly the same rate under uniform refinement while PLANE42 converges at a slower rate. The percent error in energy norm results indicate that global accuracy is best obtained by PLANE82 for any given DOF set. However, the σ_y stress at target point 1 shows that for uniform refinement, PLANE42 gives better results (at that point) under moderate mesh refinement. A fine mesh using PLANE42 in place of a coarse mesh of PLANE82 may produce better localized stress values.

VMC3: Barrel Vault Roof Under Self Weight

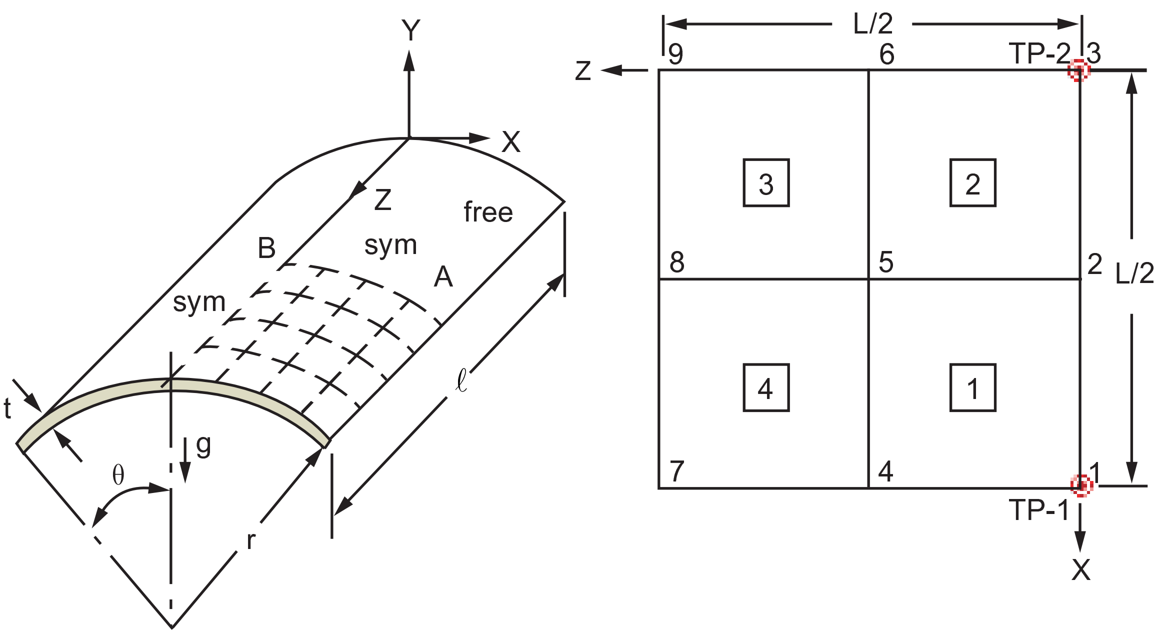
Overview

Reference:	R. D. Cook, *Concepts and Applications of Finite Element Analysis*, 2nd Edition, John Wiley and Sons, Inc., 1981, pp. 284-287.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Elastic Shell Elements (SHELL63) 4-Node Finite Strain Shell Elements (SHELL181) 8-Node Structural Shell Elements (SHELL281)
Input Listing:	vmc3.dat

Test Case

A cylindrical shell roof is subjected to gravity loading. The roof is supported by walls at each end and is free along the sides. Monitor the y displacement and bottom axial stress (σ_z) at target point 1, along with the bottom circumferential stress (σ_θ) at target point 2 for a series of test cases with increasing mesh refinement using quadrilateral and triangular element shapes. A companion problem that studies irregular element shapes is VMD2.

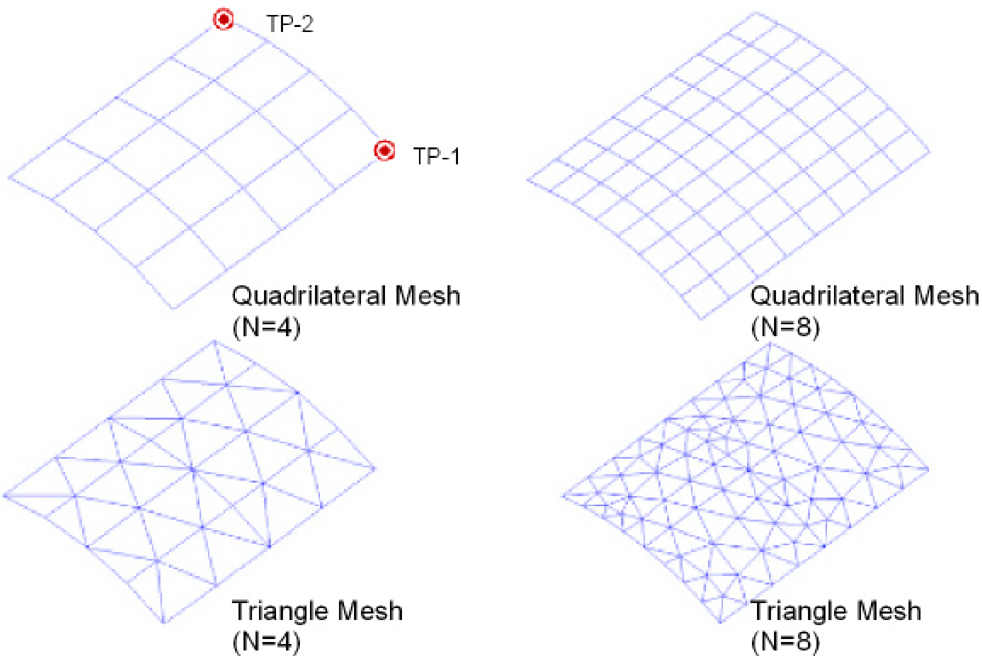
Figure C3.1: Barrel Vault Roof Problem Sketch



Material Properties	Geometric Properties	Loading and Boundary Conditions
$E = 4.32 \times 10^8$ N/m^2 $\upsilon = 0.3$ $\rho = 36.7347$ kg/m^3	L = 50 m R = 25 m t = 0.25 m $\Theta = 40°$ g = 9.8 m/sec^2	At x = 0 Symmetric At z = 0 Symmetric At x = L/2 UX = UY = ROTZ = 0

Material Properties	Geometric Properties	Loading and Boundary Conditions
	Parameter Definitions N = No. elements along each edge	

Figure C3.2: Representative Mesh Options



Target Solution

Target solution is obtained from an 8-node quadrilateral shell element solution with *N*=8, (see R. D. Cook, *Concepts and Applications of Finite Element Analysis*).

ETYP	N	DOF	UY(1), m	σ_z (1), Bottom	σ_θ (2), Bottom
--	8	2310	3016	358,420	-213,400

ETYP	N	DOF	Ratio		
			UY(1)	σ_z (1), Bottom	σ_θ (2), Bottom
Results Comparison - Quadrilateral Elements					
63	4	150	1.008	0.928	1.017
63	8	486	0.997	0.994	0.994
281	4	390	1.004	0.9536	1.024
281	8	1350	1.000	1.000	0.999
181	4	150	1.048	0.940	0.983
181	8	486	1.008	0.999	0.985
Results Comparison - Triangular Elements					
63	4	222	0.791	0.523	0.771

ETYP	N	DOF	Ratio		
			UY(1)	σ_z (1), Bottom	σ_θ (2), Bottom
63	8	558	0.911	0.620	0.899
281	4	774	0.971	0.953	0.980
281	8	2022	0.992	0.971	0.993
181	4	222	0.762	0.507	0.722
181	8	558	0.903	0.632	0.888

Assumptions, Modeling Notes, and Solution Comments

1. The problem is designed to test singly-curved shell elements under membrane and bending deformation. The quadrilateral mesh patterns produce uniform rectangular shapes while the triangle mesh patterns are as generated by the meshing algorithm in the solid modeler.

2. Results for SHELL181 in triangular form are presented, though they are not recommended for use. SHELL181 is based on a hybrid formulation for a quadrilateral element shape. Hence, degeneration of the element to a triangular shape will show some slight node-ordering dependence on the element solution.

3. The target solution is obtained in the prescribed reference for the author's 8-node shell element.

4. Results for the linear SHELL181 and SHELL63 singly-curved quadrilateral elements are comparable, with SHELL63 showing better accuracy in displacement for a given mesh discretization. As expected, the quadratic SHELL281 performs better than the linear elements for comparable meshes.

5. Results for the linear triangular-shaped elements is poor due to the constant-strain membrane behavior within the element. The effect of constant-strain membrane behavior is to overly stiffen the element under this type of loading, hence underpredicting both displacement and stresses. For triangular elements, only a fine mesh using the quadratic SHELL281 elements produces acceptable results.

VMC4: Simply-Supported Thin Annular Plate

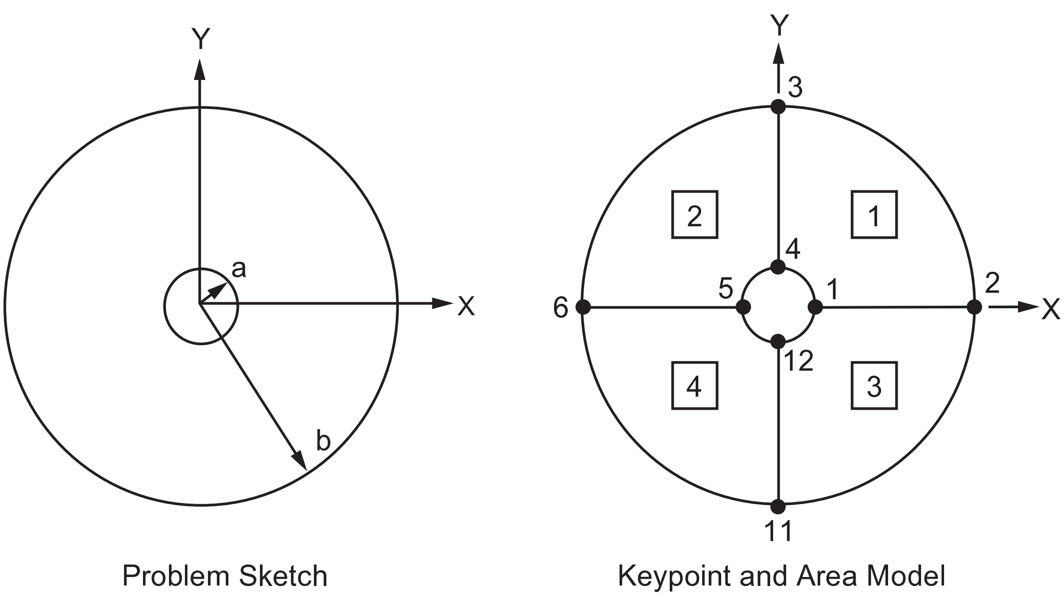
Overview

Reference:	J. Barlow, G. A. O. Davis, "Selected FE Benchmarks in Structural and Thermal Analysis", *NAFEMS Rept. FEBSTA*, Rev. 1, October 1986, Test No. 14 (modified).
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	4-Node Structural Shell Elements (SHELL181) 8-Node Structural Shell Elements (SHELL281)
Input Listing:	vmc4.dat

Test Case

A simply-supported thin annular plate of thickness t is to be analyzed to determine the first nine natural frequencies. Determine the natural frequencies for two mesh densities using both quadrilateral and triangular element shapes with Block Lanczos eigenvalue extraction.

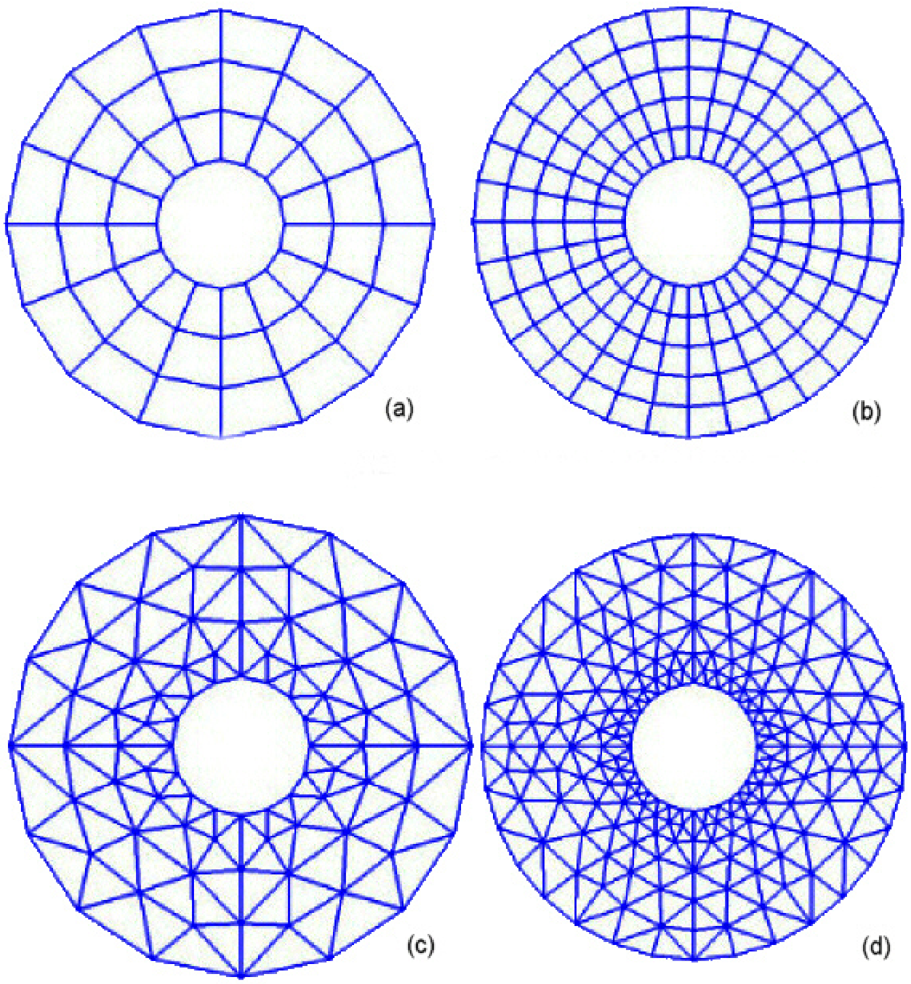
Figure C4.1: Thin Annular Plate Problem Sketch



Material Properties	Geometric Properties	Loading and Boundary Conditions
$E = 200 \times 10^9$ N/m^2 $\upsilon = 0.3$ $\rho = 8000$ kg/m^3	a = 1.8 m b = 6.0 m t = 0.06 m **Parameter Definitions** N1 = No. elements along radial direction	All nodes UX = UY = ROTZ = 0 in cylindrical coordinate system; At x = b UZ = 0 At x = b ROTX = 0

Material Properties	Geometric Properties	Loading and Boundary Conditions
	N2 = No. elements along circumferential direction	

Figure C4.2: Representative Mesh Options



(a) Quadrilateral Mesh (N1 = 3, N2 = 16)
(b) Quadrilateral Mesh (N1 = 5, N2 = 32)
(c) Triangle Mesh (N1 = 3, N2 = 16)
(d) Triangle Mesh (N1 = 5, N2 = 32)

Target Solution

Mode	1	2	3	4	5	6	7	8	9
Frequency (Hz)	1.870	5.137	5.137	9.673	9.673	14.850	15.573	15.573	18.382

Results Comparison - Block Lanczos Extraction Method Frequency Ratio

ETYP	N1	N2	DOF	1	2	3	4	5	6	7	8	9
Quadrilateral Mesh												

ETYP	N1	N2	DOF	1	2	3	4	5	6	7	8	9
181	3	16	480	0.980	1.270	1.270	1.385	1.385	1.080	1.377	1.377	1.212
181	5	32	1296	0.994	1.036	1.036	1.062	1.062	1.033	1.084	1.084	1.042
281	3	16	1224	1.001	0.996	0.996	1.011	1.011	1.006	1.044	1.044	0.998
281	5	32	3528	1.001	0.998	0.998	1.001	1.001	1.001	1.000	1.000	0.996
Triangular Mesh												
281	3	16	1992	1.020	1.040	1.041	1.035	1.038	1.055	1.059	1.069	1.094
281	5	32	4968	1.006	1.010	1.010	1.012	1.013	1.020	1.020	1.021	1.025

Assumptions, Modeling Notes, and Solution Comments

The problem is designed to test a solution involving repeated eigenvalues.

VMC5: Simply-Supported Solid Square Plate

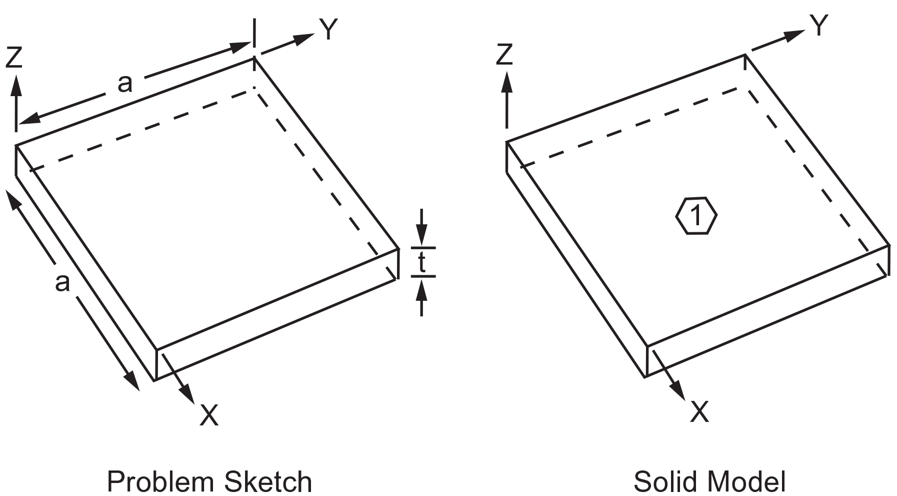
Overview

Reference:	NAFEMS, "The Standard NAFEMS Benchmarks", Rev. No. TSNB, National Engineering Laboratory, E. Kilbride, Glasgow, UK, August, 1989, Test No. FV52 (modified).
Analysis Type(s):	Mode-frequency Analysis (**ANTYPE** = 2)
Element Type(s):	3-D 8-Node Structural Solid Elements (SOLID185) 3-D 10-Node Tetrahedral Structural Solid Elements (SOLID187)
Input Listing:	vmc5.dat

Test Case

A simply-supported rectangular solid of thickness t is analyzed to determine the first P = 10 natural frequencies (the first three of which are rigid body modes). Determine the natural frequencies and mode shapes using the Block Lanczos eigenvalue extraction method for both element types.

Figure C5.1: Solid Square Plate Problem Sketch



Material Properties	Geometric Properties	Parameter Definitions
$E = 200 \times 10^9$ N/m^2 $\upsilon = 0.3$ $\rho = 8000$ kg/m^3	a = 10.0 m t = 1.0 m Loading At Z = 0 UZ = 0 along 4 edges	N1 = No. elements along edges N2 = No. elements through thickness

Target Solution

Modes 1-3 are rigid body modes (zero frequency).

Mode	4	5	6	7	8	9	10
Frequency (Hz)	45.897	109.44	109.44	167.89	193.59	206.19	206.19

Results Comparison

			Frequency Ratio						
ETYP	**N1**	**N2**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
185	8	3	0.987	1.041	1.041	1.032	1.016	1.016	1.016
187	6	1	0.970	0.992	0.992	0.988	1.000	1.000	1.000

Figure C5.2: Representative Mesh Options

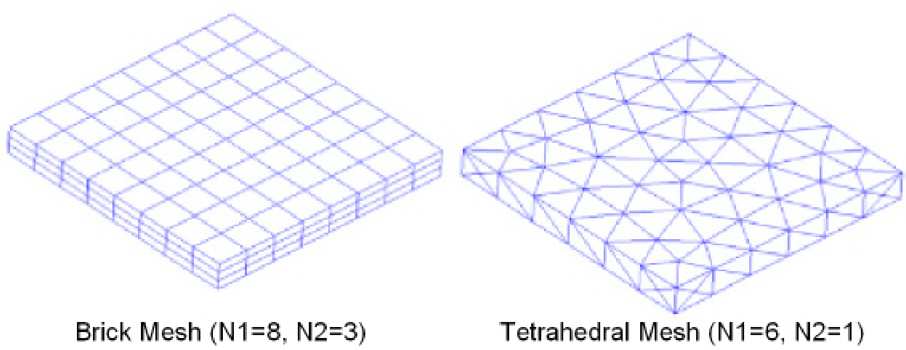
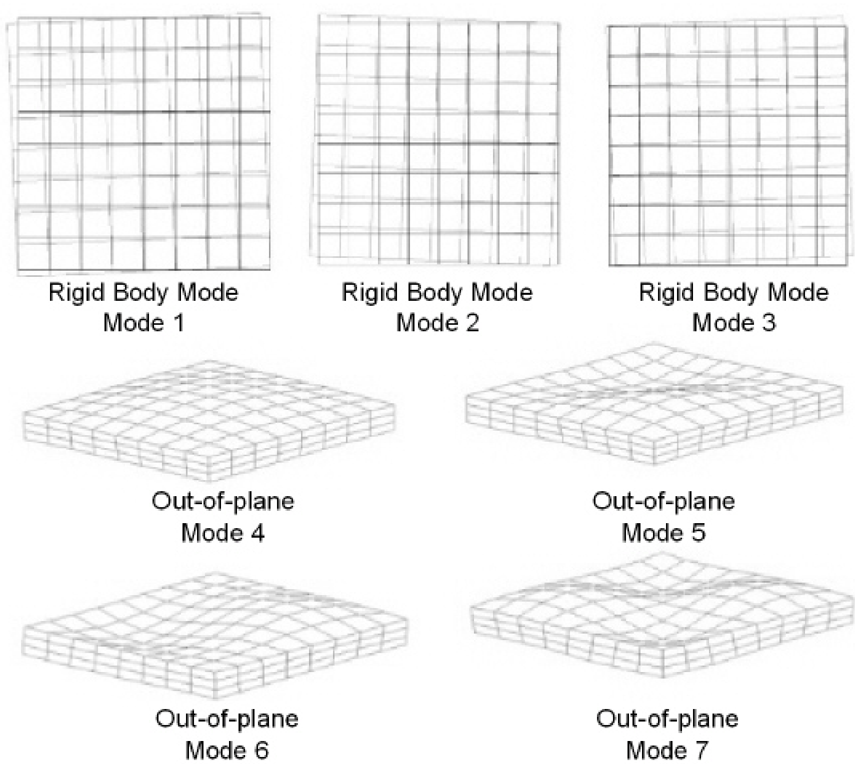
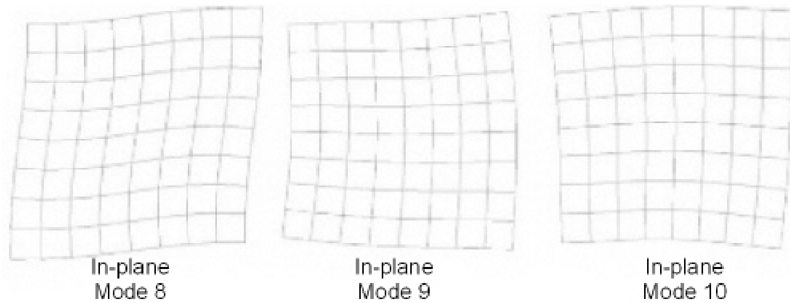


Figure C5.3: Graphical Results - Mode Shapes





Assumptions, Modeling Notes, and Solution Comments

1. The problem is designed to test the calculation of rigid body modes, coincident frequencies, and associated mode shapes.
2. The plate is simply supported on the bottom plate edges only (not at the midplane).
3. Three rigid body modes are correctly predicted in every test case analyzed.

VMC6: 2-D Heat Transfer With Convection

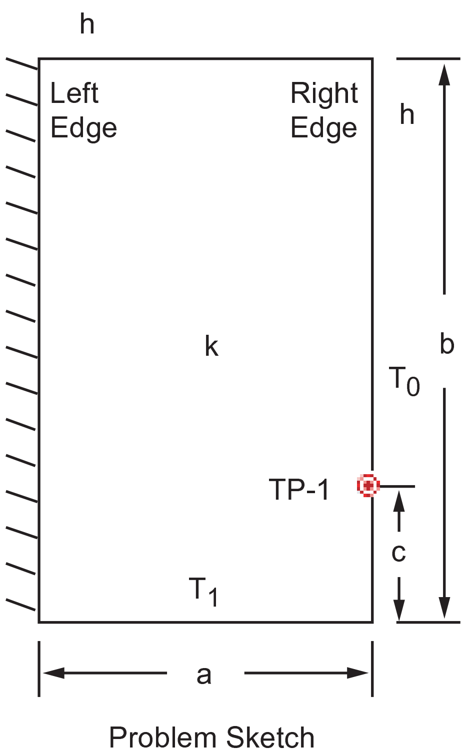
Overview

Reference:	J. Barlow, G. A. O. Davis, "Selected FE Benchmarks in Structural and Thermal Analysis", *NAFEMS Rept. FEBSTA*, Rev. 1, October 1986, Test No. T4 (modified).
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 6-Node Triangular Thermal Solid Elements (PLANE35) 2-D Thermal Solid Elements (PLANE55) 2-D 8-Node Thermal Solid Elements (PLANE77)
Input Listing:	vmc6.dat

Test Case

A two-dimensional rectangular body is insulated at the left edge and has the bottom edge held at a prescribed temperature T_1. Two other edges are subjected to a convection environment with a convection coefficient h and an ambient temperature T_0. Determine the steady-state temperature on the right edge, at a location 0.2 m above the bottom (Target Point-1) for a series of test cases with increasing mesh refinements for each element type.

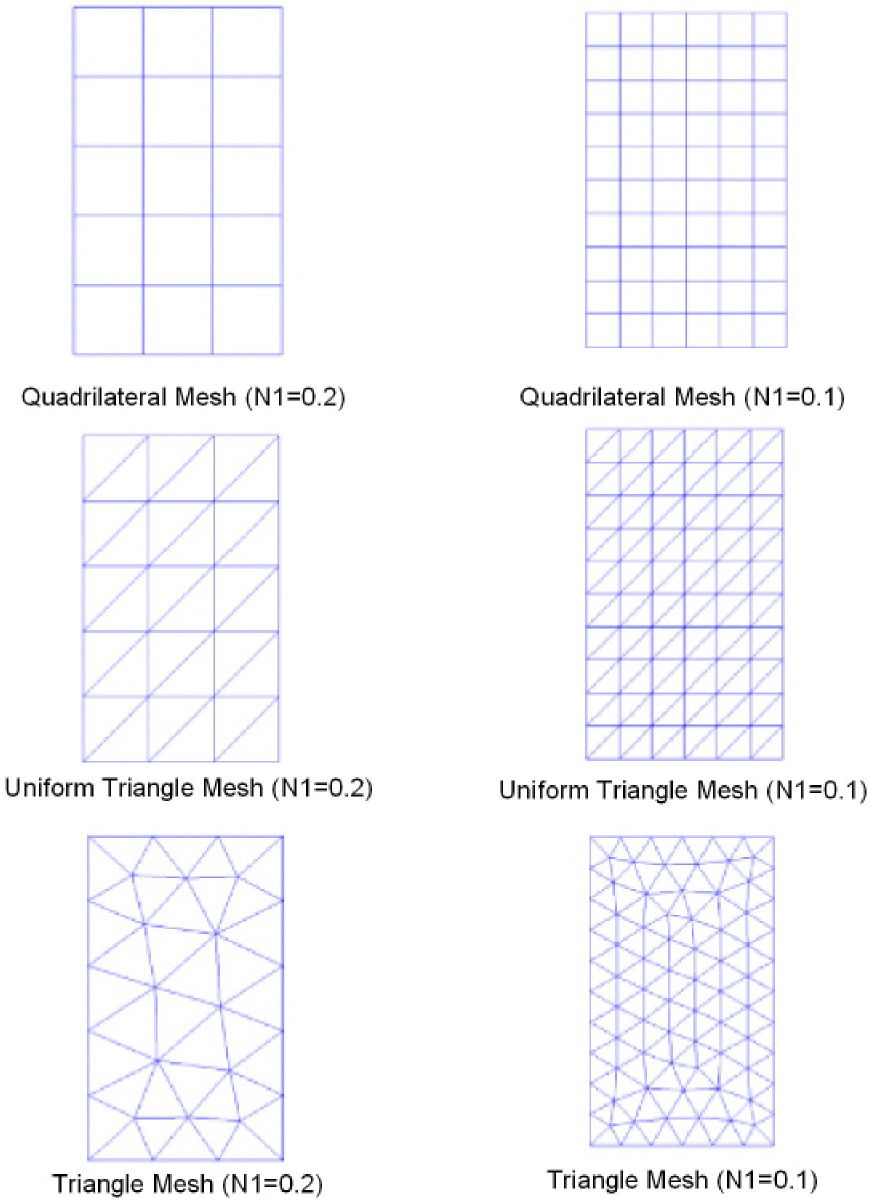
Figure C6.1: 2-D Rectangular Body Problem Sketch



Material Properties	Geometric Properties	Loading
k = 52 W/m°C **Parameter Definition**	a = 0.6 m b = 1.0 m c = 0.2 m	h = 750 W/m²°C T_0 = 0°C T_1 = 100°C

Material Properties	Geometric Properties	Loading
N1 = Element edge length		

Figure C6.2: Representative Mesh Options



Results Comparison - Triangle Mesh

ETYP	N1	DOF	Temp(°C)	Temperature Ratio
Quadrilateral Mesh				
55[1]	.2	24	19.3	1.06
55	.1	77	18.9	1.03
77[1]	.2	62	16.4	0.90

ETYP	N1	DOF	Temp(°C)	Temperature Ratio
77	.1	213	18.7	1.02
Triangle Mesh				
35	.2	93	17.9	0.98
35	.1	317	18.3	1.00
55	.2	28	20.9	1.14
55	.1	88	19.0	1.04
77	.2	93	17.9	0.98
77	.1	317	18.3	1.00
Uniform Triangle Mesh				
35[1]	2	77	16.5	0.90
35	.1	273	18.3	1.00
55	.2	24	22.4	1.22
55	.1	77	18.9	1.04
77[1]	2	77	16.5	0.90
77	.1	273	18.3	1.00

1. Test case corresponds to NAFEMS test specification

Assumptions, Modeling Notes, and Solution Comments

1. The lower order PLANE55 element converges toward the solution from above the target temperature while, in general, the higher order PLANE35 and PLANE77 elements converge from below the target temperature.

2. For the coarse meshes, the lower order PLANE55 element, in triangular form, does not predict accurate results. However, further mesh refinement produces more accurate results.

3. The higher order PLANE35 triangular element and the higher order PLANE77 element in triangular form, produce identical results.

VMC7: One-Dimensional Transient Heat Transfer

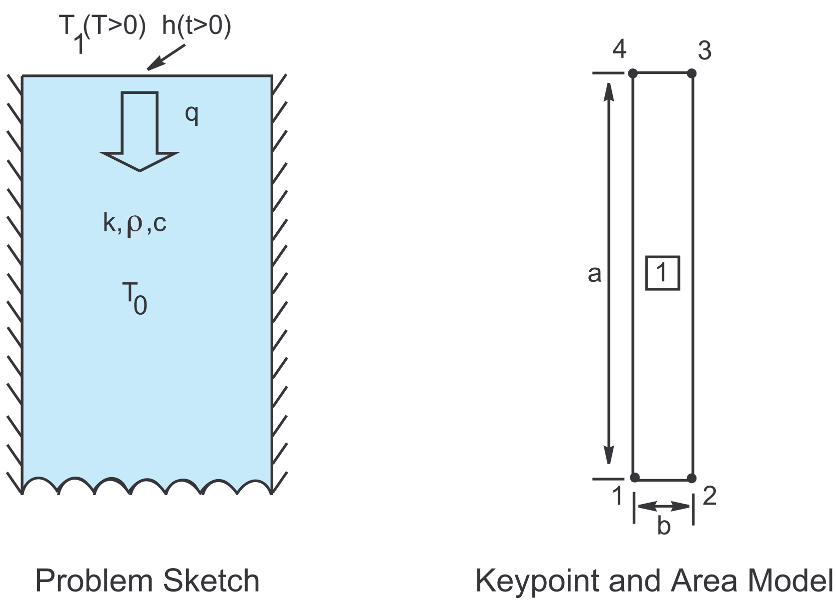
Overview

Reference:	J. P. Holman, *Heat Transfer*, 4th Edition, McGraw-Hill Book Co., Inc., New York, NY, 1976, pg. 106.
Analysis Type(s):	Thermal Analysis (**ANTYPE** = 4)
Element Type(s):	2-D 6-Node Triangular Thermal Solid Elements (PLANE35) 2-D Thermal Solid Elements (PLANE55) 2-D 8-Node Thermal Solid Elements (PLANE77)
Input Listing:	vmc7.dat

Test Case

A semi-infinite solid, initially of temperature T_o, is suddenly subjected to a convection environment with convection coefficient h and ambient temperature T_1. Determine the surface temperature after 2 seconds for a series of test cases with increasing mesh refinement for each element type.

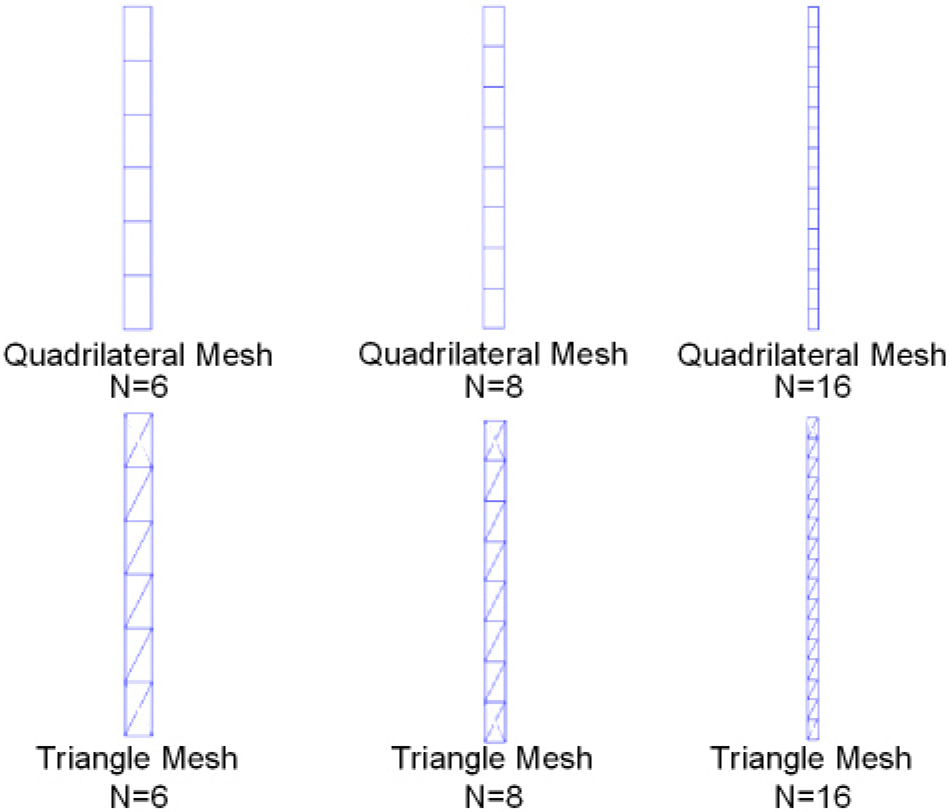
Figure C7.1: Semi-Infinite Solid Problem Sketch



Material Properties	Geometric Properties	Loading
k = 54 W/m-°C ρ = 7833 kg/m^3 c = 0.465 J/kg-°C	a = 1.0 m See Comments below b = a/2 Nm	h = 50 W/m^2-°C T_o = 0°C T_1 = 1000°C

Material Properties	Geometric Properties	Loading
	Parameter Definitions N = No. of elements in longitudinal direction N3 = Initial Δt increment	

Representative Mesh Options



Results Comparison

Target Solution: T = 157.25

ETYP	N	Deflection Δt_{min}	Cumulative Iterations	Surface Temperature	Temperature Ratio
55	6	.5	4	142.953	.909
55	8	.25	8	150.472	.957
55	16	.0667	30	155.655	.990
77	6	.5	4	151.993	.967
77	8	.25	8	154.573	.983
77	16	.0667	30	156.523	.995
35	6	.5	4	151.934	.966
35	8	.25	8	154.560	.983

ETYP	N	Deflection Δt_{min}	Cumulative Iterations	Surface Temperature	Temperature Ratio
35	16	.0667	30	156.524	.995

Assumptions, Modeling Notes, and Solution Comments

1. One-dimensional heat transfer is assumed along the model length, a, which is chosen such that no significant change in temperature occurs at the end region. This is done to ensure an infinite length approximation. The model width, b, is chosen such that the element aspect ratio remain constant for all test cases.

2. Time step optimization was activated to automatically increment the time step during the solution. The minimum Δt increments chosen were arbitrary.

3. Results tabulation includes the cumulative number of iterations per run. From these results it is shown that the time step opened up from the initial value, for the Δt = 0.5 and 0.0667 cases.

4. All three elements are shown to converge to the correct solution. The quadratic elements (PLANE35, PLANE77) provide a more accurate solution than the linear PLANE55 element for a similar mesh configuration.

VMC8: Aluminum Bar Impacting a Rigid Boundary

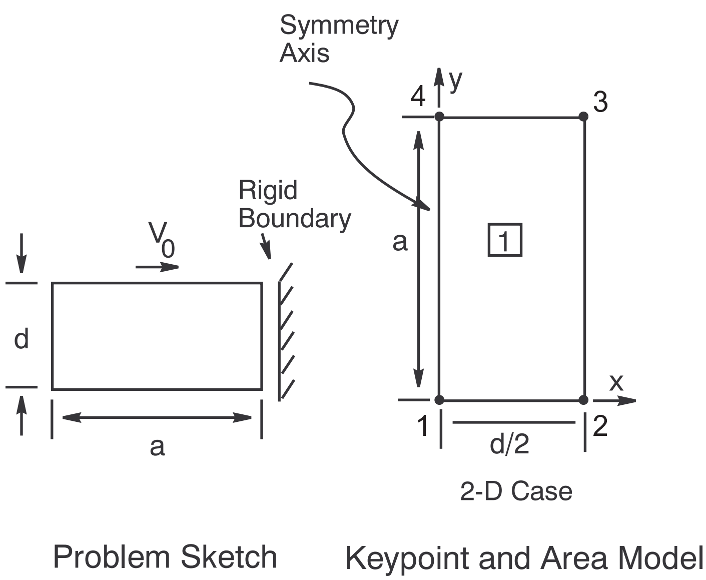
Overview

Reference:	M. L. Wilkins, M. W. Guinan, "Impact of Cylinders on a Rigid Boundary", *Journal of Applied Physics*, Vol. 44 No. 3, 1973, pp. 1200.
Analysis Type(s):	Nonlinear Transient Dynamic Analysis (**ANTYPE** = 4)
Element Type(s):	2-D Structural Solid Elements (PLANE42) 2-D 8-Node Structural Solid Elements (PLANE82) 2-D 4-Node Structural Solid Elements (PLANE182) 2-D 8-Node Structural Solid Elements (PLANE183)
Input Listing:	vmc8.dat

Test Case

A cylindrical aluminum bar impacts a rigid wall at a velocity V_o. Determine the deformed length of the bar and perform axisymmetric analyses with the element types noted above.

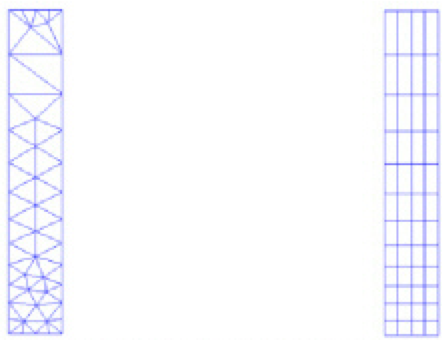
Figure C8.1: Aluminum Bar Problem Sketch



Material Properties	Geometric Properties	Loading
$E = 70 \times 10^9$ N/M^2 $ET = 100 \times 10^6$ N/M^2 $\sigma_{yp} = 420 \times 10^6$ N/M^2 $\upsilon = 0.3$ $\rho = 2700$ Kq/m^3	ℓ = 2.347 cm d = 0.762 cm	V_o = 478 m/sec

Representative Finite Element Models

2-D Axisymmetric Model



Assumptions, Modeling Notes, and Solution Comments

1. The test case is modelled as a 2-D axisymmetric analysis with elements PLANE42, PLANE82, PLANE182, and PLANE183. Each analysis consists of two load steps. The first load step is static and serves to define the initial velocity. The second load step resolves the nonlinear transient effects.

2. The material behavior is assumed to be elastic perfectly plastic and obey a bilinear isotropic hardening law. The elastic wave propagation speed is defined as $\sqrt{E/\ell}$. The time required for the elastic wave to travel across a typical element in the radial direction is used to define the minimum number of substeps. A time span of 4.5 x 10^{-5} seconds allows the bar to impact and realize its maximum deflection. Auto time stepping (**AUTOTS**) is used to control the time step increments. The large deflection effects are included using **NLGEOM**. Solution efficiency is improved by relaxing the convergence criteria (**CNVTOL**).

3. The 2-D axisymmetric analysis with PLANE42 elements fails to converge due to excessive element distortion or collapse (Figure C8.2: Deformed Shape (p. 861)). The element distortion can be attributed to an increased stiffness in element edges along the axis of symmetry resulting from dropped extra shape functions. The axisymmetric formulation removes extra shape functions along the axis of symmetry, hence incompressibility associated with large-strain plasticity is not maintained.

4. In comparison, the plane and solid elements perform equally well as the viscoplastic elements for the strain levels encountered in this problem. Introducing a rate-dependent material property to the problem would illustrate advantage to viscoplastic elements.

5. Using POST26, plots of the displacement vs. time (Figure C8.2: Deformed Shape (p. 861)) and equivalent plastic strain (Figure C8.3: Time History Graphs (p. 861) - for the center node on the impact face) vs. time are produced.

Results Comparison

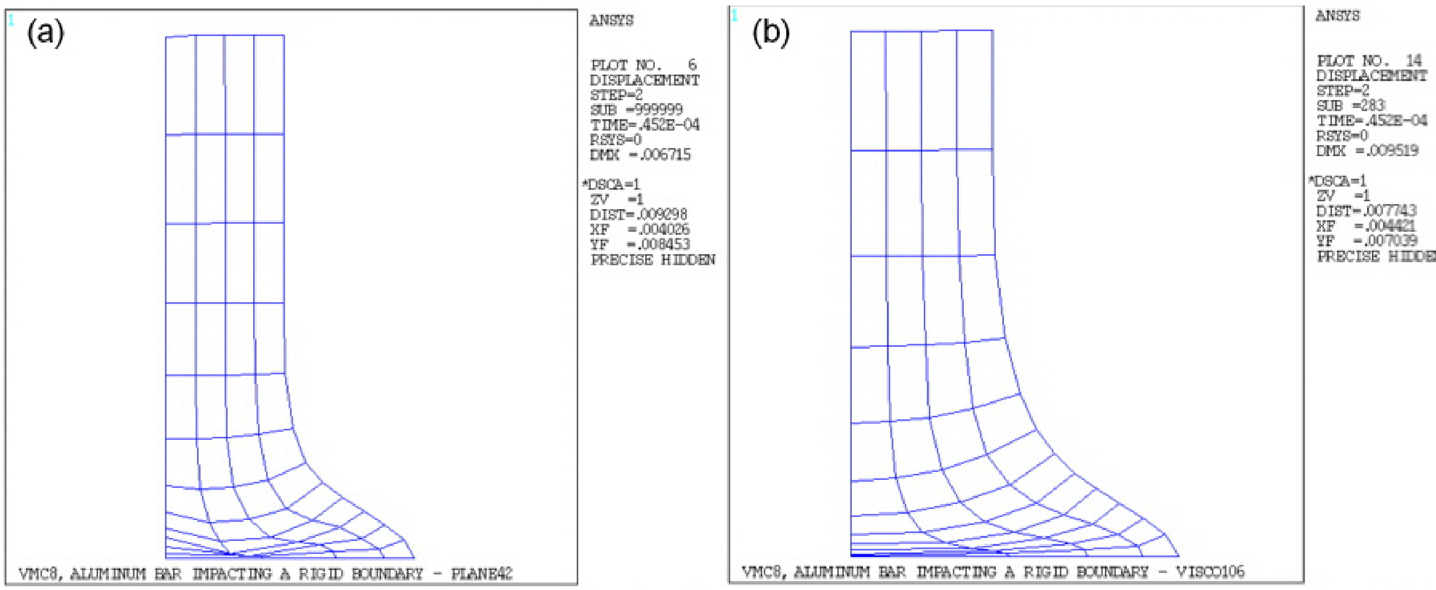
Target Solution: L_f = .01319 m (Obtained experimentally)

ETYP	L_f,m	Ratio
2	.014	1.067
42	.017 [1]	1.281
82	.014	1.066

ETYP	L_f,m	Ratio
106	.014	1.066
182	.014	1.078
183	.014	1.069

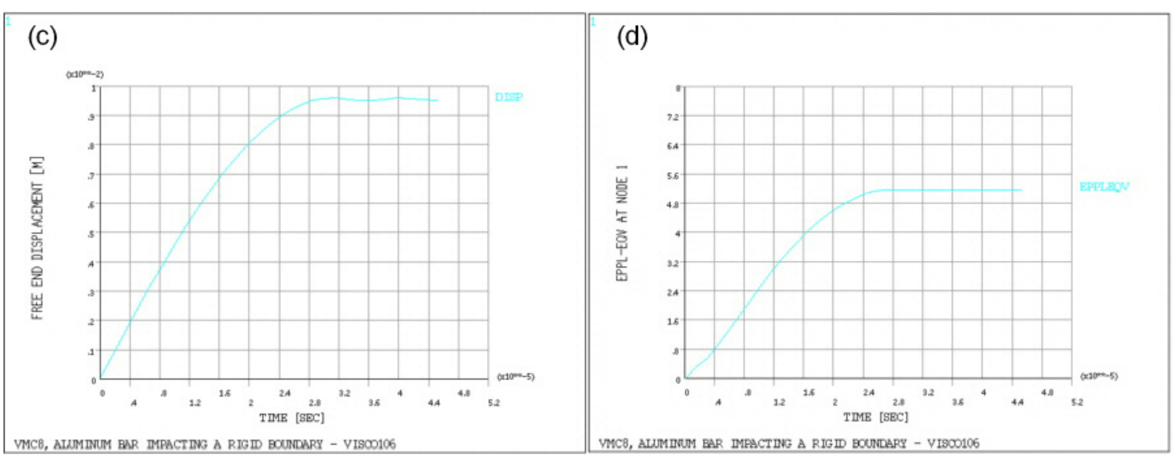
1. Solution did not converge

Figure C8.2: Deformed Shape



(a) PLANE42 Elements and (b) PLANE183 Elements

Figure C8.3: Time History Graphs



(c) Free End Displacement vs. Time and (d) Impact Face - Equivalent Plastic Strain vs. Time

VMD1: Straight Cantilever Beam Under Unit Load

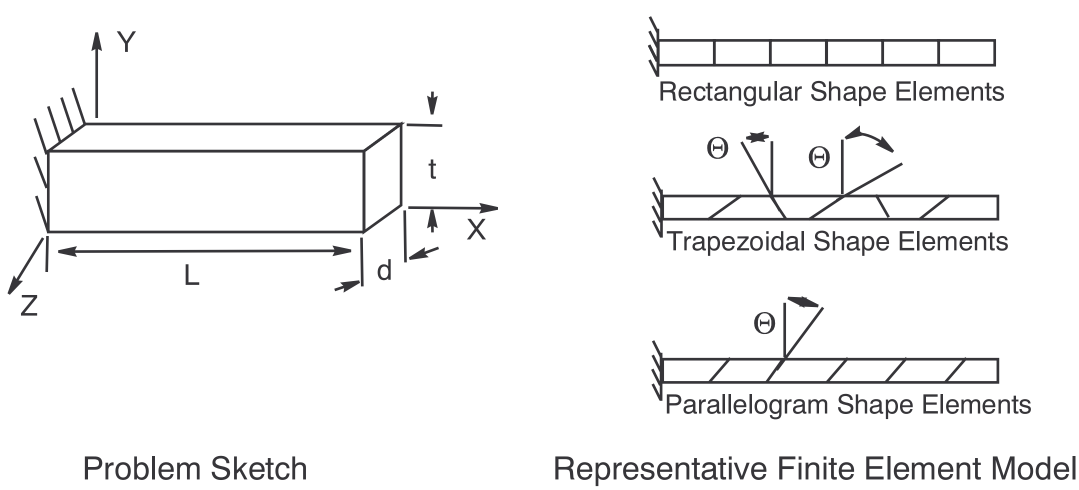
Overview

Reference:	R. H. MacNeal, R. L. Harder, "A Proposed Standard Set of Problems to Test Finite Element Accuracy", *Proceedings, 25th SDM Finite Element Validation Forum*, 1984.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	2-D 4-Node Structural Solid Elements (PLANE182) 2-D 8-Node Structural Solid Elements (PLANE183) 2-D 6-Node Structural Solid Elements (PLANE183) 3-D 8-Node Structural Solid Elements (SOLID185) 3-D 10-Node Tetrahedral Structural Solid Elements (SOLID187) 3-D 20-Node Structural Solid Elements (SOLID186)
Input Listing:	vmd1.dat

Test Case

A straight cantilever beam, fixed at one end, is subjected to a unit load. Determine the displacement at the end of the beam for unit loads including extension, in-plane shear, out-of-plane shear, and twist (where applicable). Examine the influence of rectangular, trapezoidal, and parallelogram element shape models on tip displacement and the percent energy error norm.

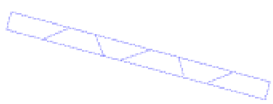
Figure D1.1: Straight Cantilever Beam Problem Sketch



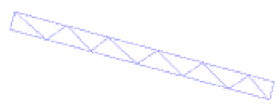
Material Properties	Geometric Properties	Loading
$E = 10 \times 10^6$ psi $\upsilon = 0.3$	L = 6 in d = 0.1 in	At X = 0 UX = UY = UZ = 0

Material Properties	Geometric Properties	Loading
	t = 0.2 in **Parameter Definitions** Θ = Element Distortion Angle	At X = L Unit Load a. Extension (FX = 1) b. In-plane (FY = 1) c. Out-plane (FZ = 1) d. Twist (Equivalent FX, FY forces applied)

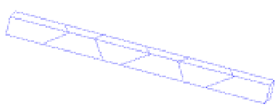
Representative Mesh Options



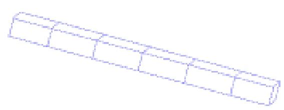
2-D Quad - Trapezoidal (θ = 15°)



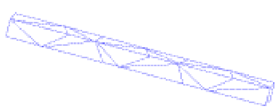
2-D Triangle - Parallelogram (θ = 30°)



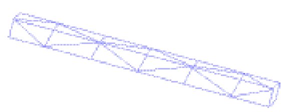
3-D Brick - Trapezoidal (θ = 45°)



3-D Brick - Parallelogram (θ = 15°)



3-D Tetrahedron - Trapezoidal (θ = 30°)



3-D Tetrahedron - Parallelogram (θ = 45°)

Results Comparison

Tip Loading	Tip Displacement Ratio / % Error in Energy Norm											
Shape/Direction	**PLANE183 Triangular element**		**PLANE182**		**PLANE183**		**SOLID185**		**SOLID187**		**SOLID186**	
Rectangular												
Extension	.997	6	.996	0	.999	5	.988	0	.993	11	.994	3
In-Plane Shear	.983	22	.993	24	0.987	0	.978	25	.960	30	.971	17
Out-Of-Plane Shear							.973	27	.959	33	.961	22
Twist							.892	10	.910	24	.903	8
Trapezoidal (θ = 15°)												
Extension	.997	6	.997	4	.999	5	.991	5	.993	11	.994	3
In-Plane Shear	.982	23	.293	66	.986	7	.272	66	.959	31	.969	18
Out-Of-Plane Shear							.215	67	.958	33	.960	23
Twist							.854	16	.910	24	.903	8
Trapezoidal (θ = 30°)												
Extension	.997	6	0.999	4	1	4	.993	6	.993	11	.994	3

Tip Loading Shape/Direction	Tip Displacement Ratio / % Error in Energy Norm											
	PLANE183 Triangular element		PLANE182		PLANE183		SOLID185		SOLID187		SOLID186	
In-Plane Shear	.976	26	0.109	64	.982	17	.100	64	.954	32	.957	23
Out-Of-Plane Shear							.072	64	.954	34	.954	25
Twist							.742	27	.910	25	.903	8
Trapezoidal (θ = 45°)												
Extension	.997	6	0.999	3	1.000	4	.994	4	.993	11	.994	3
In-Plane Shear	.961	32	0.052	59	0.967	36	.047	59	.939	37	.891	34
Out-Of-Plane Shear							.030	60	.941	38	.921	36
Twist							.563	40	.910	25	.903	8
Parallelogram (θ = 15°)												
Extension	.998	6	.997	4	.999	5	.991	5	.993	11	.994	3
In-Plane Shear	.983	22	0.812	38	.988	1	.798	40	.959	31	.971	18
Out-Of-Plane Shear							.749	49	.958	33	.960	23
Twist							.886	19	.910	24	.903	8
Parallelogram (θ = 30°)												
Extension	.998	6	.999	4	.999	5	.993	5	.993	11	.994	3
In-Plane Shear	.980	24	.680	51	.991	4	.669	53	.954	33	.972	21
Out-Of-Plane Shear							.608	65	.953	35	.955	26
Twist							.866	34	.910	25	.903	8
Parallelogram (θ = 45°)												
Extension	.998	6	0.999	3	1.000	4	.994	4	.992	11	.994	3
In-Plane Shear	.970	29	0.632	55	0.997	8	.624	57	.940	38	.968	27
Out-Of-Plane Shear							.528	74	.935	40	.942	32
Twist							.820	51	.909	26	.903	8

Assumptions, Modeling Notes, and Solution Comments

1. The straight cantilever beam is a frequently used test problem applicable to beam, plate, and solid elements. The problem tests elements under constant and linearly varying strain conditions. Although the problem appears rather simplistic in nature, it is a severe test for linear elements, especially when distorted element geometries are present.

2. The fixed boundary conditions at the left edge of the beam are not representative of a "patch test." Thus, under extensional loading, the finite element solution will not agree with the beam theory solution.

3. Element solution accuracy degrades as elements are distorted. The degradation is more pronounced for linear elements (PLANE182, SOLID185) than it is for quadratic elements (PLANE183, SOLID187, SOLID186). The degradation in performance for linear elements is most pronounced for bending loads coupled with irregular element shapes.

4. Distorted linear elements show more pronounced locking (excessive stiffness) for trapezoidal element shapes than for parallelogram shapes. Results clearly show under predicted displacements for trapezoidal element shapes for PLANE182 and SOLID185.

5. The quadratic elements show very good performance under all loadings and geometries. The good performance is attributed to the ability of the elements to properly handle bending and shear energy, in contrast to the linear elements.

6. The percent error in energy norm for each test case is displayed against the tip displacement ratio to illustrate the general correlation between the two for this particular problem. The linear elements show a patterned correlation between solution accuracy and the percent error in energy norm. For the quadratic elements the correlation pattern is similar. In both cases, the results illustrate that a considerable bandwidth on norm values may exist at any desired solution accuracy level for problems under a variety of load conditions with irregular element shapes.

VMD2: Barrel Vault Roof Under Self Weight

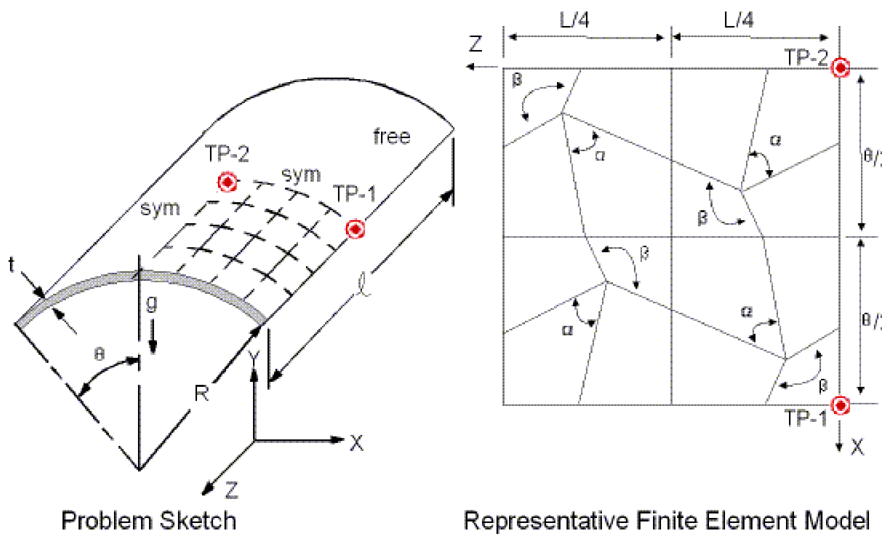
Overview

Reference:	R. D. Cook, *Concepts and Applications of Finite Element Analysis*, 2nd Edition, John Wiley and Sons, Inc., 1981, pp. 284-287.
Analysis Type(s):	Static Analysis (**ANTYPE** = 0)
Element Type(s):	Elastic Shell Elements (SHELL63) 4-Node Finite Strain Shell Elements (SHELL181) 8-Node Finite Strain Shell Elements (SHELL281)
Input Listing:	vmd2.dat

Test Case

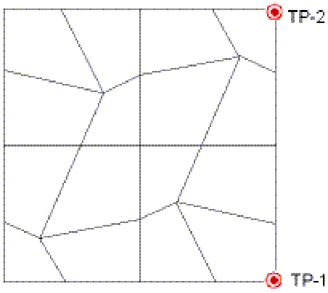
A cylindrical shell roof is subjected to gravity loading. The roof is supported by walls at each end and is free along the sides. Monitor the y-displacement and bottom axial stress (σ_z) at target point 1 along with the bottom circumference stress (σ_θ) at target point 2 for a series of test cases with varying skew angle β for each element type. A companion problem that studies uniform element mesh refinement is VMC3.

Figure D2.1: Cylindrical Shell Roof Problem Sketch

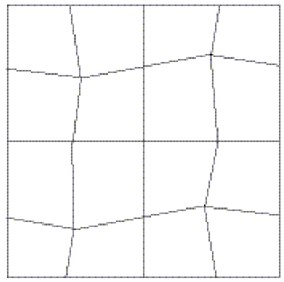


Material Properties	Geometric Properties	Loading and Boundary Conditions
$E = 4.32 \times 10^8$ N/m^2 $\upsilon = 0.0$ $\rho = 36.7347$ kg/m^3 **Parameter Definitions** β = Skew Angle	L = 50 m R = 25 m t = 0.25 m $\Theta = 40°$ g = 9.8 m/sec^2	At x = 0 Symmetric At z = 0 Symmetric At x = L UX = UY = ROTZ = 0

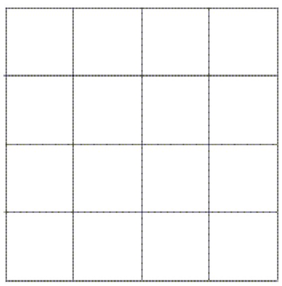
Representative Mesh Options



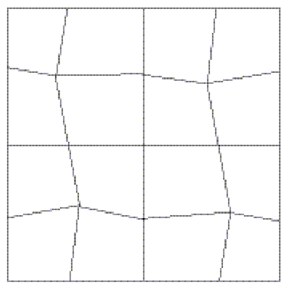
β = 65 α = 133.4



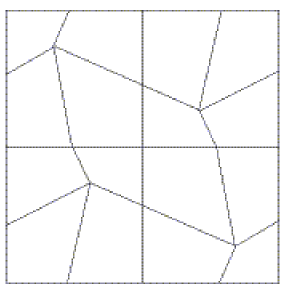
β = 77.5 α = 106.0



β = 90 α = 90



β = 115 α = 72.5



β = 130 α = 66.2

Target Solution

Target solution is obtained using a uniform 8 x 8 quadrilateral mesh of an 8-node quadrilateral shell element, (see R. D. Cook, *Concepts and Applications of Finite Element Analysis*).

ETYP	Beta (Deg.)	Alpha (Deg.)	UY (1), in	Axial Stress (1) Bottom,kPa	Hoop Stress (2) Bottom,kPa
--	90	90	-.3016	358.42	-213.40

Results Comparison - Quadrilateral Elements

			Ratio		
ETYP	**Beta**	**Alpha**	**UY (1)**	**Axial Stress (1) Bottom**	**Hoop Stress (2) Bottom**
63[1]	65.0	133.4	1.003	1.136	0.958
63[2]	77.5	106.0	1.006	1.025	1.002
63	90.0	90.0	1.008	0.928	1.017

			Ratio		
ETYP	Beta	Alpha	UY (1)	Axial Stress (1) Bottom	Hoop Stress (2) Bottom
63[3]	110.0	75.1	1.009	0.796	1.022
63[4]	130.0	66.2	1.008	0.674	1.018
181	65	133.4	1.019	0.946	0.918
181	77.5	106	1.037	0.950	0.965
181	90	90	1.048	0.940	0.983
181	110	75.1	1.056	0.910	0.956
181	130	66.2	1.055	0.863	0.889
281	65	133.4	0.974	0.985	1.129
281	77.5	106	0.999	0.967	1.046
281	90	90	1.004	0.953	1.024
281	110	75.1	0.994	0.949	1.045
281	130	66.2	0.971	0.960	1.056

1. Test case results in Mechanical APDL warning message on element warping:

   .155 < Warping Factor < .278

2. Test case results in Mechanical APDL warning message on element warping:

   .105 < Warping Factor < .105

3. Test case results in Mechanical APDL warning message on element warping:

   .114 < Warping Factor < .131

4. Test case results in Mechanical APDL warning message on element warping:

   .179 < Warping Factor < .257

Assumptions, Modeling Notes, and Solution Comments

1. The problem is designed to test singly-curved shell elements under combined membrane and bending deformation. The solid model is set up to produce irregular element shapes for quadrilateral elements. The angle β is prescribed, while the angle α is calculated from the resulting geometry. The range of β is set such that all element interior angles fall within 90° ± 45°.

2. The target solution is obtained from the author's 8-node shell element, (see R. D. Cook, *Concepts and Applications of Finite Element Analysis*), under a uniform rectangular element geometry using an 8 x 8 mesh pattern.

3. Results for uniform quadrilateral element shapes are noted in the tabular and graphical output for β = 90° and should be used as a basis for comparison of distorted element performance.

4. SHELL63 is permitted for use in a curved shell environment for slightly warped shapes. Excessive warping produces warning messages. These are noted in the tabular output.

5. Displacement results over the range of element distortion vary the greatest for SHELL181 and the least for SHELL63. In this problem, SHELL63 and SHELL281 predict the displacement more accurately for mild element geometry distortion.

6. Axial (σ_z) stress results, over the range of element distortion, show wide variation for SHELL63, but considerably less variation for SHELL181, and SHELL281 elements. The wide variation in results for SHELL63 is due to nodal stress extrapolation inaccuracies for distorted, warped element configurations. Hoop (σ_θ) stress results are less affected by irregular element shapes except at the extreme β angle range.

VMD3: Free-Free Vibration of a Solid Beam

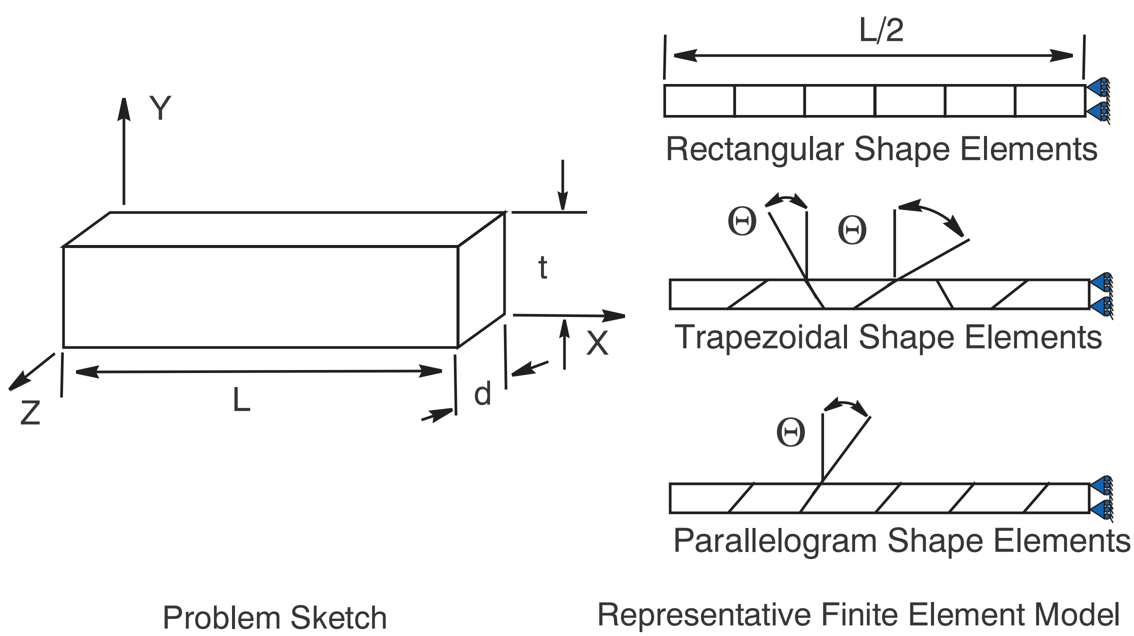
Overview

Reference:	R. D. Blevins, *Formulas for Natural Frequency and Mode Shape*, Van Nostrand Reinhold Co., New York, NY, 1979, Tables 8-1 and 8-16.
Analysis Type(s):	Mode-frequency analysis (**ANTYPE** = 2)
Element Type(s):	2-D 4-Node Structural Solid Elements (PLANE182) 2-D 8-Node Structural Solid Elements (PLANE183) 3-D 8-Node Structural Solid Elements (SOLID185) 3-D 10-Node Tetrahedral Structural Solid Elements (SOLID187) 3-D 20-Node Structural Solid Elements (SOLID186)
Input Listing:	vmd3.dat

Test Case

A free-free solid beam is analyzed to determine the first axial and bending mode natural frequencies. The axial and bending modes are extracted using the Block Lanczos eigenvalue extraction method. Examine the influence of rectangular, trapezoidal, and parallelogram element shape models on the eigenvalue calculations.

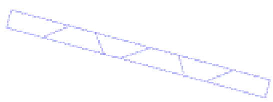
Figure D3.1: Free-Free Solid Beam Problem Sketch



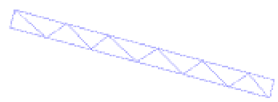
Material Properties	Geometric Properties	Loading and Boundary Conditions
$E = 200 \times 10^9$ N/m^2 $\upsilon = 0.3$ $\rho = 8000$ kg/m^3	L = 12 m d = 0.1 m t = 0.2 m	At X = L/2 UX = 0 At Z = 0 UZ = 0 At Y = 0 UY = 0 (Axial mode)

Material Properties	Geometric Properties	Loading and Boundary Conditions
	Parameter Definitions Θ = Element Distortion Angle	

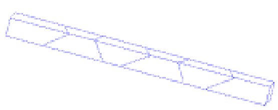
Representative Mesh Options



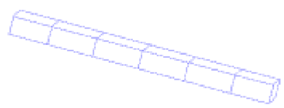
2-D Quad - Trapezoidal ($\theta = 15^\circ$)



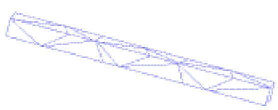
2-D Triangle - Parallelogram ($\theta = 30^\circ$)



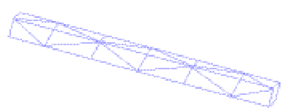
3-D Brick - Trapezoidal ($\theta = 45^\circ$)



3-D Brick - Parallelogram ($\theta = 15^\circ$)



3-D Tetrahedron - Trapezoidal ($\theta = 30^\circ$)



3-D Tetrahedron - Parallelogram ($\theta = 45^\circ$)

Target Solution and Results Comparison

Target Solution:

Freq = 208.333 Hz (Axial Mode)

Freq = 7.138 Hz (Bending Mode)

Results Comparison:

		1st Natural Frequency Ratio				
		Axial Mode				
Shape	Angle	PLANE182	PLANE183	SOLID185	SOLID187	SOLID186
Rectangular	0	1.003	1.000	1.003	1.000	1.000
Trapezoidal	15	1.003	1.000	1.003	1.000	1.000
Trapezoidal	30	1.003	1.000	1.004	1.000	1.000
Trapezoidal	45	1.004	1.000	1.005	1.000	1.000
Parallelogram	15	1.003	1.000	1.003	1.000	1.000
Parallelogram	30	1.003	1.000	1.003	1.000	1.000
Parallelogram	45	1.003	1.000	1.003	1.000	1.000
		Bending Mode				
Rectangular	0	1.010	0.999	1.010	1.004	1.002

		1st Natural Frequency Ratio				
Trapezoidal	15	1.567	1.000	1.598	1.005	1.003
Trapezoidal	30	1.973	1.003	2.015	1.008	1.010
Trapezoidal	45	2.207	1.012	2.254	1.020	1.051
Parallelogram	15	1.040	0.999	1.043	1.005	1.002
Parallelogram	30	1.091	0.999	1.097	1.009	1.004
Parallelogram	45	1.119	0.999	1.127	1.020	1.010

Assumptions, Modeling Notes, and Solution Comments

1. The problem tests the influence of irregular element shapes on eigenvalue calculations. Although the problem appears rather simplistic in nature, it is a severe test for linear irregular shaped elements where accurate bending mode frequencies are required.

2. Since the beam is free of any constraints, only one-half of the beam is required for modeling. Symmetry constraints are applied at the mid-length of the models. To obtain the desired bending mode (in the XY plane) all nodes at Z = 0 are constrained in the Z direction. Additionally, for the axial mode only, all nodes at Y = 0 are constrained in the Y direction.

3. All load cases show good agreement in the prediction of the first axial natural frequency. This mode is simply linearly-varying longitudinal motion which is easily handled by both linear and quadratic elements. Irregular element shapes have only a minor effect on solution accuracy since axial motion is predominant.

4. For the linear elements (PLANE182, SOLID185), prediction of the first bending mode is significantly affected by irregularly shaped elements. If the elements are distorted, the stiffness of the element increases hence over predicting the bending mode natural frequency.

5. For the quadratic elements (PLANE183, SOLID186, SOLID187), prediction of the first bending mode is very good. Irregular element shapes for quadratic elements have little effect on the solution accuracy.

Part III: ANSYS LS-DYNA Study Descriptions

Chapter 1: ANSYS LS-DYNA Study Overview

This section of the manual contains ANSYS LS-DYNA studies. The related input listings appear in Appendix C (p. 1851).

The ANSYS LS-DYNA Studies are presented to demonstrate the use of the LS-DYNA Solver with the Mechanical APDL preprocessor and postprocessor.

The LS-DYNA Solver that is packaged with ANSYS LS-DYNA is not an ANSYS, Inc. product. It is a Livermore Software Technology Corporation (LSTC) product which ANSYS, Inc. resells. Test cases including the LS-DYNA Solver exist in the ANSYS test set. ANSYS, Inc. reports any errors in the LS-DYNA Solver to LSTC.

The results presented in these studies are representative of the platform and version on which the studies were completed. It is normal that these results will be slightly different in different platforms and other versions of LS-DYNA. The difference is due to different numerical accuracy in different platforms and/or due to the improvements made by LSTC.

VME1: Response of Spring-Mass System to Step Input

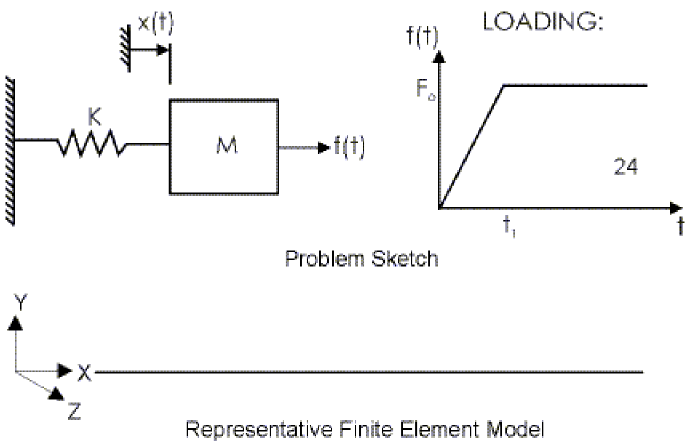
Overview

Reference:	W. T. Thomson, *Vibration Theory and Applications*, 2nd Printing, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1965, pp. 98-99.
Analysis Type(s):	Explicit Dynamics with ANSYS LS-DYNA
Element Type(s):	Explicit 3-D Structural Mass Elements (MASS166) Explicit Spring-Damper Elements (COMBI165)
Input Listing:	vme1.dat

Test Case

The one-DOF system consists of a spring, K, and mass, M. The load is a step function with a rise time, as shown. The peak displacement of M from the finite element solution is compared to an analytical result.

Figure E1.1: Response of Spring-Mass System Problem Sketch



Material Properties	Geometric Properties	Loading
M = 1kg K = 100 N/m	Spring L.C. = 1m	Applied force, f(t), to the mass in the form shown in Figure E1.1: Response of Spring-Mass System Problem Sketch (p. 879), with t_1 =1 second, and F_o = 3 N.

Analysis Assumptions and Modeling Notes

The magnitude and rise time of the force input were chosen arbitrarily. As outlined in W. T. Thomson, *Vibration Theory and Applications*, for the system in Figure E1.1: Response of Spring-Mass System Problem Sketch (p. 879), with the force input shown, the peak response is given by:

$$x_{peak} = (F_o/K)\left[1 + \frac{1}{\omega_n t_1}\sqrt{2(1 - \cos(\omega_n t_1))}\right]$$

where ω_n is the system undamped natural frequency in units of radians per second.

Results Comparison

	Target	Mechanical APDL	Ratio
Peak Ux of Mass	3.575E-2	3.575E-2	1.000

VME2: Drop Analysis of a Block Onto a Spring Scale

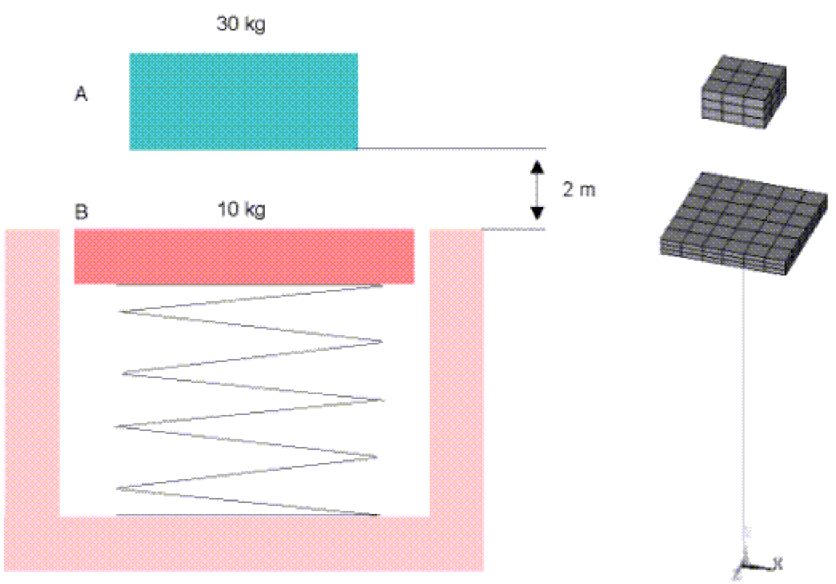
Overview

Reference:	F. P. Beer, E. R. Johnston, Jr., *Vector Mechanics for Engineers, Statics and Dynamics*, 5th Edition, McGraw-Hill Book Co., Inc., New York, NY, 1962, pg. 635.
Analysis Type(s):	Explicit Dynamics with ANSYS LS-DYNA
Element Type(s):	Explicit 3-D Structural Solid Elements (SOLID164) Explicit Spring-Damper Elements (COMBI165)
Input Listing:	vme2.dat

Test Case

A 30 kg block is dropped from a height of 2 m onto a 10 kg pan of a spring scale. The maximum deflection of the pan will be determined for a spring with a stiffness of 20 kN/m.

Figure E2.1: Drop Analysis Of A Block Onto A Spring Scale Problem Sketch and Finite Element Model



Problem Sketch

Representative Finite Element Model

Material Properties	Geometric Properties	Loading
Block E = 207 GPa ρ = 60 kg/m^3 υ = .29 **Pan** E = 207 GPa ρ = 10 kg/m^3 υ = .29 **Spring** k = 20 kN/m	**Block** base = 1 m width = 1 m height = .5m **Pan** base = 2 m width = 2 m height = .25 m **Spring** length = 6m	The block is dropped from rest at a height of 2 m. g = 9.81 m/sec^2

Analysis Assumptions and Modeling Notes

The sizes of the block, pan, and spring have been arbitrarily selected. The densities of the block and pan, however, are based on the respective volumes of each component. A relatively course mesh was chosen for both the block and pan.

Results Comparison

	Target	Mechanical APDL	Ratio
Maximum Uy of Pan	.225	.226	1.004

VME3: Response of Spring-Mass-Damper System

Overview

Reference:	C. M. Close, D. R. Frederick, *Modeling and Analysis of Dynamic Systems*, 2nd Edition, John Wiley and Sons, Inc., New York, NY, 1994, pp. 314-315, G. F. Franklin, J. D. Powell, A. Emami-Naeini, *Feedback Control of Dynamic Systems*, 3rd Edition, Addison-Wesley Publishing Co., Inc., Reading, MA, 1994, pp. 126-127.
Analysis Type(s):	Explicit Dynamics with ANSYS LS-DYNA
Element Type(s):	Explicit 3-D Structural Mass Elements (MASS166) Explicit Spring-Damper Elements (COMBI165)
Input Listing:	vme3.dat

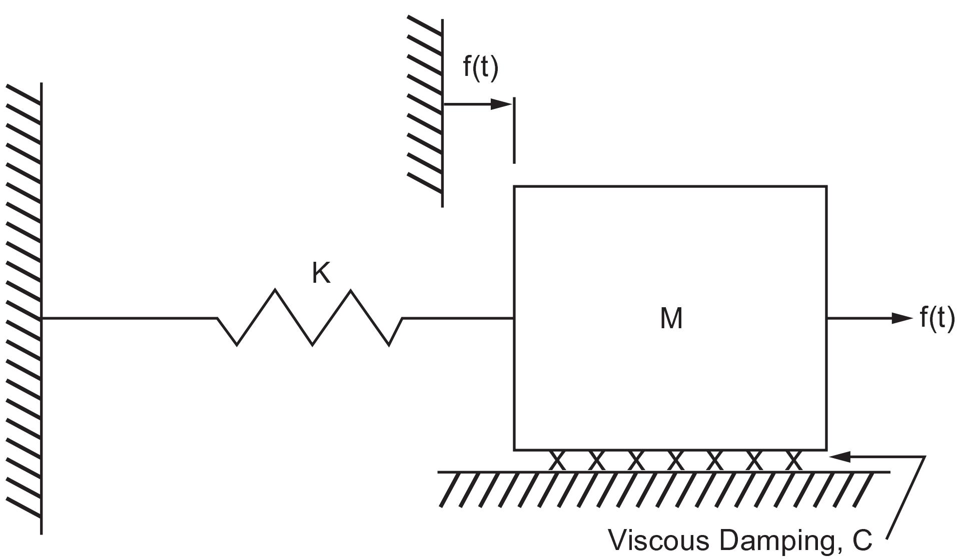
Test Case

The one-DOF system consists of a spring, K, and mass, M, with viscous damping, C. There are two loading cases:

- Case 1: f(t) = A = constant (step input)
- Case 2: f(t) = At (ramp input)

For this underdamped system, the displacement of M for Case 1 overshoots the steady-state static displacement. The overshoot and the peak time, t_p are compared to theory outlined in C. M. Close, D. R. Frederick, *Modeling and Analysis of Dynamic Systems*. Based on the discussion in G. F. Franklin, J. D. Powell, A. Emami-Naeini, *Feedback Control of Dynamic Systems*, the mass velocity in response to the ramp input, in theory, is equal to the mass displacement due to the step input.

Figure E3.1: Response of Spring-Mass-Damper System



Problem Sketch

Material Properties	Geometric Properties	Loading
Mass M = 1.0 kg **Spring** $K = 4\pi^2$ N/m **Damper** C = 0.21545376	**Spring** Length = 1 m	Case 1: A step force input, $f(t) = 4\pi^2$ on the mass M in the +x direction. Case 2: A ramp force input, $f(t) = (4\pi^2)t$, on the mass M in the +x direction.

Analysis Assumptions and Modeling Notes

The magnitude of the step force input for Case 1 was chosen to equal the spring stiffness constant to produce a steady-state static deflection of unity. The ramp input for Case 2 was defined such that the input for Case 1 is the time derivative of the input for Case 2. The value of the stiffness constant was chosen so that the system undamped natural frequency equals 2 Hz. The damping constant was chosen to produce a damping ratio that results in a theoretical 50% overshoot of the steady-state deflection for the step input.

As outlined in G. F. Franklin, J. D. Powell, A. Emami-Naeini, *Feedback Control of Dynamic Systems*, for a single DOF system subjected to a step input, the relationship between overshoot, M_p, and damping ratio, ζ, is given by:

$$M_p = \exp\left(-\pi\zeta / \sqrt{1-\zeta^2}\right)$$

For the system in Figure 3.1: Support Structure Problem Sketch (p. 29):

$$M_p = (X_{max} - X_{steady\text{-}state})/X_{steady\text{-}state}$$

The expression for peak time, t_p which is the time to reach x_{max} is given by:

$$t_p = \pi / \left(\omega_n \sqrt{1-\zeta^2}\right)$$

where $\omega_n$is the system undamped natural frequency in units of radians per second.

Results Comparison

Table E3.1: Case 1: Step Input

	Target	Mechanical APDL	Ratio
Maximum Ux of Mass	1.5000	1.499	0.999

	Target	Mechanical APDL	Ratio
Peak Time for Mass Ux	0.2560	0.2559	1.000

Table E3.2: Case 2: Ramp Input

	Target	Mechanical APDL	Ratio
Maximum Vx of Mass	1.5000	1.499	0.999
Peak Time for Mass Vx	0.2560	0.2560	1.000

VME4: Undamped Vibration Absorber

Overview

Reference:	L. Meirovitch, *Elements of Vibration Analysis*, 2nd Edition, McGraw-Hill Book College Division, 1986, pp. 131-134.
Analysis Type(s):	Explicit Dynamics with ANSYS LS-DYNA
Element Type(s):	Explicit Spring-Damper Elements (COMBI165) Explicit 3-D Structural Mass Elements (MASS166)
Input Listing:	vme4.dat

Test Case

A sinusoidal force is applied to the main mass, M_1 of the undamped system with a dynamic vibration absorber. The response of the main mass is zero for the case of a tuned main system / absorber system at steady-state. The absorber system consists of a spring, K_2 and an absorber mass, M_2.

Material Properties	Geometric Properties	Loading
Main Mass M_1 = 5 kg **Main Spring** K_1 = 10 N/m **Absorber Mass** M_2 = 1 kg **Absorber Spring** K_2 = 10 N/m	**Spring** Length of Springs = 1 m	Force of Main Mass = 1.0 sin(10t) (Entered as discrete values in an array.) Initial Absorber Mass Velocity = -0.1 m/s

Analysis Assumptions and Modeling Notes

As outlined in L. Meirovitch, *Elements of Vibration Analysis*, if a sinusoidal force, of the form $f(t)=F_o \sin(\omega t)$, acts on the main mass of a system with a vibration absorber, and if the forcing frequency equals the natural frequency of the absorber system alone:

$$(\omega = \omega_a = \sqrt{K_2 / M_2})$$

then at steady-state, the main mass motion, $x_1(t)$, is zero, and the absorber mass motion, $x_2(t)$ is given by:

$$x_2(t) = -\frac{F_o}{K_2} \sin(\omega t)$$

In the analysis, a sinusoidal force, of unit amplitude, is approximated by entering discrete values in an array and specifying the array in a dynamic load definition. An initial velocity is provided to the absorber mass, corresponding to the steady-state condition. The resulting motion agrees with the theory of the vibration absorber. The system parameters were selected arbitrarily, resulting in a natural frequency for the absorber system alone of 10 radians per second. This is the required absorber natural frequency for eliminating main mass motion if the input frequency is also 10 radians per second. Also, the chosen parameters result in a steady-state absorber mass response amplitude of 0.01 m.

Results Comparison

	Target	Mechanical APDL	Ratio
Amplitude of Absorber Deflection	0.01	0.01	1.000
Maximum Main Mass Deflection	0.00	5.96E-7	

VME5: Pinned Bar Under Gravity Loading

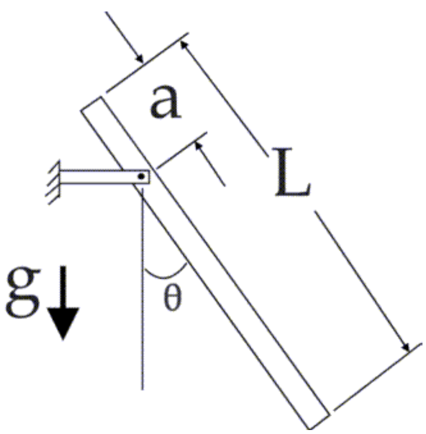
Overview

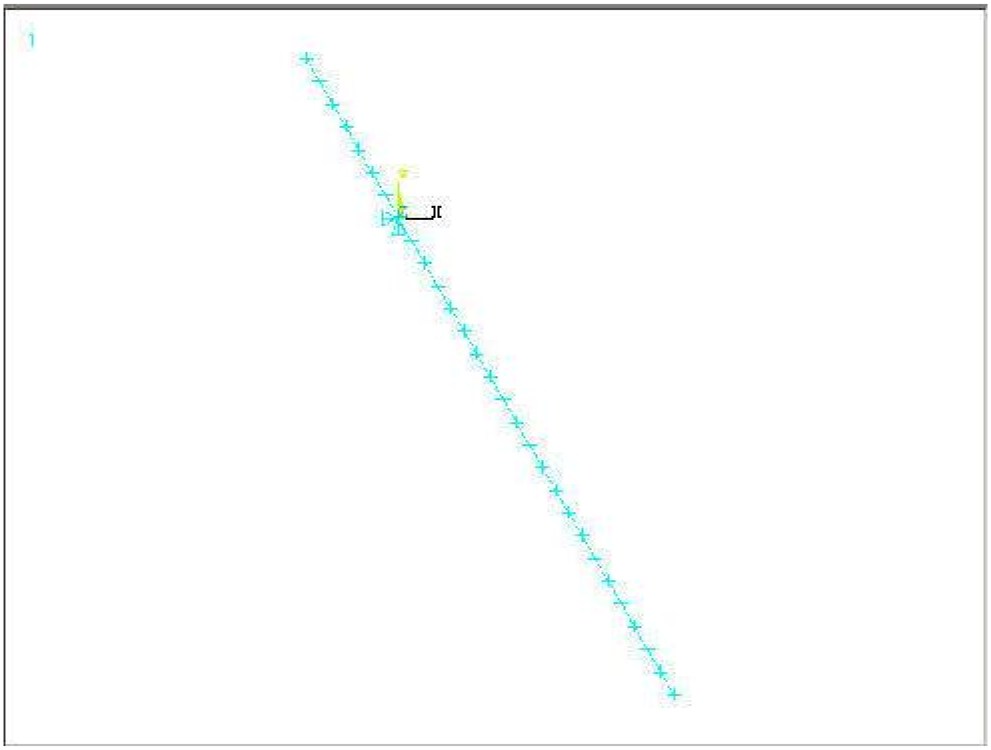
Reference:	W. G. McLean, E. W. Nelson, C. L. Best, *Schaum's Outline of Theory and Problems of Engineering Mechanics, Statics and Dynamics*, McGraw-Hill Book Co., Inc., New York, NY, 1978, p. 336.
Analysis Type(s):	Explicit Dynamics with ANSYS LS-DYNA
Element Type(s):	Explicit 3-D Beam Elements (BEAM161)
Input Listing:	vme5.dat

Test Case

A homogeneous bar, pinned at a distance **a** from one end, with total length, L, is subjected to gravity loading and released from rest at an angle θ = 30° from the vertical. The rotational speed when it passes through θ = 0° is calculated and compared to an analytical expression.

Figure E5.1: Pinned Bar Under Gravity Loading Problem Sketch





Material Properties	Geometric Properties	Loading
Density = 1.0 kg/m^3 Modulus of Elasticity = 10E6 N/m^2 Poisson's Ratio = 0.30	Constant square cross-section of 0.1 x 0.1 m^2 Total Length, L = 1.0 m; a = 0.25m	The acceleration due to gravity is 9.8 m/s^2 in the y-direction. One node is constrained in UX, UY, and UZ. All other nodes constrained only in UZ. At y = 0 UY = 0

Analysis Assumptions and Modeling Notes

The material properties were selected arbitrarily. As noted in W. G. McLean, E. W. Nelson, C. L. Best, *Schaum's Outline of Theory and Problems of Engineering Mechanics, Statics and Dynamics*, the magnitude of the bar's angular velocity when $\theta = 0°$, can be written as,

$$|\omega| = \sqrt{\frac{0.402g(L-2a)}{L^2 - 3La + 3a^2}}$$

assuming the bar is released at $\theta = 30°$. Based on the geometry chosen for this analysis, it can be seen that, at the time the bar passes through $\theta = 0°$, $\omega = v_x / 0.75$, where v_x is the translational velocity in the global Cartesian x-direction of the end of the bar. Twenty-eight BEAM161 elements were used to model the bar.

Results Comparison

	Target	Mechanical APDL	Ratio
| Angular Velocity | when $\theta = 0°$ (rad/sec)	2.121	2.07	0.976

VME6: Projectile with Air Resistance

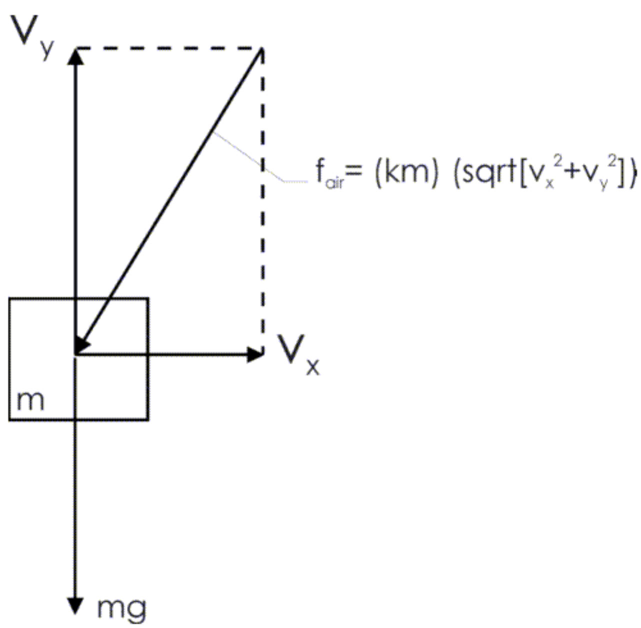
Overview

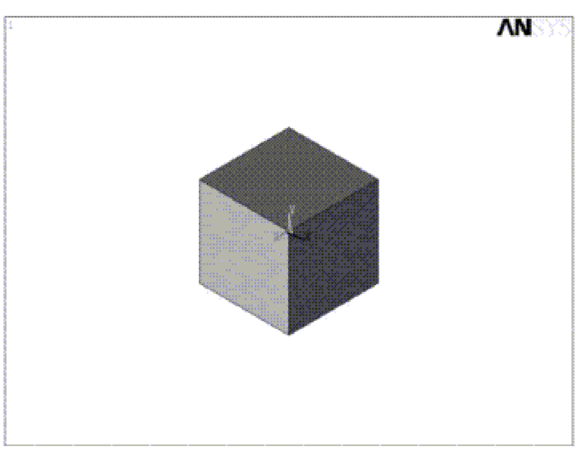
Reference:	J. B. Marion, S. T. Thornton, *Classical Dynamics of Particles & Systems*, 3rd Edition, Saunders College Publishing, 1988, pp. 60-63.
Analysis Type(s):	Explicit Dynamics with ANSYS LS-DYNA
Element Type(s):	Explicit 3-D Structural Solid Elements (SOLID164)
Input Listing:	vme6.dat

Test Case

A projectile is subjected to gravity and air resistance loading. The total travel time and travel distance are calculated for an assumed initial velocity and air resistance proportionality constant, k.

Figure E6.1: Projectile with Air Resistance Problem Sketch





Material Properties	Geometric Properties	Loading
Projectile Density = 1.0 lb-sec^2/in^4 Modulus of Elasticity = 1.0 lb/in^2 Poisson's Ratio = 0.30 **Air Resistance (Viscous Damping)** Alpha Damping Used, Alpha = 1.0	**Projectile** Volume = 1 in^3 (1 in x 1 in x 1 in)	The acceleration due to gravity is a_y = 386.4 in/s^2 in the y-direction. The initial velocity in the x-direction is V_{xi} = 100 in/s^2, and the initial velocity in the y-direction is V_{yi} = 500 in/s^2.

Analysis Assumptions and Modeling Notes

The acceleration due to gravity is a_y = 386.4 in/s^2 in the y-direction. The initial velocity in the x-direction is V_{xi} = 100 in/s^2, and the initial velocity in the y-direction is V_{yi} = 500 in/s^2.

The material properties have no effect on the results of interest, so they are selected arbitrarily. As outlined in J. B. Marion, S. T. Thornton, *Classical Dynamics of Particles & Systems*, the force due to the air resistance is assumed to be proportional to the mass, m, and the velocity, v, according to:

$$f_{air} = -kmv$$

where k is a constant of proportionality. If the initial projectile velocity in the x-direction is U, the initial projectile velocity in the y-direction (vertical) is V, and the acceleration due to gravity is g, then the x and y-direction projectile displacements are given by:

$$x = \frac{U}{k}(1-\exp(-kt)) \; ; \; y = -\frac{gt}{k} + \frac{kV+g}{k^2}(1-\exp(-kt))$$

For a projectile fired from the ground, the total travel time, T, before returning to the ground, is given by the transcendental equation:

$$T = \frac{kV+g}{gk}(1-\exp(-kT))$$

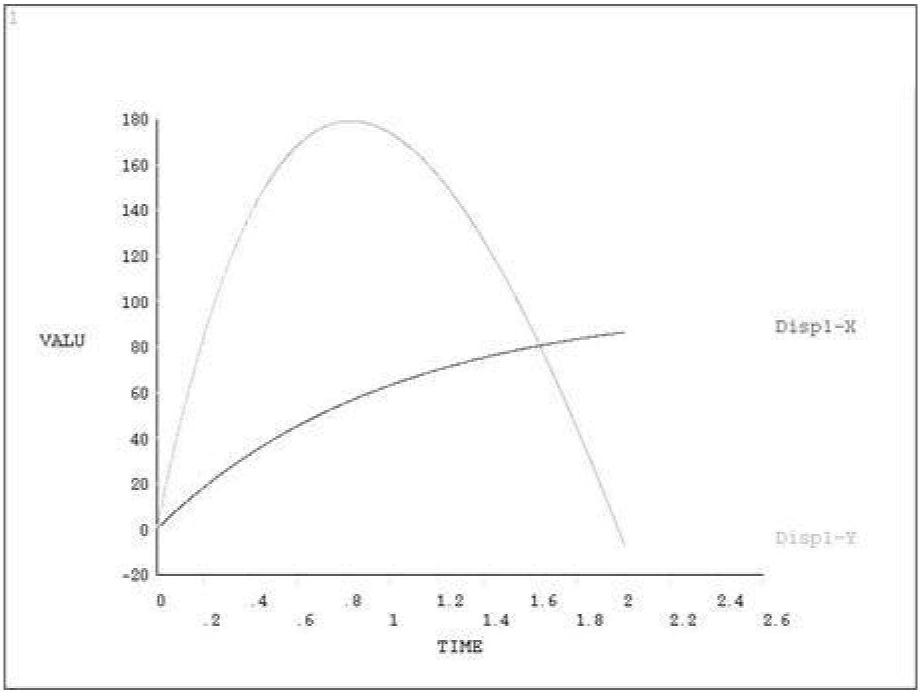
In this analysis, for simplicity, k was taken to equal 1. This produces a theoretical total travel time of T = 1.976 seconds, and a total x-direction travel distance of 86.138. In the analysis, the total travel time and the total x-direction travel distance are estimated by linearly interpolating between two time points. This is because there is not a time point in the solution, after the initial condition, at which the projectile y-location is exactly zero, but a close estimate is obtained by interpolation between two time points in the solution.

Results Comparison

	Target	Mechanical APDL	Ratio
Travel Time for Projectile (sec)	1.9760	1.9756	1.000

	Target	Mechanical APDL	Ratio
X-direction Travel Distance (in)	86.138	86.112	1.000

Figure E6.2: Displacement of Projectile Over Time



Part IV: NAFEMS Benchmarks

Chapter 1: NAFEMS Benchmarks Overview

The following section contains Mechanical APDL solutions of several NAFEMS benchmark publications. NAFEMS (National Agency for Finite Element Methods and Standards) has published many excellent technical reports on engineering analysis subjects which have become industry standard benchmarks. Some of those benchmarks have been reproduced here as Verification Manual test cases.

In this chapter benchmarks from the following publications are presented:

FEBSTA - Selected FE Benchmarks in Structural and Thermal Analysis, Davies,et al.,
LSB2 - The Standard NAFEMS benchmark, Report:LSB2
P09 - Free Vibration Benchmarks, Abbassian,F,Dawswell,D J, and Knowles, N C,
R0027 - Fundamental Tests of Creep Behavior, Becker,A A, and Hyde, T H,
R0029 - Assembly Benchmark Tests for 3D Beams and Shell Exhibiting Geometric Non-Linear Behaviour, Prinja, N K, and Clegg, R A,
R0038 - Two Dimensional Test Cases In Post Yield Fracture Mechanics, Remzi, E M
R0049 - Background to Material Non-Linear Benchmarks, Becker, A A
R0031 - Composite Benchmarks, Hardy, S
R0020 - 2D Test Cases in Linear Elastic Fracture Mechanics H.L.J.Pang, R.H.Leggat
R0038 - Benchmarks for Radiation and Scattering of Sound

Each different load condition is presented as a problem to be solved by appropriate Mechanical APDL element types. The test case includes a text description of the geometry, material properties, boundary conditions and loads. A results table of the verified solution is included at the end of the description of each test case. Test case inputs for each element type are also included.

If you are interested in the benchmark technical reports, you can contact NAFEMS using the following information;

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www.nafems.org

VMFEBSTA-LE1: Linear Elastic Analysis on an Elliptical Membrane

Test Description

An elliptical membrane with thickness 0.1m is modeled with symmetry boundary conditions. Uniform outward pressure is applied at outer edge BC. Linear elastic static analysis is performed on the model.

Geometric Properties	Material Properties	Loading
Thickness = 0.1m Origin to D = 2.0m Length DC = 1.25m Origin to A = 1.0m Length AB = 1.75m Curve AD: (x/2)2 + y2 = 1 Curve BC: (x/3.25)2 + (y/2.75)2 = 1 Boundary Condition: Ux = 0 along AB Uy = 0 along CD	E = 210E+03 Mpa υ = 0.3	Outward pressure at BC = 10 Mpa

Results Comparison

Results are tabulated and displayed as in the NAFEMS manual.

```
          |    Mechanical APDL    |   RATIO   |        INPUT        |

 SHELL 181
 SYY at C          93.026            1.004      vmfebsta-le1-181

 --------------------------------------------------------------------
```

vmfebsta-le1-181.dat

VMFEBSTA-LE5: Linear Elastic Analysis on a Z-Section Cantilevered Plate

Test Description

A cantilevered plate of thickness 0.1m is modeled and meshed with shell elements. The model has uniform mesh of eight elements along length and one element across width. Torque load is applied at the end by two uniformly distributed edge shears at each flange. Linear elastic static analysis is performed to compute the axial stress at mid surface point A.

Geometric Properties	Material Properties	Loading
Thickness = 0.1m Length = 10m Flange length = 1m Width = 2m Point A is at 2.5m from orgin Boundary Condition: All DOF are constrained at X = 0	E = 210E+03 Mpa υ = 0.3	Torque of 1.2MNm applied at end X=10 by two uniformly distributed edge shears, S = 0.6MN at each flange

Results Comparison

Results are tabulated and displayed as in the NAFEMS manual.

```
            |    Mechanical APDL    |   RATIO   |        INPUT        |
  SHELL 181
  SXX at A        -111.204            1.030      vmfebsta-le5-181
  SHELL 281
  SXX at A        -116.124            1.075      vmfebsta-le5-281
  --------------------------------------------------------------------
```

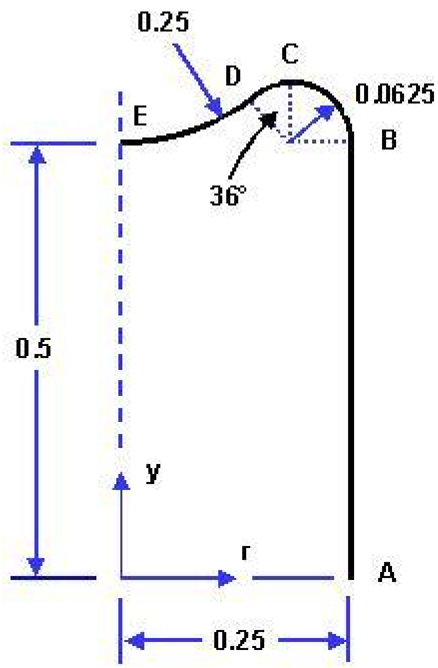
vmfebsta-le5-181.dat
vmfebsta-le5-281.dat

VMLSB2-LE8: Linear Elastic Axisymmetric Shell with Pressure Loading

Test Description

An axisymmetric shell with thickness of 0.01m is modeled with zero y displacement at point A and zero radial displacement and zero rotation at point E. The shell model is subjected to uniform internal pressure loading. Linear elastic static analysis is performed on the model.

Figure LSB2-LE8.1: Problem sketch



Geometric Properties	Material Properties	Loading
Thickness = 0.01m Refer to Figure LSB2-LE8.1: Problem sketch (p. 905) Boundary condition: U_Y = 0 at point A U_X, ROT_Z = 0 at point E	E = 210E+03 Mpa υ = 0.3	Internal pressure loading = 1 Mpa

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |    Mechanical APDL     |   RATIO   |        INPUT        |

  SHELL208
```

```
 SZ AT D           91.348            0.966        vmlsb2-le8-208

SHELL209

 SZ AT D           90.548            0.958        vmlsb2-le8-209

-------------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

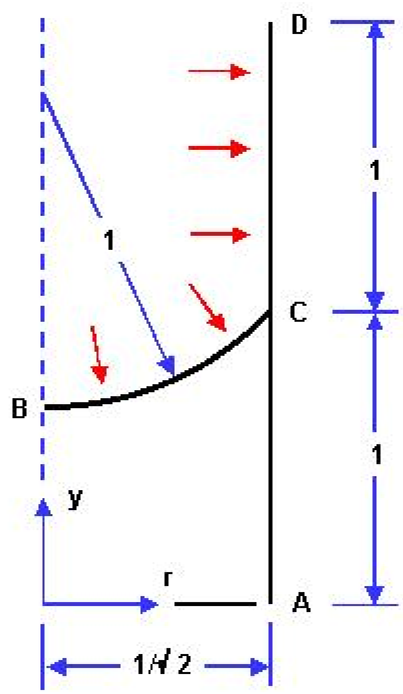
vmlsb2-le8-208.dat
vmlsb2-le8-209.dat

VMLSB2-LE9: Linear Elastic Axisymmetric Branched Shell with Pressure Loading

Test Description

An axisymmetric branched shell of thickness 0.01m is modeled with point A fully fixed. The shell model is subjected to uniform internal pressure loading over edge BCD. Linear elastic static analysis is performed on the model.

Figure LSB2-LE9.1: Problem sketch



Geometric Properties	Material Properties	Loading
Thickness = 0.01m Refer to Figure LSB2-LE9.1: Problem sketch (p. 907) Boundary condition: Ux, Uy, ROTz = 0 at A	E = 210E+03 Mpa υ = 0.3	Internal pressure loading over edge BCD = 1 Mpa

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
           |   Mechanical APDL    |   RATIO   |       INPUT        |

 SHELL208
```

```
 SYY at C         -304.509           0.952         vmlsb2-le9-208

SHELL209

 SYY at C         -304.151           0.951         vmlsb2-le9-209

--------------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

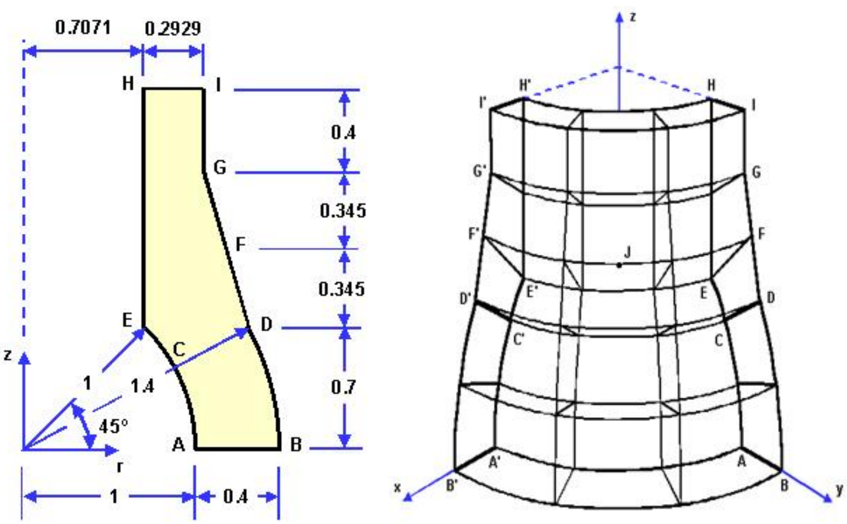
VMLSB2-LE9-208.dat
VMLSB2-LE9-209.dat

VMLSB2-LE11: Linear Elastic Axisymmetric Shell with Pressure Loading

Test Description

An axisymmetric solid is modeled with symmetry boundary conditions. Linear temperature loading is applied in the radial and axial direction. Linear elastic static analysis is performed on the model.

Figure LSB2-LE11.1: Problem sketch



Geometric Properties	Material Properties	Loading
Thickness = 0.01m Refer to Figure LSB2-LE11.1: Problem sketch (p. 909) Boundary condition: Symmetry on XZ plane Uy = 0 Symmetry on YZ plane Ux = 0 Symmetry on XY plane Uz = 0 Face HIH'I' Uz = 0	E = 210E+03 Mpa υ = 0.3 Thermal expansion co-efficient = 2.3e-04 /°C	Linear temperature gradient in radial and axial direction T °C = (x2 + y2) ½ + z

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
          |    Mechanical APDL     |   RATIO   |       INPUT          |
```

```
SOLID185

 SZZ at A         -102.156           0.973        vmlsb2-le11-185

SOLID186

 SZZ at A         -103.261           0.983        vmlsb2-le11-186

-------------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

vmlsb2-lE11-185.dat
vmlsb2-lE11-186.dat

VMP09-T2: Pin-Ended Double Cross: In-Plane Vibration

Test Description

Eight beams of equal length L = 5 equally spaced apart and interconnected at center are constrained in the x and y direction at all 8 beam endpoints. Frequency vibration analysis is performed on the model.

Geometic Properties	Material Properties	Boundary Conditions
L = 5m	$E = 200 \times 10^9$ N/m^2 ρ = 8000.0 kg/m^3	Applied at beam endpoints: $u_y = 0$ $u_x = 0$

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
                  |   Mechanical APDL    |   RATIO  |         INPUT          |

BEAM188
MODE1                     11.3279         0.9993        vmp09-t2-188
MODE2,3                   17.6607         0.9973        vmp09-t2-188
MODE4,5,6,7,8             17.6901         0.9989        vmp09-t2-188
MODE9                     45.4101         1.0014        vmp09-t2-188
MODE10,11                 57.3386         0.9991        vmp09-t2-188
MODE12,13,14,15,16        57.6622         1.0047        vmp09-t2-188
BEAM189
MODE1                     11.3279         0.9993        vmp09-t2-189
MODE2,3                   17.6607         0.9973        vmp09-t2-189
MODE4,5,6,7,8             17.6901         0.9989        vmp09-t2-189
MODE9                     45.4101         1.0014        vmp09-t2-189
MODE10,11                 57.3386         0.9991        vmp09-t2-189
MODE12,13,14,15,16        57.6622         1.0047        vmp09-t2-189

 ---------------------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

vmp09-t2-188.dat
vmp09-t2-189.dat

VMP09-T4: Cantilever with Off-Center Point Masses

Test Description

A cantilever beam situated horizontally with two off-center lump masses of mass M_1 = 10000 kg and M_2 = 1000 kg at right free ends. The beam is constrained in all DOF at left end. Frequency vibration analysis is performed on the model.

Geometic Properties	Material Properties	Boundary Conditions
L = 10m H = 4m	$E = 200 \times 10^9$ N/m^2 $\rho = 8000.0$ kg/m^3 $\nu = 0.3$	Applied at right beam endpoint: $U_y = 0$ $U_x = 0$ $U_z = 0$ $R_x = 0$ $R_y = 0$ $R_z = 0$

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
           |   Mechanical APDL   |   RATIO  |         INPUT         |

 BEAM188
 MODE1            1.7197          0.9981       vmp09-t4-188
 MODE2            1.7235          0.9979       vmp09-t4-188
 MODE3            7.4014          0.9984       vmp09-t4-188
 MODE4            9.9699          0.9999       vmp09-t4-188
 MODE5           18.0582          0.9947       vmp09-t4-188
 MODE6           27.0503          1.0035       vmp09-t4-188
 BEAM189
 MODE1            1.7202          0.9984       vmp09-t4-189
 MODE2            1.7237          0.9981       vmp09-t4-189
 MODE3            7.4026          0.9986       vmp09-t4-189
 MODE4            9.9333          0.9962       vmp09-t4-189
 MODE5           18.0094          0.9920       vmp09-t4-189
 MODE6           26.6520          0.9887       vmp09-t4-189

 ----------------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

vmp09-t4-188.dat
vmp09-t4-189.dat

VMP09-T5: Deep Simply-Supported Beam

Test Description

A simply-supported beam of length L = 10 is situated along the x-axis. The beam is constrained in the x, y, z and R_x direction on the left endpoint and in the y and z direction on the right endpoint. Frequency vibration analysis is performed on the model.

Geometic Properties	Material Properties	Boundary Conditions
L = 10m	$E = 200 \times 10^9\ N/m^2$ $\rho = 8000.0\ kg/m^3$ $\nu = 0.3$	Applied at left beam endpoint: $U_y = 0$ $U_x = 0$ $U_z = 0$ $R_x = 0$ Applied at right beam endpoint: $U_y = 0$ $U_z = 0$

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
             |   Mechanical APDL   |   RATIO  |         INPUT         |

 BEAM188
  MODE1,2          42.167          0.9887       vmp09-t5-188
  MODE3            71.453          1.0035       vmp09-t5-188
  MODE4           124.872          0.9990       vmp09-t5-188
  MODE5,6         143.711          0.9700       vmp09-t5-188
  MODE7           212.598          0.9953       vmp09-t5-188
  MODE8,9         270.131          0.9529       vmp09-t5-188
 BEAM189
  MODE1,2          42.078          0.9866       vmp09-t5-189
  MODE3            71.713          1.0072       vmp09-t5-189
  MODE4           125              1.000        vmp09-t5-189
  MODE5,6         143.463          0.9684       vmp09-t5-189
  MODE7           215.080          1.0069       vmp09-t5-189
  MODE8,9         272.068          0.9598       vmp09-t5-189

 ----------------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

vmp09-t5-188.dat
vmp09-t5-189.dat

VMP09-T12: Free Thin Square Plate

Test Description

A square plate of length L = 10 is situated in the x-y plane and is constrained in the x, y, and R_z direction at all nodes. Frequency vibration analysis is performed on the model.

Geometic Properties	Material Properties	Boundary Conditions
L = H = 10m	$E = 200 \times 10^9$ N/m^2 $\rho = 8000.0$ kg/m^3 $\nu = 0.3$	Applied at all nodes: $U_x = 0$ $U_y = 0$ $R_z = 0$

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |   Mechanical APDL   |   RATIO  |          INPUT          |

 SHELL181
  MODE4            1.632           1.0060      vmp09-t12-181
  MODE5            2.403           1.0181      vmp09-t12-181
  MODE6            3.007           1.0290      vmp09-t12-181
  MODE7,8          4.271           1.0089      vmp09-t12-181
  MODE9            7.905           1.0659      vmp09-t12-181
  MODE10           8.029           1.0002      vmp09-t12-181
 SHELL281
  MODE4            1.620           0.9988      vmp09-t12-281
  MODE5            2.360           0.9999      vmp09-t12-281
  MODE6            2.923           1.0003      vmp09-t12-281
  MODE7,8          4.181           0.9877      vmp09-t12-281
  MODE9            7.373           0.9943      vmp09-t12-281
  MODE10           7.373           0.9186      vmp09-t12-281

 ----------------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

vmp09-t12-181.dat
vmp09-t12-281.dat

VMP09-T15: Clamped Thin Rhombic Plate

Test Description

A rhombus plate of length L = 10 and angle offset θ = 45° from the y-axis is constrained in the x, y, and R_z direction at all nodes and the z', R_x' and R_y' direction along the four edges. Frequency vibration analysis is performed on the model.

Geometic Properties	Material Properties	Boundary Conditions
L = 10m θ = 45°	E = 200 x 10^9 N/m^2 ρ = 8000.0 kg/m^3 ν = 0.3	Applied at all nodes: U_x = 0 U_y = 0 R_z = 0 Applied along all 4 edges: U_z' = 0 R_x' = 0 R_y' = 0

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
              |   Mechanical APDL   |   RATIO  |         INPUT          |

  SHELL181
   MODE1            8.1425          1.0258      vmp09-t15-181
   MODE2           13.8919          1.0823      vmp09-t15-181
   MODE3           20.0380          1.1169      vmp09-t15-181
   MODE4           20.1671          1.0540      vmp09-t15-181
   MODE5           27.9538          1.1643      vmp09-t15-181
   MODE6           32.0477          1.1478      vmp09-t15-181
  SHELL281
   MODE1            7.9358          0.9997      vmp09-t15-281
   MODE2           12.8568          1.0017      vmp09-t15-281
   MODE3           18.0159          1.0042      vmp09-t15-281
   MODE4           19.0948          0.9980      vmp09-t15-281
   MODE5           24.1072          1.0041      vmp09-t15-281
   MODE6           27.8501          0.9974      vmp09-t15-281

  ----------------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

vmp09-t15-181.dat
vmp09-t15-281.dat

VMP09-T33: Free Annular Membrane

Test Description

A hollow circular plate of inner radius R_1 = 1.8 and outer radius R_2 = 6 is situated in the x-y plane constrained in the z direction at all nodes. Frequency vibration analysis is performed on the model.

Geometic Properties	Material Properties	Boundary Conditions
R_1 = 1.8m R_2 = 6m	$E = 200 \times 10^9$ N/m^2 ρ = 8000.0 kg/m^3 ν = 0.3	Applied at all nodes: $U_z = 0$

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |   Mechanical APDL   |   RATIO  |         INPUT        |

 PLANE182
  MODE4,5          137.164           1.061      vmp09-t33-182
  MODE6            228.563           1.011      vmp09-t33-182
  MODE7,8          240.395           1.024      vmp09-t33-182
  MODE9,10         292.317           1.105      vmp09-t33-182
  MODE11,12        354.146           1.052      vmp09-t33-182
  MODE13,14        433.481           1.150      vmp09-t33-182
 PLANE183
  MODE4,5          125.834           0.974      vmp09-t33-183
  MODE6            224.207           0.991      vmp09-t33-183
  MODE7,8          232.940           0.992      vmp09-t33-183
  MODE9,10         263.489           0.996      vmp09-t33-183
  MODE11,12        335.553           0.997      vmp09-t33-183
  MODE13,14        376.986           1.001      vmp09-t33-183

 ----------------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

vmp09-t33-182.dat
vmp09-t33-183.dat

VMP09-T52: Simply-Supported 'Solid' Square Plate

Test Description

A solid rectangular plate of length and width L = 10 and height H = 1 is situated in the x-y plane and constrained in the z direction. Frequency vibration analysis is performed on the model.

Geometic Properties	Material Properties	Boundary Conditions
L = H = 10m W = 1m	$E = 200 \times 10^9$ N/m^2 ρ = 8000.0 kg/m^3 ν = 0.3	Applied along the 4 edges on the plane Z = -0.5m $U_z = 0$

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |   Mechanical APDL   |   RATIO  |        INPUT         |

 SHELL181
  MODE4             44.396          0.9673       vmp09-t52-181
  MODE5,6          108.221          0.9889       vmp09-t52-181
  MODE7            164.503          0.9816       vmp09-t52-181
  MODE8            194.097          1.0026       vmp09-t52-181
  MODE9,10         206.734          1.0026       vmp09-t52-181
 SOLID185
  MODE4             48.925          1.0660       vmp09-t52-185
  MODE5,6          123.931          1.1324       vmp09-t52-185
  MODE7            184.648          1.0998       vmp09-t52-185
  MODE8            195.655          1.0107       vmp09-t52-185
  MODE9,10         209.403          1.0121       vmp09-t52-185
 SOLID186
  MODE4             43.837          0.9551       vmp09-t52-186
  MODE5,6          106.751          0.9754       vmp09-t52-186
  MODE7            161.176          0.9600       vmp09-t52-186
  MODE8            193.796          1.0011       vmp09-t52-186
  MODE9,10         205.971          0.9989       vmp09-t52-186
 SOLID187
  MODE4             45.375          0.9886       vmp09-t52-187
  MODE5,6          112.672          1.0295       vmp09-t52-187
  MODE7            179.272          1.0678       vmp09-t52-187
  MODE8            193.940          1.0018       vmp09-t52-187
  MODE9,10         206.608          1.0020       vmp09-t52-187
 SHELL281
  MODE4             44.110          0.9611       vmp09-t52-281
  MODE5,6          106.982          0.9775       vmp09-t52-281
  MODE7            162.337          0.9687       vmp09-t52-281
  MODE8            193.609          1.0001       vmp09-t52-281
  MODE9,10         202.570          0.9824       vmp09-t52-281

 ----------------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

- vmp09-t52-181.dat
- vmp09-t52-185.dat
- vmp09-t52-186.dat
- vmp09-t52-187.dat

vmp09-t52-281.dat

VMR020-t1a: Center Cracked Plate in Tension

Test Description

A plate with center crack and plane strain elements is subjected to uniform tensile stress of 100Mpa. Symmetry has been taken into account. Only one quarter of the plate is modeled. U_Y=0 along uncracked portion. U_X=0 along symmetry.

Geometic Properties	Material Properties	Loading
b=20mm a/b=0.5 h/b=1 where: b=width a=length of crack h=height	E=207000MPa =0.3	Uniform tensile stress of 100MPa

Results

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	Ratio	Test
SIF	1.333	1.006	vmr020-t1a-183
J integral	1.335	1.007	vmr020-t1a-183

Input Files

vmr020-t1a-183

VMR020-t1b: Center Cracked Plate with Quadratic Thermal Distribution

Test Description

A plate with center crack and plane strain elements is subjected to quadratic thermal distribution that varies from 0°C to 100°C. Symmetry has been taken into account and only one quarter of the plate is modeled. U_Y=0 along un-cracked portion. U_X=0 along symmetry.

Geometic Properties	Material Properties	Loading
b=100mm a/b=0.1 h/b=2.5 where: b=width a=length of crack h=height	E=207000MPa =0.3 α=1.35e-5/°C	Quadratic thermal distribution

Results

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	Ratio	Test
SIF	1.010	1.010	vmr020-t1b-183
J integral	1.000	1.000	vmr020-t1b-183

Input Files

vmr020-t1b-183

VMR020-t2a: Single Edge Cracked Plate Subjected to Uniform Tensile Stress

Test Description

A single edge cracked plate with plane strain elements is subjected to a uniform tensile stress of 100MPa. Symmetry has been taken into account and only one quarter of the plate is modeled. U_Y=0 along un-cracked portion, U_X=0 at location, X=10, and Y=0.

Geometic Properties	Material Properties	Loading
b=20mm a/b=0.5 h/b=0.5 where: b=width a=length of crack h=height	E=207000MPa =0.3	Uniform tensile stress of 100MPa

Results

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	Ratio	Test
SIF	2.966	0.989	vmr020-t2a-183
J integral	2.965	0.988	vmr020-t2a-183

Input Files

vmr020-t2a-183

VMR020-t2b: Single Edge Cracked Plate Subjected to Uniform Normal Displacement

Test Description

A single edge cracked plate with plane strain elements is subjected to a uniform normal displacement of 0.01mm. Symmetry has been taken into account and only one quarter of the plate is modeled. U_Y=0 along uncracked portion, U_X =0 at location X=10 and Y=0.

Geometic Properties	Material Properties	Loading
b=20mm a/b=0.5 h/b=0.5 where: b=width a=length of crack h=height	E=207000MPa =0.3	Uniform displacement of 0.01mm

Results

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	Ratio	Test
SIF	1.027	0.988	vmr020-t2b-183
J integral	1.029	0.989	vmr020-t2b-183

Input Files

vmr020-t2b-183

VMR020-t3a: An Angle Crack Embedded in a Plate Subjected to Uniaxial Tension

Test Description

A crack of length *2a* is embedded in a plate at an angle of 22.5° with respect to the vertical axis. The plate is subjected to uniform tension of 100MPa. Plane strain elements are used. Full geometry is considered. U*y* is constrained at the base and U_x is constrained at the right corner of the base.

Geometic Properties	Material Properties	Loading
b=50mm a/b=0.5 h/b=1.25 β=22.5° where: b=width a=length of crack h=height β=angle of the inclined crack	E=207000MPa =0.3	Uniform tensile stress of 100MPa

Results

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	Ratio	Test
K_I	0.186	0.979	vmr020-t3a-183
K_{II}	0.405	1.000	vmr020-t3a-183

Input Files

vmr020-t3a-183

VMR020-t3b: An Angle Crack Embedded in a Plate Subjected to Uniaxial Tension

Test Description

A crack of length *2a* is embedded in a plate at an angle of 67.5° with respect to the vertical axis. The is plate subjected to uniform tension of 100MPa. Plane strain elements are used. Full geometry is considered. U_y is constrained at the base and U_x is constrained at the right corner of the base.

Geometic Properties	Material Properties	Loading
b=50mm a/b=0.5 h/b=1.25 β=67.5° where: b=width a=length of crack h=height β=angle of the inclined crack	E=207000MPa =0.3	Uniform normal stress of 100 MPa

Results

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	Ratio	Test
K_I	1.057	1.026	vmr020-t3c-183
K_{II}	0.375	1.013	vmr020-t3c-183

Input Files

vmr020-t3b-183

VMR020-t3c: An Angle Crack Embedded in a Plate Subjected to Uniaxial Tension

Test Description

An angle crack of length *2a* is embedded in a plate at an angle 90° with respect to the vertical axis. The plate is subjected to uniform tension of 100 MPa. Plane strain elements are used. Full geometry is considered. U_y is constrained at the base and U_x is constrained at the right corner of the base.

Geometic Properties	Material Properties	Loading
b=50mm a/b=0.5 h/b=1.25 β=90° where: b=width a=length of crack h=height β=angle of the inclined crack	E=207000MPa =0.3	Uniform normal stress of 100MPa

Results

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	Ratio	Test
SIF	1.214	1.011	vmr020-t3b-183
J integral	1.213	1.011	vmr020-t3b-183

Input Files

vmr020-t3c-183

VMR020-t4a: Crack at a Hole in a Plate Subjected to Uniaxial Tension

Test Description

A plate with a crack at the hole of radius R is subjected to uniform tensile stress of 100MPa. Plane stress elements are used. Symmetry has been taken into account and only one quarter of the plate is modeled. U_Y=0 along un-cracked portion, U_X=0 along symmetry.

Geometic Properties	Material Properties	Loading
b=10mm a/b=0.3 R/b=0.25 h/b=2 where: b=width a=length of crack h=height R=radius of hole	E=207000MPa =0.3	Uniform normal stress of 100MPa

Results

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	Ratio	Test
SIF	1.087	1.035	vmr020-t4a-183
J integral	1.083	1.031	vmr020-t4a-183

Input Files

vmr020-t4a-183

VMR020-t4b: Crack at a Hole in a Plate Subjected to Uniaxial Tension

Test Description

A plate with a crack at the hole of radius R is subjected to uniform tensile stress of 100MPa. Plane strain elements are used. Symmetry has been taken into account and only one quarter of the plate is modeled. U_Y=0 along un-cracked portion, U_X=0 along symmetry.

Geometic Properties	Material Properties	Loading
b=10mm a/b=0.3 R/b=0.25 h/b=2 where: b=width a=length of crack h=height R=radius of hole	E=207000 MPa =0.3	Uniform normal stress of 100 MPa

Results

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	Ratio	Test
SIF	1.087	1.036	vmr020-t4b-183
J integral	1.083	1.032	vmr020-t4b-183

Input Files

vmr020-t4b-183

VMR020-t5: Axisymmetric Crack in a Bar

Test Description

A circumferentially cracked round bar of radius R with axisymmetric elements is subjected to uniform stress of 100MPa. Symmetry has been taken into account and only one quarter of the bar is modeled. U_Y=0 along un-cracked portion, U_X=0 along symmetry.

Geometic Properties	Material Properties	Loading
b=20mm h/R=1 b/R=0.5 where: b=bar ligament width a=length of crack h=height R=radius of bar	E=207000MPa =0.3	Uniform normal stress of 100MPa

Results

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	Ratio	Test
SIF	0.461	0.970	vmr020-t5a-183
J integral with plane stress formulation	0.463	0.975	vmr020-t5a-183
J integral with plane strain formulation	0.486	1.022	vmr020-t5a-183

Input Files

vmr020-t5a-183

VMR020-t6: Compact Tension Specimen

Test Description

A compact tension specimen with plane strain elements is subjected to a point load of 1000N.

One half of the test geometry is considered. U_Y=0 along uncracked portion, U_X=0 at location X=25 and Y=0.

Geometic Properties	Material Properties	Loading
a/W=0.5 W=50mm t=1mm where: W=width of the specimen a=length of crack h=height of plate t=thickness of the plate	E=207000MPa =0.3	Point load of 1000N

Results

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	Ratio	Test
SIF	9.666	1.001	vmr020-t6a-183
J integral	9.637	0.998	vmr020-t6a-183

Input Files

vmr020-t6a-183

VMR020-t8a: V-Notch Cracked Plate Subjected to Uniform Tensile Stress

Test Description

A *v* notch plate of crack length *a* with plane strain elements is subjected to a uniform normal stress of 100MPa. Symmetry has been taken into account and only one quarter of the plate is modeled. U_Y=0 along uncracked portion, U_X=0 along symmetry

Geometic Properties	Material Properties	Loading
a/d=0.2 d/W=0.1 h/W=1.0 β=90° W=250mm where: W=width of the specimen a=length of crack h=height of plate d=depth of the v-notch	E=207000000MPa =0.3	Uniform normal stress of 100MPa

Results

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	Ratio	Test
SIF	2.798	1.021	vmr020-t8a-183
J integral	2.809	1.025	vmr020-t8a-183

Input Files

vmr020-t8a-183

VMR020-t8b: V-Notch Cracked Plate Subjected to Uniform Normal Displacement

Test Description

A *v* notch plate of crack length *a* with plane strain elements is subjected to a uniform normal displacement of 0.1mm. Symmetry has been taken into account and only one quarter of the plate is modeled. U_Y=0 along uncracked portion, U_X=0 along symmetry.

Geometic Properties	Material Properties	Loading
a/d=0.2 d/W=0.1 h/W=1.0 β=90° W=250mm where: W=width of the specimen a=length of crack h=height of plate thickness of the plate d=depth of the v-notch	E=207000000 MPa =0.3	Uniform normal displacement of 0.1mm

Results

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	Ratio	Test
SIF	3.193	0.990	vmr020-t8b-183
J integral	3.224	0.999	vmr020-t8b-183

Input Files

vmr020-t8b-183

VMR027-3A: 2-D Plane Stress - Biaxial (negative) Load Secondary Creep

Test Description

A square of length L and height L is constrained in the Y-direction on the bottom edge and constrained in the X-direction on the left edge. A tensile distributed load, σ_1, is applied on the right edge and a compressive distributed load, σ_2, is applied to the top edge.

Geometic Properties	Material Properties	Loading
L = 100 mm **Boundary Conditions** Bottom Edge: $u_y = 0$ Left Edge: $u_x = 0$	$E = 200 \times 10^3$ N/mm^2 $\nu = 0.3$ **Creep Law:** $\varepsilon = A\sigma^n t^m$ $A = 3.125 \times 10^{-14}$ per hour (σ in N/mm^2) n = 5	Right Edge: σ_1 = 200 N/mm^2 Top Edge: σ_2 = -200 N/mm^2

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |   Mechanical APDL    |   RATIO  |         INPUT         |

 SHELL181
  ECR6X          134.984            0.9999     vmr027-cr3a-181
  ECR6Y         -134.984            0.9999     vmr027-cr3a-181
 PLANE182
  ECR6X          135.000            1.0000     vmr027-cr3a-182
  ECR6Y         -135.000            1.0000     vmr027-cr3a-182
 PLANE183
  ECR6X          135.000            1.0000     vmr027-cr3a-183
  ECR6Y         -135.000            1.0000     vmr027-cr3a-183
 SHELL281
  ECR6X          134.984            0.9999     vmr027-cr3a-281
  ECR6Y         -134.994            0.9999     vmr027-cr3a-281

 -----------------------------------------------------------------------
```

vmr027-cr3a-181.dat
vmr027-cr3a-182.dat
vmr027-cr3a-183.dat
vmr027-cr3a-281.dat

VMR027-3B: 2-D Plane Stress - Biaxial (negative) Displacement Secondary Creep

Test Description

A square of length L and height L is constrained in the Y-direction on the bottom edge and constrained in the X-direction on the left edge. The model is displaced in the X-direction by u_1 and in the Y-direction by u_2

Geometic Properties	Material Properties	Loading
L = 100 mm **Boundary Conditions** Top Edge: u_y = -0.1, Bottom Edge: u_y = 0 Right Edge: u_x = 0.1, Left Edge: u_x = 0	E = 200 x 10^3 N/mm^2 ν = 0.3 **Creep:** $\varepsilon = A\sigma^n t^m$ n = 5	No applied forces

Results

Results are tabulated and displayed as in the NAFEMS manual.

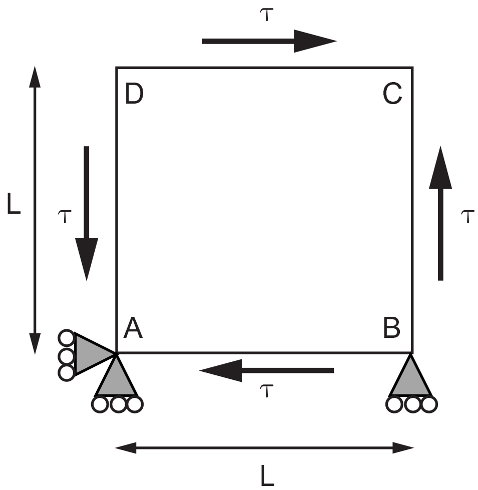
```
            |   Mechanical APDL   |   RATIO  |          INPUT         |

 SHELL181
  ECR6X                7.976            1.0318     vmr027-cr3b-181
 PLANE182
  ECR6X                7.976            1.0318     vmr027-cr3b-182
 PLANE183
  ECR6X                7.976            1.0318     vmr027-cr3b-183
 SHELL281
  ECR6X                7.976            1.0318     vmr027-cr3b-281

 ----------------------------------------------------------------------
```

vmr027-cr3b-181.dat
vmr027-cr3b-182.dat
vmr027-cr3b-183.dat
vmr027-cr3b-281.dat

VMR027-4C: 2-D Plane Stress - Shear Loading Secondary Creep

Test Description

A square of length L and height L is constrained in the Y-direction at the corners on the bottom edge and constrained in the X-direction on the bottom edge, left corner. The same shear stress, τ, is applied on all four faces as shown in the figure.



Geometic Properties	Material Properties	Loading
L = 100 mm **Boundary Conditions** Bottom Edge: u_y = 0.0 at Points (0,0) and (L,0) Bottom Edge: u_x = 0 at Point (0,0)	E = 200 x 10^3 N/mm^2 ν = 0.3 **Creep Law:** $\varepsilon = A\sigma^n t^m$ n = 5	τ = 100 N/mm^2 Shear Force on all Edges: $\tau/6$, $2\tau/3$, $\tau/6$

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
             |   Mechanical APDL   |   RATIO  |         INPUT          |

SHELL181
 ECR2X                 8.436            0.9999     vmr027-cr4c-181
PLANE182
 ECR2X                 8.437            1.0000     vmr027-cr4c-182
PLANE183
 ECR2X                 8.437            1.0000     vmr027-cr4c-183
PLANE281
 ECR2X                 6.898            0.8175     vmr027-cr4c-281

 ----------------------------------------------------------------------
```

vmr027-cr4c-181.dat

vmr027-cr4c-182.dat
vmr027-cr4c-183.dat
vmr027-cr4c-281.dat

VMR027-5B: 2-D Plane Strain - Biaxial Displacement Secondary Creep

Test Description

A square of length L and height L is constrained in the X-direction on the left edge and constrained in the Y-direction on the bottom edge. A displacement, u_1, is applied in the X-direction on the right edge and another displacement, u_2, is applied in the Y-direction on the top edge.

Geometic Properties	Material Properties	Loading
L = 100 mm **Boundary Conditions** Bottom Edge: u_y = 0, Top Edge: u_y = 0.05 Right Edge: u_x = 0.1, Left Edge: u_x = 0	E = 200 x 10^3 N/mm^2 ν = 0.3 **Creep Law:** $\varepsilon = A\sigma^n t$ A = 3.125 x 10^{-14} per hour (σ in N/mm^2) n = 5	No applied forces

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |   Mechanical APDL    |   RATIO  |         INPUT          |

PLANE182
 ECR6X             257.947           1.0008     vmr027-cr5b-182
PLANE183
 ECR6X             257.947           1.0008     vmr027-cr5b-183

----------------------------------------------------------------------
```

vmr027-cr5b-182.dat
vmr027-cr5b-183.dat

VMR027-6B: 3-D - Triaxial Displacement Secondary Creep

Test Description

A block of length, height, and width L is constrained on the left face in the X-direction and constrained on the bottom face in the Y-direction. The model is displaced in all three directions by a given quantity.

Geometic Properties	Material Properties	Loading
L = 100 mm **Boundary Conditions** Left Face: u_x = 0, Right Face: u_x = 0.3 Bottom Face: u_y = 0, Top Face: u_y = 0.2 Front Face: u_z = 0, Back Face: u_z = 0.1	E = 200 x 10^3 N/mm^2 ν = 0.3 **Creep Law:** $\varepsilon = A\sigma^n t$ A = 3.125 x 10^{-14} per hour (σ in N/mm^2) n = 5	No applied forces

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
           |   ANSYS    |   RATIO  |          INPUT          |

 SOLID185
 ISOCRX       1007.950       1.0002     vmr027-cr6b-185
 ANICRX       1007.950       1.0002     vmr027-cr6b-185
 SOLID186
 ISOCRX       1007.950       1.0002     vmr027-cr6b-186
 ANICRX       1007.950       1.0002     vmr027-cr6b-186
 SOLID187
 ISOCRX       1007.950       1.0002     vmr027-cr6b-187
 ANICRX       1007.950       1.0002     vmr027-cr6b-187

----------------------------------------------------------------
```

vmr027-cr6b-185.dat
vmr027-cr6b-186.dat
vmr027-cr6b-187.dat

VMR027-10A: 2-D Plane Stress - Biaxial (negative) Load Primary Creep

Test Description

A square of length L and height L is constrained in the Y-direction on the bottom edge and constrained in the X-direction on the left edge. A tensile distributed load, σ_1, is applied on the right edge and a compressive distributed load, σ_2, is applied to the top edge.

Geometic Properties	Material Properties	Loading
L = 100 mm **Boundary Conditions** Bottom Edge: $u_y = 0$ Left Edge: $u_x = 0$	$E = 200 \times 10^3$ N/mm^2 $\nu = 0.3$ **Creep Law:** $\varepsilon = A\sigma^n t^m$ n = 5 m = 0.5	Right Edge: $\sigma_1 = 200$ N/mm^2 Top Edge: $\sigma_2 = -200$ N/mm^2

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
              |   Mechanical APDL    |   RATIO  |          INPUT         |

SHELL181
 ECR6X              4.251            0.9958     vmr027-cr10a-181
 EFFCR              4.909            0.9957     vmr027-cr10a-181
PLANE182
 ECR6X              4.267            0.9996     vmr027-cr10a-182
 EFFCR              4.928            0.9995     vmr027-cr10a-182
PLANE183
 ECR6X              4.267            0.9996     vmr027-cr10a-183
 EFFCR              4.928            0.9995     vmr027-cr10a-183
SHELL281
 ECR6X              4.251            0.9958     vmr027-cr10a-281
 EFFCR              4.909            0.9957     vmr027-cr10a-281

----------------------------------------------------------------------
```

vmr027-cr10a-181.dat
vmr027-cr10a-182.dat
vmr027-cr10a-183.dat
vmr027-cr10a-281.dat

VMR027-10B: 2-D Plane Stress - Biaxial (negative) Displacement Primary Creep

Test Description

A square of length L and height L is constrained in the Y-direction on the bottom edge and constrained in the X-direction on the left edge. The model is displaced in the X-direction by u_1 and in the Y-direction by u_2.

Geometic Properties	Material Properties	Loading
L = 100 mm **Boundary Conditions** Top Edge: u_y = -0.1, Bottom Edge: u_y = 0 Right Edge: u_x = 0.1, Left Edge: u_x = 0	E = 200 x 10^3 N/mm^2 ν = 0.3 **Creep Law:** $\varepsilon = A\sigma^n t^m$ n = 5 m = 0.5	No applied forces

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |   Mechanical APDL    |   RATIO  |          INPUT          |

SHELL181
 S6              19.061          1.0393     vmr027-cr10b-181
 S7              26.636          1.0206     vmr027-cr10b-181
PLANE182
 S6              19.061          1.0393     vmr027-cr10b-182
 S7              26.636          1.0206     vmr027-cr10b-182
PLANE183
 S6              19.061          1.0393     vmr027-cr10b-183
 S7              26.636          1.0206     vmr027-cr10b-183
SHELL281
 S6              19.061          1.0393     vmr027-cr10b-281
 S7              26.636          1.0206     vmr027-cr10b-281

----------------------------------------------------------------------
```

vmr027-cr10b-181.dat
vmr027-cr10b-182.dat
vmr027-cr10b-183.dat
vmr027-cr10b-281.dat

VMR027-10C: 2-D Plane Stress - Biaxial (negative) Stepped Load - Primary Creep

Test Description

A square of length L and height L is constrained in the Y-direction on the bottom edge and constrained in the X-direction on the left edge. A tensile distributed load, σ_1, is applied on the right edge and a compressive distributed load, σ_2, is applied to the top edge.

Geometic Properties	Material Properties	Loading
Plane Stress L = 100 mm **Boundary Conditions** Bottom Edge: $u_y = 0$ Left Edge: $u_x = 0$	$E = 200 \times 10^3$ N/mm^2 $\nu = 0.3$ **Creep Law:** $\varepsilon = A\sigma^n t^m$ n = 5 m = 0.5	Right Edge: $\sigma = 200\ N/mm^2$ (t = 100 hrs) $\sigma = 250 N/mm^2$ (t > 100 hrs) Top Edge: $\sigma = -200\ N/mm^2$(t = 100 hrs) $\sigma = -250 N/mm^2$ (t > 100 hrs)

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |   Mechanical APDL    |   RATIO  |         INPUT         |

SHELL181
 S2                2.933           0.9595     vmr027-cr10c-181
 S7                4.211           0.9714     vmr027-cr10c-181
PLANE182
 S2                2.934           0.9598     vmr027-cr10c-182
 S7                4.211           0.9714     vmr027-cr10c-182
PLANE183
 S2                2.934           0.9598     vmr027-cr10c-183
 S7                4.211           0.9714     vmr027-cr10c-183
SHELL281
 S2                2.933           0.9595     vmr027-cr10c-281
 S7                4.211           0.9714     vmr027-cr10c-281

----------------------------------------------------------------------
```

vmr027-cr10c-181.dat
vmr027-cr10c-182.dat
vmr027-cr10c-183.dat
vmr027-cr10c-281.dat

VMR027-12B: 2-D Plane Stress - Uniaxial Displacement Primary-Secondary Creep

Test Description

A square of length L and height L is constrained in the X-direction on the left edge and constrained in the Y-direction at the midpoint of the left edge. A displacement, u_1, is applied in the X-direction.

Geometic Properties	Material Properties	Loading
L = 100 mm **Boundary Conditions** Bottom Edge: u_y = 0 Left Edge: u_x = 0 Left Edge (midpoint): u_y = 0 Right Edge: u_x = 0.1	E = 200 x 10^3 N/mm^2 ν = 0.3 **Creep Law:** $\varepsilon = A_1\sigma^{n_1}t + A_2\sigma^{n_2}t^m$ $n_1 = n_2 = 5$ m = 0.5	No applied forces

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |   Mechanical APDL    |    RATIO   |         INPUT        |

 SHELL181
  ECR11X            42.218          1.0146      vmr027-cr12b-181
 PLANE182
  ECR11X            42.218          1.0146      vmr027-cr12b-182
 PLANE183
  ECR11X            42.218          1.0146      vmr027-cr12b-183
 SHELL281
  ECR11X            42.218          1.0146      vmr027-cr12b-281

 -----------------------------------------------------------------------
```

vmr027-cr12b-181.dat
vmr027-cr12b-182.dat
vmr027-cr12b-183.dat
vmr027-cr12b-281.dat

VMR027-12C: 2-D Plane Stress - Stepped Load Primary - Secondary Creep

Test Description

A square of length L and height L is constrained in the X-direction on the left edge and constrained in the Y-direction at the midpoint of the left edge. A distributed load, σ_1, is applied in the X-direction on the right edge.

Geometic Properties	Material Properties	Loading
L = 100 mm **Boundary Conditions** Left Edge: $u_x = 0$ Left Edge (midpoint): $u_y = 0$	$E = 200 \times 10^3$ N/mm^2 $\nu = 0.3$ **Creep Law:** $\varepsilon = A_1\sigma^{n_1}t + A_2\sigma^{n_2}t^m$ $n_1 = n_2 = 5$ $m = 0.5$	Right Edge: $\sigma = 100$ N/mm^2 (t = 10000 hrs) $\sigma = 110$ N/mm^2 (t > 10000 hrs)

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |   Mechanical APDL    |   RATIO  |         INPUT          |

SHELL181
 ECR11X             0.043            0.9965     vmr027-cr12c-181
PLANE182
 ECR11X             0.043            0.9988     vmr027-cr12c-182
PLANE183
 ECR11X             0.043            0.9988     vmr027-cr12c-183
SHELL281
 ECR11X             0.043            0.9965     vmr027-cr12c-281

----------------------------------------------------------------------
```

vmr027-cr12c-181.dat
vmr027-cr12c-182.dat
vmr027-cr12c-183.dat
vmr027-cr12c-281.dat

VMR029-T1: Elastic Large Deflection Response of a Z-Shaped Cantilever Upper End Load

Test Description

A Z-shaped cantilever of length L = 180, height H = 30, width W = 20 and thickness t = 1.7 is constrained in all directions at the origin and a total conservative end load of P_{max} = 4000 is applied to the rightmost edge of the cantilever. Elastic large deflection analysis is performed.

Geometic Properties	Material Properties	Loading
L = 180 H = 30 W = 20 t = 1.7 **Boundary Conditions** Applied at built-in end: $U_y = 0$ $U_x = 0$ $U_z = 0$	$E = 2.0 \times 10^5$ $\nu = 0.3$	Applied at right edge: $P_{max} = 4000$

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
 |  LOAD  |       Mechanical APDL       |  RATIO   |       TEST       |

SHELL181
  4000.00          142.99             1.00      vmr029-t1-181
SOLID185
  4000.00          142.47             0.99      vmr029-t1-185
BEAM188
  4000.00          143.42             1.00      vmr029-t1-188
BEAM189
  4000.00          143.45             1.00      vmr029-t1-189
SOLSH190
  4000.00          144.14             1.00      vmr029-t1-190
SHELL281
  4000.00          142.95             1.00      vmr029-t1-281

 ------------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

- vmr029-t1-181.dat
- vmr029-t1-185.dat
- vmr029-t1-188.dat
- vmr029-t1-189.dat
- vmr029-t1-190.dat
- vmr029-t1-281.dat

VMR029-T4: Lateral Torsional Buckling of an Elastic Cantilever Subjected to Transverse End Load

Test Description

A cantilever of length L = 100, height H = 5 and thickness t = 0.2 is supported in all directions at the built-in end. A conservative load and a non-conservative load are applied using arc-length procedures and the model is solved for tip lateral displacement.

Geometic Properties	Material Properties	Loading
L = 100 H = 5 t = 0.2 **Boundary Conditions** Applied at built-in end: $U_y = 0$ $U_x = 0$ $U_z = 0$	$E = 1.0 \times 10^4$ $G = 0.5 \times 10^4$	Conservative: nodal force P Non-conservative: nodal follower force P

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
          |   Mechanical APDL    |   RATIO    |       TEST       |

 SHELL181
  PCR            .01899           1.0039      vmr029-t4-181
 SOLID185
  PCR            .02002           1.0583      vmr029-t4-185
 BEAM188
  PCR            .01908           1.0085      vmr029-t4-188
 BEAM189
  PCR            .01893           1.0003      vmr029-t4-189
 SOLSH190
  PCR            .01950           1.0307      vmr029-t4-190
 SHELL281
  PCR            .01890           0.9991      vmr029-t4-281

 ------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

vmr029-t4-181.dat
vmr029-t4-185.dat
vmr029-t4-188.dat
vmr029-t4-189.dat
vmr029-t4-190.dat
vmr029-t4-281.dat

VMR029-T5: Large deflection of a curved elastic cantilever under transverse end load

Test Description

A curved cantilever beam of radius R = 100 is constrained in all directions at left end and a conservative transverse load of P_{max} = 3000 is applied at the right end. Large deflection analysis is performed.

Geometic Properties	Material Properties	Loading
R = 100 θ = 45° **Boundary Conditions** Applied at built-in end: $U_y = 0$ $U_x = 0$ $U_z = 0$	$E = 1.0 \times 10^7$ $G = 0.5 \times 10^7$	Applied at unbounded end: $P_{max} = 3000$

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |    Mechanical APDL    |   RATIO   |      INPUT     |

  SOLID185
     UX          25.3500            1.0152      vmr029-t5-185
     UY          47.2331            0.9984      vmr029-t5-185
     UZ          67.1181            0.9857      vmr029-t5-185
  BEAM188
     UX          24.9903          1.0008      vmr029-t5-188
     UY          47.6259            1.0067      vmr029-t5-188
     UZ          68.4148            1.0048      vmr029-t5-188
  BEAM189
     UX          25.0732            1.0041      vmr029-t5-189
     UY          47.7445            1.0092      vmr029-t5-189
     UZ          68.5204            1.0063      vmr029-t5-189
  SOLSH190
     UX          24.9927            1.0009      vmr029-t5-190
     UY          47.3291            1.0004      vmr029-t5-190
     UZ          67.1028            0.9855      vmr029-t5-190

  -----------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

- vmr029-t5-185.dat
- vmr029-t5-188.dat
- vmr029-t5-189.dat
- vmr029-t5-190.dat

VMR029-T7: Large Displacement of a Hinged Spherical Shell under Uniform Pressure Loading

Test Description

A spherical shell plate of length L = 1570 is simply supported along all 4 edges and a uniform distributed pressure load is applied on the shell surface. Elastic large deflection analysis is performed.

Geometic Properties	Material Properties	Loading
L = 1570 Shell mid-surface equation: $Z = 2.0285 \times 10^{-4}[X \times (1570 - X) + Y \times (1570 - Y)]$ **Boundary Conditions** Applied along edges: $U_y = 0$ $U_x = 0$ $U_z = 0$	E = 69 $\nu = 0.3$	Evenly distributed pressure load normal to shell surface with $P_{max} = 0.1$

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
          |    Mechanical APDL    |   RATIO   |      INPUT      |

 SHELL181
 LIMIT1          0.05910          0.90998      vmr029-t7-181
 LIMIT2          0.03225          1.04578      vmr029-t7-181
 SOLID185
 LIMIT1          0.05405          0.83224      vmr029-t7-185
 LIMIT2          0.03330          1.07979      vmr029-t7-185
 SOLSH190
 LIMIT1          0.05277          0.81244      vmr029-t7-190
 LIMIT2          0.02868          0.92986      vmr029-t7-190
 SHELL281
 LIMIT1          0.05910          0.90998      vmr029-t7-281
 LIMIT2          0.03225          1.04572      vmr029-t7-281

 -----------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

vmr029-t7-181.dat
vmr029-t7-185.dat
vmr029-t7-190.dat
vmr029-t7-281.dat

VMR029-T9: Large Elastic Deflection of a Pinched Hemispherical Shell

Test Description

A hemispherical shell of radius R = 10 and thickness t = 0.04 with symmetry boundary conditions applied along the planes x = 0 and y = 0 and a concentrated load P_{max} = 100 applied inward and outward diametrically. Elastic large deflection analysis is performed.

Geometic Properties	Material Properties	Loading
R = 10 t = 0.04 θ = 0° - 90° φ = 18° - 90° **Boundary Conditions** Symmetry on plane y = 0 U_y = 0 R_x = 0 R_z = 0 Symmetry on plane x = 0 U_x = 0 R_y = 0 R_z = 0 Applied at node location (10,0,0) U_z = 0	E = 6.825 x 10^7 ν = 0.3	P_{max} = 100 applied inward at node location (10,0,0) P_{max} = 100 applied outward at node location (0,10,0)

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |    Mechanical APDL    |   RATIO    |       INPUT      |

 SHELL181
  NODE  A          -5.5230            0.9361      vmr029-t9-181
  NODE  B           3.2167            0.9406      vmr029-t9-181
 SOLID185
  NODE  A          -5.7381            0.9726      vmr029-t9-185
  NODE  B           3.3280            0.9731      vmr029-t9-185
 SOLSH190
  NODE  A          -5.8983            0.9997      vmr029-t9-190
  NODE  B           3.4113            0.9974      vmr029-t9-190
 SHELL281
  NODE  A          -5.6584            0.9590      vmr029-t9-281
  NODE  B           3.3056            0.9666      vmr029-t9-281

  ----------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

vmr029-t9-181.dat
vmr029-t9-185.dat
vmr029-t9-190.dat
vmr029-t9-281.dat

VMR031-T1: Laminated Strip under Three-Point Bending

Test Description

A 7-layered symmetric strip of length 50mm, width 10mm, and thickness 1mm is simply supported from either end at a distance of 10mm, and is loaded by a central line load of 10N/mm.

Material Properties	Geometric Properties	Lay up	Boundary conditions and loading
E_1= 1.0E5MPa E_2= 5E3MPa $_{12}$= 0.4 G_{12}= 3E3MPa $_{23}$= 0.3 G_{13}= G_{23}= 2E3MPa	Length =50mm Width =10mm Thickness=1mm	[0/90/0/90/0/90/0] Thickness of central ply is four times as thick as others	Simply supported at x=10mm and x=45mm Symmetry is approximately =25mm and y=5mm Line load of 10N/mm at x=25mm and z=1mm

Results Comparison

Results are tabulated and displayed as in the NAFEMS manual.

	Mechanical APDL	RATIO	TEST
Deflection mm	-1.117	1.054	vmr031-t1-281
Bending stress MPa	690.361	1.009	vmr031-t1-281

Element Mechanical APDL Ratio Test Input

vmr031-t1-281.dat

VMR031-T2: Wrapped Thick Cylinder under Pressure and Thermal Loading

Test Description

A long thick cylinder made from isotropic material onto which external hoop windings of orthotropic material have been added is subjected to two cases:

Case 1: Internal pressure of 200MPa
Case 2: Internal pressure of 200MPa and a uniform increase in temperature of 130°C

A quarter model is considered.

Material Properties	Geometric Properties	Boundary conditions	Loaading
Inner Cylinder (isotropic): E= 2.1E5MPa = 0.3 α=2E-5°C^{-1} Outer Cylinder (orthotropic): E_1=1.3E5MPa E_2=5.0E3MPa ${}_{12}$=0.25 G_{12}=1.0E4MPa G_{33}=5.0E3MPa α_1=3E-6°C^{-1} α_2=2E-5°C^{-1}	Inner Cylinder: Inner radius=23mm Outer radius=25mm Outer Cylinder: Inner radius=25mm Outer radius=27mm	u_z=0 at z=0 Symmetric constraints are specified at lines 3 and 1 because a quarter symmetry model is considered.	Case 1: internal pressure of 200MPa Case 2: Internal pressure of 200MPa and a uniform in crease in temperature of 130°C

Results Comparison

Results are tabulated and displayed as in the NAFEMS manual.

	Hoop stress	Mechanical APDL	RATIO	TEST
Case 1	Inner cylinder at r=23mm	1558.465	0.996	vmr031-t2-281
	Inner cylinder at r=25mm	1452.677	1.016	vmr031-t2-281
	outer cylinder at r=25mm	868.629	0.993	vmr031-t2-281

	Hoop stress	Mechanical APDL	RATIO	TEST
	outer cylinder at r=27mm	764.821	1.008	vmr031-t2-281
Case 2	Inner cylinder at r=23mm	1401.278	1.015	vmr031-t2-281
	inner cylinder at r=25mm	1276.423	1.013	vmr031-t2-281
	outer cylinder at r=23mm	1054.253	0.998	vmr031-t2-281
	outer cylinder at r=23mm	955.252	1.020	vmr031-t2-281

Element Mechanical APDL Ratio Test Input

vmr031-t2-281.dat

VMR031-T3: Three-Layer Sandwich Shell under Normal Pressure Loading

Test Description

A simply supported square sandwich plate with a 10 inch side length is subjected to a uniform pressure of 100 psi.

A quarter model is considered.

Material Properties	Geometric Properties	Boundary conditions	Loading
Outer face sheets: E_x=10.0E6 psi E_y=4.0E6 psi $_{xy}$=0.3 G_{xy}=1.875E6 psi Central core: E_x=0 G_{xz}=3.0E4 psi G_{yz}=1.2E4 psi	Side length of the square=10 inches	Simply supported at x=0 and y=0 Symmetric at approximately x=5 and y=5	Uniform normal pressure of 100 psi

Results Comparison

Results are tabulated and displayed as in the NAFEMS manual.

Table VMR031-T3.1: Using SHELL281

	Mechanical APDL	RATIO	TEST
Z deflection	-0.122	0.993	vmr031-t3-281
$_{xx}$	33752.207	0.980	vmr031-t3-281
$_{yy}$	13143.214	0.985	vmr031-t3-281

	Mechanical APDL	RATIO	TEST
xy	-4982.367	0.983	vmr031-t3-281

Table VMR031-T3.2: Using SHELL181

	Mechanical APDL	RATIO	TEST
Z deflection	-0.122	0.993	vmr031-t3-181
xx	32874.289	0.954	vmr031-t3-181
yy	12943.019	0.970	vmr031-t3-181
xy	-4880.513	0.963	vmr031-t3-181

Element Mechanical APDL Ratio Test Input

vmr031-t3-181.dat
vmr031-t3-281.dat

VMR038-2A: J Integral Value for Centered Crack Plate with BISO Material Model

Test Description

A rectangular plate with centered crack and with plane strain condition under uniform tension loading is considered for this problem. Symmetry has been taken into account and only one quarter of the plate is modeled. Symmetry boundary conditions are applied (U_Y = 0 along uncracked ligament and U_x = 0 along symmetry). Uniform tensile loading is applied on the top edge of the plate under displacement control conditions.

Geometric Properties	Material Properties	Loading
Plate width (b) = 100mm Plate height (h) = 200mm Crack length (a) = 25mm	E = 205000 Mpa υ = 0.3 Yield stress = 1000 Mpa Tangent modulus = 2450 Mpa	Displacement control condition Top edge Uy = 2.0 mm

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
           |   Mechanical APDL    |   RATIO   |     INPUT      |

  PLANE182

   JVALUE          1463.5978        1.001      vmr038-2a-182

  PLANE183

   JVALUE          1558.3019        1.066      vmr038-2a-183

 ----------------------------------------------------------------
```

Element Mechanical APDL Ratio Test Input

vmr038-2a-182.dat
vmr038-2a-183.dat

VMR038-2B: J Integral Value for Centered Crack Plate with Elastic Perfectly Plastic Material

Test Description

A rectangular plate with centered crack and with plane strain condition under uniform tension loading is considered for this problem. Symmetry has been taken into account and only one quarter of the plate is modeled. Symmetry boundary conditions are applied (U_Y = 0 along uncracked ligament and U_X = 0 along symmetry). Uniform tensile loading is applied on the top edge of the plate under both displacement and load control conditions.

Geometric Properties	Material Properties	Loading
Plate width (b) = 100mm Plate height (h) = 200mm Crack length (a) = 25mm	E = 205000 Mpa υ = 0.3 Yield stress = 1000 Mpa Tangent modulus = 0 Mpa	Displacement control condition Top edge Uy = 2.0 mm Load control condition Pressure load = 850 Mpa

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |     Target     |   Mechanical APDL    |   RATIO   |     INPUT      |

  PLANE182 - DISPLACEMENT CONTROL

   JVALUE        1468.0000           1408.1142          0.959      vmr038-2b-182

  PLANE183 - LOAD CONTROL

   JVALUE         198.0000            207.4277          1.048      vmr038-2b-183
 ----------------------------------------------------------------------------------
```

vmr038-2b-182.dat
vmr038-2b-183.dat

VMR038-2E: J Integral Value for Centered Crack Plate with Elastic Perfectly Plastic Material

Test Description

A rectangular plate with centered crack and with plane stress condition under uniform tension loading is considered for this problem. Symmetry has been taken into account and only one quarter of the plate is modeled. Symmetry boundary conditions are applied (U_Y = 0 along uncracked ligament and U_X = 0 along symmetry). Uniform tensile loading is applied on the top edge of the plate under displacement control conditions.

Geometric Properties	Material Properties	Loading
Plate width (b) = 100mm Plate height (h) = 200mm Crack length (a) = 25mm	E = 205000 Mpa υ = 0.3 Yield stress = 1000 Mpa Tangent modulus = 0 Mpa Tangent modulus = 0 Mpa	Displacement control condition Top edge Uy = 2.0 mm

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
             |    Target     |    Mechanical APDL     |   RATIO    |      INPUT       |

   PLANE182 - DISPLACEMENT CONTROL

    JVALUE        1189.0000          1169.9740           0.984     vmr038-2e-182

  -------------------------------------------------------------------------------
```

vmr038-2e-182.dat

VMR038-2g: Centered Crack Plate Ender Thermal Loading with Elastic Perfectly Plastic Material

Test Description

A 2D plate with centered crack and with plane strain condition is considered for this problem. Symmetry is taken into account and only one quarter of the plate is modeled. Displacement along Y direction is constrained on the uncracked ligament and displacement along X direction is constrained along symmetry edge at location X=0. The plate is subjected to thermal loading with the temperature load distributed as a quadratic function of X coordinate.

Geometric Properties	Material Properties	Loading
Plate width (b) = 100mm Plate height (h) = 200mm Crack length (a) = 25mm	E = 205000 Mpa υ = 0.3 Coefficients of thermal expansion α = 0.0001 mm/mm °C Yield stress = 1000 Mpa Tangent modulus = 0 Mpa	Temperature distribution is a quadratic function of X coordinate and is given by T = 0.01 x^2 T = 0° C @ x = 0 mm T = 100 °C @ x = 100 mm

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
            |    Target     |  Mechanical APDL    |  RATIO   |     INPUT      |

  PLANE182

   JVALUE         105.8000          109.1444          1.032     vmr038-2g-182

 --------------------------------------------------------------------------------
```

vmr038-2g-182.dat

VMR038-3A: J integral value for compact tension specimen with BISO material model

Test Description

A compact tension specimen with plane strain condition is considered for this problem. Symmetry is taken into account and only one half of the plate is modeled. The details of the hole and the notch are not modeled. Displacement in Y direction is made zero along the uncracked ligament and displacement in X direction is constrained at the bottom right corner of the symmetric plate to prevent rigid body motion. The plate is subjected to tension loading under displacement control conditions.

Geometric Properties	Material Properties	Loading
Plate width (b) = 30mm Plate height (h) = 50mm Crack length (a) = 29.78mm	E = 205000 Mpa υ = 0.3 Yield stress = 550 Mpa Tangent modulus = 3044 Mpa	Displacement control condition U_y at point P= 1.05 mm

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
           |   Mechanical APDL    |   RATIO   |     INPUT      |

  PLANE182 - DISPLACEMENT CONTROL

   JVALUE           234.027            1.014     vmr038-3a-182

  PLANE183 - DISPLACEMENT CONTROL

   JVALUE           220.154            0.954     vmr038-3a-183

 -----------------------------------------------------------------
```

vmr038-3a-182.dat
vmr038-3a-183.dat

VMR038-4A: J Integral Value for Three Point Bend Specimen with Power Law Hardening

Test Description

A three point bend specimen with plane strain condition is considered for this problem. Symmetry is taken into account and only one half of the plate is modeled. Displacement in Y direction is constrained along the uncracked ligament and displacement in X direction is constrained at the bottom left corner of the symmetric plate to prevent rigid body motion. Displacement load is applied at the node corresponding to point P.

Geometric Properties	Material Properties	Loading
Plate width (b) = 25.4mm Plate height (h) = 50.8mm Crack length (a) = 12.7mm	E = 214800 Mpa υ = 0.3 Yield stress = 275 Mpa Power value (N) = 0.1	Displacement control condition U_x at point P=2.0 mm

Results

Results are tabulated and displayed as in the NAFEMS manual.

```
          |     Target     |     Mechanical APDL     |    RATIO    |      INPUT      |
 PLANE182 - DISPLACEMENT CONTROL
  JVALUE         203.8000          202.7365            0.995       vmr038-4a-182
 PLANE183 - DISPLACEMENT CONTROL
  JVALUE         203.8000          211.3828            1.037       vmr038-4a-183
 ------------------------------------------------------------------------------
```

vmr038-4a-182.dat
vmr038-4a-183.dat

VMR049-CR1: Constant-Load Creep Benchmark

Test Description

A 2-D box of length L and height L is constrained at left edge in Y-direction and in both X and Y directions at midpoint. A distributed load, σ, is applied on the right edge.

Geometric Properties	Material Properties	Loading
L = 100 mm **Boundary Conditions** Left End: $u_x = 0$ Left End Midpoint: $u_y = 0$	$E = 200 \times 10^3$ N/mm ^{2} $\nu = 0.3$ **Secondary Creep:** $\varepsilon = A\sigma^n t^m$ $A = 3.125 \times 10^{-14}$ (t in hours, σ in N/mm^2) m = 1, n = 5 **Primary Creep:** As Secondary Creep, except m = 0.5 **Combined Primary-Secondary Creep:** $\varepsilon\ A_1\sigma_{n1}t + A_2\sigma_{n2}t^m$ $A_1 = 10^{-16}$ $A_2 = 10^{-14}$ (t in hour,σ in N/mm^2) $n_1 = n_2 = 5$	$\sigma = 200$ N/mm^2 (Secondary Creep and Primary Creep) $\sigma = 100$ N/mm ^{2} (Combined Primary-Secondary Creep)

Results

Reference: Creep strain results are displayed at intervals of 200 ending at 1000.

```
           |   Mechanical APDL   |   RATIO  |         INPUT         |

 SHELL181
  ECR2X            9.9912          0.9991      vmr049-cr1a-181
  ECR2Y           -4.9941          0.9988      vmr049-cr1a-181
 PLANE182
  ECR2X           10.0000          1.0000      vmr049-cr1a-182
  ECR2Y           -5.0000          1.0000      vmr049-cr1a-182
 PLANE183
  ECR2X           10.0000          1.0000      vmr049-cr1a-183
  ECR2Y           -5.0000          1.0000      vmr049-cr1a-183
 SHELL281
  ECR2X            9.9912          0.9991      vmr049-cr1a-281
  ECR2Y           -4.9941          0.9988      vmr049-cr1a-281

-----------------------------------------------------------------------
```

```
           |   Mechanical APDL    |   RATIO  |          INPUT         |

 PLANE181
  ECR2X             0.2496          0.9945      vmr049-cr1b-181
  ECR2Y            -0.1247          0.9980      vmr049-cr1b-181
 PLANE182
  ECR2X             0.2509          0.9997      vmr049-cr1b-182
  ECR2Y            -0.1255          1.0037      vmr049-cr1b-182
 PLANE183
  ECR2X             0.2509          0.9997      vmr049-cr1b-183
  ECR2Y            -0.1255          1.0037      vmr049-cr1b-183
 SHELL281
  ECR2X             0.2496          0.9945      vmr049-cr1b-281
  ECR2Y            -0.1247          0.9980      vmr049-cr1b-281

-----------------------------------------------------------------------
```

```
           |   Mechanical APDL    |   RATIO  |          INPUT         |

 PLANE181
  ECR11X            0.0041          0.9992      vmr049-cr1c-181
  ECR11Y           -0.0021          0.9987      vmr049-cr1c-181
 PLANE182
  ECR11X            0.0042          1.0032      vmr049-cr1c-182
  ECR11Y           -0.0021          1.0031      vmr049-cr1c-182
 PLANE183
  ECR11X            0.0042          1.0032      vmr049-cr1c-183
  ECR11Y           -0.0021          1.0031      vmr049-cr1c-183
 SHELL281
  ECR11X            0.0041          0.9992      vmr049-cr1c-281
  ECR11Y           -0.0021          0.9987      vmr049-cr1c-281

-----------------------------------------------------------------------
```

vmr049-cr1a-181.dat
vmr049-cr1a-182.dat
vmr049-cr1a-183.dat
vmr049-cr1a-281.dat
vmr049-cr1b-181.dat
vmr049-cr1b-182.dat
vmr049-cr1b-183.dat
vmr049-cr1b-281.dat
vmr049-cr1c-181.dat
vmr049-cr1c-182.dat
vmr049-cr1c-183.dat
vmr049-cr1c-281.dat

VMR049-CR2: Constant-Displacement Creep Benchmark

Test Description

A box of length L and height L (and thickness L if 3D) is constrained in the Y-direction along the bottom edge and in the X-direction along the left edge. The box is displaced in all directions by a set amount.

Geometric Properties	Material Properties	Loading
L = 100 mm **Boundary Conditions** **2D Plane Stress** Left Edge: $u_x = 0$, Right Edge: $u_x = 0.1$ Top Edge: $u_y = 0.1$, Bottom Edge: $u_y = 0$ **3D** Left Face: $u_x = 0$, Right Face: $u_x = 0.3$ Top Face: $u_y = 0.2$, Bottom Face: $u_y = 0$ Front Face: $u_z = 0$, Back Face: $u_z = 0.1$	$E = 200 \times 10^3$ N/mm^2 $\nu = 0.3$ **Creep Law:** $\varepsilon = A\sigma^n t^m$ $A = 3.125 \times 10^{-14}$ (t in hours, σ in N/mm^2) n = 5 2D Plane Stress: m = 0.5 3D: m = 1	No applied forces

Results

Reference: Stress results are displayed at incremented time intervals of 200 hours ending at 1000 hours

```
             |   Mechanical APDL   |   RATIO  |          INPUT         |

 SHELL181
  S6              37.2112            1.0000      vmr049-cr2-181
  S7              51.6610            1.0000      vmr049-cr2-181
 PLANE182
  S6              37.2112            1.0000      vmr049-cr2-182
  S7              51.6610            1.0000      vmr049-cr2-182
 PLANE183
  S6              37.211             1.0000      vmr049-cr2-183
  S7              51.661             1.0000      vmr049-cr2-183
 SOLID185
  S6X           1009.911             1.0009      vmr049-cr2-185
  S6Y           1000.000             1.0000      vmr049-cr2-185
  S6Z            990.089             0.9991      vmr049-cr2-185
 SOLID187
  S6X           1008.189             0.9991      vmr049-cr2-187
  S6Y           1000.000             1.0000      vmr049-cr2-187
  S6Z            991.811             1.0009      vmr049-cr2-187
 SHELL281
  S6              37.2112            1.0000      vmr049-cr2-281
  S7              51.6610            1.0000      vmr049-cr2-281
```

- -

vmr049-cr2-181.dat
vmr049-cr2-182.dat
vmr049-cr2-183.dat
vmr049-cr2-185.dat
vmr049-cr2-187.dat
vmr049-cr2-281.dat

VMR049-CR3: Variable-Load Uniaxial Creep Benchmark

Test Description

A 2-D box of length L and height L is constrained at left edge in Y-direction and in both X and Y directions at midpoint. A distributed load, σ, is applied on the right edge

Geometric Properties	Material Properties	Loading
L = 100 mm **Boundary Conditions** Left End: $u_x = 0$ Midpoint of Left End: $u_y = 0$	$E = 200 \times 10^3$ N/mm^2 $\nu = 0.3$ **Creep Law:** $\varepsilon = A\sigma^n t^m$ n = 5 m = 0.5	Tensile Stress, σ_1, on right edge **Uniaxial Load** $\sigma_1 = 200$ N/mm^2 (t = 0-100 hrs) $\sigma_1 = 250$ N/mm^2 (t > 100 hrs)

Results

Reference: Creep strain results in X-direction are displayed by incrementing the time every 50 hours ending at 200 hours.

```
           |   Mechanical APDL   |   RATIO  |         INPUT         |

SHELL181
S2                 0.2211           1.0005       vmr049-cr3-181
S7                 0.3147           0.9991       vmr049-cr3-181
PLANE182
S2                 0.2213           1.0015       vmr049-cr3-182
S7                 0.3148           0.9995       vmr049-cr3-182
PLANE183
S2                 0.2213           1.0015       vmr049-cr3-183
S7                 0.3149           0.9997       vmr049-cr3-183
SHELL281
S2                 0.2211           1.0005       vmr049-cr3-281
S7                 0.3147           0.9991       vmr049-cr3-281

-----------------------------------------------------------------------
```

vmr049-cr3-181.dat
vmr049-cr3-182.dat
vmr049-cr3-183.dat
vmr049-cr3-281.dat

VMR049-CR4: Pressurised Cylinder Creep Benchmark

Test Description

A box of length R_2-R_1 and height H is offset from the origin by a distance R_1. The bottom and top edge is constrained in the Y-direction and a distributed load, P, is applied to the left edge.

Geometric Properties	Material Properties	Loading
R_1 = 100 mm R_2 = 200 mm H = 25 mm P = 200 N/mm^2 **Boundary Conditions** Bottom and Top Edge: u_z = 0	E = 200 x 10^3 N/mm^2 ν = 0.3 **Creep Law:** $\varepsilon = A\sigma^n t^m$ A = 3.125 x 10^{-14} (t in hours, σ in N/mm^2) n = 5 m = 1	Pressure, P, applied to left edge.

Results

Reference: The elastic and steady-state radial and hoop stresses obtained from MAPDL are compared against reference for radius starting from 100mm to 200mm at an increment level of 25.

```
          |   MAPDL    |   RATIO  |         INPUT          |

  PLANE182
  RESULTS TAKEN AT RADIUS=175
  ELS6X        -20.8547       1.0702     vmr049-cr4-182
  ELS6Z        154.1880       1.0089     vmr049-cr4-182
  SSS6X        -34.4550       0.9983     vmr049-cr4-182
  SSS6Z        229.4624       0.9991     vmr049-cr4-182
  PLANE183
  RESULTS TAKEN AT RADIUS=175
  ELS6X        -19.4872       1.0000     vmr049-cr4-183
  ELS6Z        152.8205       1.0000     vmr049-cr4-183
  SSS6X        -34.5117       1.0000     vmr049-cr4-183
  SSS6Z        229.6722       1.0000     vmr049-cr4-183

 ----------------------------------------------------------------
```

vmr049-cr4-182.dat
vmr049-cr4-183.dat

VMR049-CR5: Torsional Creep of Square Shaft

Test Description

A block of length L_1, height L_2, and thickness $L_3$is rotated about the Z axis by β.

Geometric Properties	Material Properties	Loading
L_1 = 1 mm L_2 = 2 mm L_3 = 0.2 mm Angle of Rotation: β = 0.01 radians per unit length **Boundary Conditions** Back Face: u_x = 0, u_y = 0 Bottom Face and Left Face: u_z = unknown (multi-point constraints) u_z = 0 at location (0,0,0), (L_1,0,0), and (0,L_2,0)	E = 10.0 N/mm^2 ν = 0.3 **Creep Law:** $d\varepsilon/dt = A\sigma^n t^m$ A = 1.0E4 (t in hours, σ in N/mm^2) n = 5 m = -0.5	No applied forces

Note

Front face and mid-plane, located at half the thickness, are rotated by an angle β. All nodes on the front face and mid-plane have $u_x = -r\beta L\sin\theta$ and $u_y = r\beta L\sin\theta$, where L = 0.2 mm for the front face and L = 0.1 mm for the mid-plane. θ = angle measured anticlockwise from the X axis.

Results

Reference: Shear stress values in YZ-direction for constant twist are displayed with respect to time.

```
           |   MAPDL    |   RATIO  |         INPUT          |

SOLID185
SYZ2           0.0143       1.0004     vmr049-cr5-185
SOLID186
SYZ2           0.0143       1.0000     vmr049-cr5-186
SOLID187
SYZ2           0.0142       0.9966     vmr049-cr5-187

----------------------------------------------------------------
```

vmr049-cr5-185.dat

vmr049-cr5-186.dat
vmr049-cr5-187.dat

VMR049-CR6: Thermally Induced Creep Benchmark

Test Description

A 10° slice of an axisymmetric sphere having an inner radius of R_1 and outer radius of R_2 is constrained at the top and bottom edges in the Y-direction. A distributed load, P, is applied to the left edge.

Geometric Properties	Material Properties	Loading
R_1 = 200 mm R_2 = 500 mm β = 10° P = 30 N/mm^2 **Boundary Conditions** Bottom Edge: u_z = 0 Top Edge: Perpendicular Displacement = 0 (symmetry condition) Temperature prescibed at all nodes as follows: T = 333(1+100/r) where r is radius measured from the center of the sphere.	E = 10x10^3 N/mm^2 ν = 0.25 **Creep Law:** $d\varepsilon/dt = A\sigma^n f(T)$ A = 3.0x10^{-6} (t in hours, σ, in N/mm^2) n = 5.5 $f(T) = e^{-12500/T}$ where T is temperature in °K	Pressure, P, on left edge.

Results

Reference: Effective stress results are displayed for each hour starting from 0 and ending at 10 (log scale).

```
              |   Mechanical APDL    |    RATIO   |          INPUT          |

 PLANE182
  SR205            11.2551           1.0005        vmr049-cr6-182
  SR350            17.5837           1.0002        vmr049-cr6-182
  SR495            21.1643           1.0002        vmr049-cr6-182
 PLANE183
  SR205            11.5369           1.0255        vmr049-cr6-183
  SR350            17.6113           1.0018        vmr049-cr6-183
  SR495            21.0756           0.9960        vmr049-cr6-183

 ----------------------------------------------------------------
```

vmr049-cr6-182.dat
vmr049-cr6-183.dat

VMR049-PL1: 2D Plane Strain Plasticity Benchmark

Test Description

A square of length L and height L is constrained in the Y-direction along the bottom edge and in the X-direction along the left edge. The model is displaced in the X and Y directions.

Geometric Properties	Material Properties
L = 1.0 mm	$E = 250.0 \times 10^3$ N/mm^2 $\nu = 0.25$ **Plasticity Model** Perfect Plasticity: $\sigma_{ys} = 5.0$ N/mm^2 Isotropic Hardening: $E_T = 50.0 \times 10^3$ N/mm^2
Boundary Conditions Left Edge: $u_x = 0$ Bottom Edge: $u_y = 0$ Right Edge: $u_x = \delta_x$ Top Edge: $u_y = \delta_y$	
Loading No applied forces Displacements prescribed in 8 increments ($R = 2.5 \times 10^{-5}$), as follows:	
Step: Disp. Change	**Step: Stress State**
Step 1: $\Delta u_x = +R$	**Step 1:** First Yield
Step 2: $\Delta u_x = +R$	**Step 2:** Plastic Flow
Step 3: $\Delta u_y = +R$	**Step 3:** Elastic Unloading
Step 4: $\Delta u_y = +R$	**Step 4:** Plastic Reloading
Step 5: $\Delta u_x = -R$	**Step 5:** Plastic Flow
Step 6: $\Delta u_x = -R$	**Step 6:** Plastic Flow
Step 7: $\Delta u_y = -R$	**Step 7:** Elastic Unloading
Step 8: $\Delta u_y = -R$	**Step 8:** Plastic Flow

Results

Reference: Stress results are displayed as the step is incremented by 1 starting with 0 and ending at 8.

```
           |   Mechanical APDL   |   RATIO  |         INPUT         |

 PLANE182
  RESULTS LISTED USING LOAD STEP 6
  SX                  5.1140          0.9961       vmr049-pl1a-182
  SY                 10.6919          0.9951       vmr049-pl1a-182
  SZ                  9.1935          1.0081       vmr049-pl1a-182
 PLANE183
  RESULTS LISTED USING LOAD STEP 6
  SX                  5.1140          0.9961       vmr049-pl1a-183
  SY                 10.6919          0.9951       vmr049-pl1a-183
```

```
 SZ                 9.1935           1.0081       vmr049-pl1a-183

-----------------------------------------------------------------------



            |   Mechanical APDL    |   RATIO  |          INPUT          |

PLANE182
 RESULTS REPORTED USING LOAD STEP 7
 SX                 1.5057           0.9701       vmr049-pl1b-182
 SY                 4.9217           0.9937       vmr049-pl1b-182
 SZ                 6.0725           1.0129       vmr049-pl1b-182
PLANE183
 RESULTS REPORTED USING LOAD STEP 7
 SX                 1.5057           0.9701       vmr049-pl1b-183
 SY                 4.9217           0.9937       vmr049-pl1b-183
 SZ                 6.0725           1.0129       vmr049-pl1b-183

-----------------------------------------------------------------------
```

vmr049-pl1a-182.dat (a)
vmr049-pl1a-183.dat (a)
vmr049-pl1b-182.dat (b)
vmr049-pl1b-183.dat (b)

VMR049-PL2: 2D Plane Stress Plasticity Benchmark

Test Description

A square of length L and height L is constrained in the Y-direction along the bottom edge and in the X-direction along the left edge. The model is displaced in the X and Y directions.

Geometry L = 1.0 mm	**Material Properties** $E = 250.0 \times 10^3$ N/mm^2 $\nu = 0.25$ **Plasticity Model** Perfect Plasticity: $\sigma_{ys} = 5.0$ N/mm^2 Isotropic Hardening: $E_T = 50.0 \times 10^3$ N/mm^2
Boundary Conditions Left Edge: $u_x = 0$ Bottom Edge: $u_y = 0$ Right Edge: $u_x = \delta_x$ Top Edge: $u_y = \delta_y$	
Loading No applied forces Displacements prescribed in 8 increments ($R = 2.5 \times 10^{-5}$), as follows:	
Step: Disp. change	**Step: Stress state**
Step 1: $\Delta u_x = +R$	**Step 1:** First Yield
Step 2: $\Delta u_x = +R$	**Step 2:** Plastic Flow
Step 3: $\Delta u_y = +R$	**Step 3:** Elastic Unloading
Step 4: $\Delta u_y = +R$	**Step 4:** Plastic Reloading
Step 5: $\Delta u_x = -R$	**Step 5:** Plastic Flow
Step 6: $\Delta u_x = -R$	**Step 6:** Plastic Flow
Step 7: $\Delta u_y = -R$	**Step 7:** Elastic Unloading
Step 8: $\Delta u_y = -R$	**Step 8:** Plastic Flow

Results

Reference: Stress results are displayed as the step is incremented by 1 starting with 0 and ending at 8.

```
              |   Mechanical APDL    |   RATIO  |         INPUT          |

  SHELL181
   SX              -3.3494             1.0001     vmr049-pl2a-181
   SY              -5.7473             1.0001     vmr049-pl2a-181
   SEFF             5.0000             1.0000     vmr049-pl2a-181
  PLANE182
   SX              -3.3494             1.0001     vmr049-pl2a-182
   SY              -5.7473             1.0001     vmr049-pl2a-182
   SEFF             5.0000             1.0000     vmr049-pl2a-182
  PLANE183
```

```
 SX              -3.3494            1.0001     vmr049-pl2a-183
 SY              -5.7473            1.0001     vmr049-pl2a-183
 SEFF             5.0000            1.0000     vmr049-pl2a-183
SHELL281
 SX              -3.3494            1.0001     vmr049-pl2a-281
 SY              -5.7473            1.0001     vmr049-pl2a-281
 SEFF             5.0000            1.0000     vmr049-pl2a-281

-----------------------------------------------------------------



            |   Mechanical APDL    |    RATIO   |          INPUT         |

SHELL181
 SX              -9.1555            1.0001     vmr049-pl2b-181
 SY              -8.4910            1.0000     vmr049-pl2b-181
 SEFF             8.8420            1.0000     vmr049-pl2b-181
PLANE182
 SX              -9.1555            1.0001     vmr049-pl2b-182
 SY              -8.4910            1.0000     vmr049-pl2b-182
 SEFF             8.8420            1.0000     vmr049-pl2b-182
SHELL281
 SX              -9.1555            1.0001     vmr049-pl2b-281
 SY              -8.4910            1.0000     vmr049-pl2b-281
 SEFF             8.8420            1.0000     vmr049-pl2b-281

-----------------------------------------------------------------
```

vmr049-pl2a-181.dat (a)
vmr049-pl2a-182.dat (a)
vmr049-pl2a-183.dat (a)
vmr049-pl2a-281.dat (a)
vmr049-pl2b-181.dat (b)
vmr049-pl2b-182.dat (b)
vmr049-pl2b-281.dat (b)

VMR049-PL3: 3D Plasticity Benchmark

Test Description

A block with length, height, and length L is constrained at Z = L in the Y-direction and constrained in the X-direction when Z = L and Y ranges from 0 to L. The block is displaced according to the given boundary conditions.

Geometry	Material Properties
L = 1.0 mm	$E = 250 \times 10^3$ N/mm^2 $\nu = 0.25$ **Plasticity Model** Perfect Plasticity: $\sigma_{ys} = 5.0$ N/mm^2 Isotropic Hardening: $E_T = 50 \times 10^3$ N/mm^2
Boundary Conditions Left Face: $u_x = 0$ Bottom Face: $u_y = 0$ Front Face: $u_z = 0$ Right Face: $u_x = \delta_x$ Top Face: $u_y = \delta_y$ Back Face: $u_z = \delta_z$	
Loading No applied forces Displacements prescribed in 12 steps ($R = 2.5 \times 10^{-5}$) as follows:	
Step:	**Disp. change**
Step 1:	$\Delta u_x = +R$
Step 2:	$\Delta u_x = +R$
Step 3:	$\Delta u_y = +R$
Step 4:	$\Delta u_y = +R$
Step 5:	$\Delta u_z = +R$
Step 6:	$\Delta u_z = +R$
Step 7:	$\Delta u_x = -R$
Step 8:	$\Delta u_x = -R$
Step 9:	$\Delta u_y = -R$
Step 10:	$\Delta u_y = -R$
Step 11:	$\Delta u_z = -R$
Step 12:	$\Delta u_z = -R$

Results

Reference: Stress results are displayed for each step as the step is incremented by 1 starting from 0 and ending at 12.

```
             |   Mechanical APDL    |   RATIO   |         INPUT          |

 SOLID185
  SX               2.7470            1.0000     vmr049-pl3a-185
  SY               0.2618            0.9991     vmr049-pl3a-185
  SZ              -3.0087            0.9999     vmr049-pl3a-185
  SEFF             5.0000            1.0000     vmr049-pl3a-185
 SOLID186
  SX               2.7470            1.0000     vmr049-pl3a-186
  SY               0.2618            0.9991     vmr049-pl3a-186
  SZ              -3.0087            0.9999     vmr049-pl3a-186
  SEFF             5.0000            1.0000     vmr049-pl3a-186
 SOLID187
  SX               2.7470            1.0000     vmr049-pl3a-187
  SY               0.2618            0.9991     vmr049-pl3a-187
  SZ              -3.0087            0.9999     vmr049-pl3a-187
  SEFF             5.0000            1.0000     vmr049-pl3a-187

 -----------------------------------------------------------------------
```

```
             |   Mechanical APDL    |   RATIO   |         INPUT          |

 SOLID185
  SX               1.9340            1.0000     vmr049-pl3b-185
  SY              -0.5406            0.9993     vmr049-pl3b-185
  SZ              -1.3934            1.0003     vmr049-pl3b-185
  SEFF             2.9936            0.9999     vmr049-pl3b-185
 SOLID186
  SX               1.9340            1.0000     vmr049-pl3b-186
  SY              -0.5406            0.9993     vmr049-pl3b-186
  SZ              -1.3934            1.0003     vmr049-pl3b-186
  SEFF             2.9936            0.9999     vmr049-pl3b-186
 SOLID187
  SX               1.9340            1.0000     vmr049-pl3b-187
  SY              -0.5406            0.9993     vmr049-pl3b-187
  SZ              -1.3934            1.0003     vmr049-pl3b-187
  SEFF             2.9936            0.9999     vmr049-pl3b-187
 SOLSH190
  SX               1.9340            1.0000     vmr049-pl3b-190
  SY              -0.5406            0.9993     vmr049-pl3b-190
  SZ              -1.3934            1.0003     vmr049-pl3b-190
  SEFF             2.9936            0.9999     vmr049-pl3b-190

 -----------------------------------------------------------------------
```

vmr049-pl3a-185.dat (a)
vmr049-pl3a-186.dat (a)
vmr049-pl3a-187.dat (a)
vmr049-pl3b-185.dat (b)
vmr049-pl3b-186.dat (b)
vmr049-pl3b-187.dat (b)
vmr049-pl3b190.dat (b)

VMR049-PL5: Pressurised Cylinder Plasticity Benchmark

Test Description

A square of length R_2-R_1 and height H is constrained in the Z-direction on the top and bottom edges and offset a distance R_1 from the origin. A distributed pressure load is applied to the left edge.

Geometric Properties (Axisymmetric)	**Material Properties**
R_1 = 100 mm R_2 = 200 mm H = 100 mm	E = 21.0 x 10^3 N/mm^2 ν = 0.3 **Plasticity Model** Perfect Plasticity: σ_{ys} = 24.0 N/mm^2 Isotropic Hardening: E_T = 4.2 x 10^3 N/mm^2
Boundary Conditions Top and Bottom Edges: u_z = 0	
Loading Internal pressure, P, at the bore (left edge) applied in 4 steps.	
Step: Perfect Plasticity	**Step: Iso. Hardening**
1: P = 10.0 N/mm^2	**1:** P = 10.0 N/mm^2
2: P = 14.0 N/mm^2	**2:** P = 14.0 N/mm^2
3: P = 16.6 N/mm^2	**3:** P = 24.0 N/mm^2
4: P = 19.2 N/mm^2	**4:** P = 34.0 N/mm^2

Results

Reference: Stress results are displayed for each step as the step is incremented by 1 starting at 0 and ending at 4.

```
             |   Mechanical APDL   |   RATIO  |          INPUT         |

 PLANE182
  SRAD               -15.3322         0.9720       vmr049-pl5a-182
  SAXI                -1.9040         1.0133       vmr049-pl5a-182
  SHOOP               12.3762         1.0371       vmr049-pl5a-182
  SEFF                24.0000         1.0000       vmr049-pl5a-182
 PLANE183
  SRAD               -16.2156         1.0280       vmr049-pl5a-183
  SAXI                -1.8541         0.9868       vmr049-pl5a-183
  SHOOP               11.4910         0.9629       vmr049-pl5a-183
  SEFF                24.0000         1.0000       vmr049-pl5a-183

 ----------------------------------------------------------------------
```

```
             |   Mechanical APDL   |   RATIO  |          INPUT         |

 PLANE182
  SRAD               -26.7817         0.9910       vmr049-pl5b-182
  SAXI                 3.1492         0.8671       vmr049-pl5b-182
```

```
 SHOOP              38.6501         1.0231       vmr049-pl5b-182
PLANE183
 SRAD              -27.2679         1.0090       vmr049-pl5b-183
 SAXI                4.1140         1.1327       vmr049-pl5b-183
 SHOOP              36.9054         0.9769       vmr049-pl5b-183

----------------------------------------------------------------------
```

vmr049-pl5a-182.dat (a)
vmr049-pl5a-183.dat (a)
vmr049-pl5b-182.dat (b)
vmr049-pl5b-183.dat (b)

VMR083-CA1: Sound Radiation of a Vibrating Sphere

Test Description

A sphere with radius R = 1 m is pulsating and radiating sound into an exterior unbounded field. At the surface of the sphere a normal velocity of v_n = 0.1 m/s is prescribed.

Geometric Properties	Material Properties	Loading
Sphere radius, R = 1 m	Density of Air, ρ = 1.225 kg/m^3 Speed of Sound, c = 340 m/s	Normal velocity on the surface of sphere, v_n = 0.1 m/s

Results

The frequency spectrum of the sound pressure level value is calculated at the surface of the sphere (r = 1 m) and a distance of r = 15 m from the center of the sphere. The results are compared with the analytical solutions for frequencies 20, 40, 60, 80, and 100 Hz with the frequency range of excitation from 0 to 100 Hz and at 200, 300, 400, and 500 Hz for frequency range of excitation from 100 to 500 Hz. Analytical values of pressure are calculated by:

$$p(r) = \rho c \frac{v_n R^2}{1 + k^2 R^2} \left(\frac{k^2 R}{r} - i \frac{k}{r} \right) e^{ik(r-R)}$$

$$k = \frac{\omega}{c} = \frac{2\pi f}{c}$$

Analytical values of sound pressure level in dB are calculated by:

$$L_{spl} = 20 \lg \left(\frac{p_{rms}}{p_{ref}} \right) = 20 \lg \left(\frac{p(r)}{p_{ref}\sqrt{2}} \right)$$

where

p_{ref} = the reference pressure (2 x 10^{-5} N/m^2 by default)

$p_{rms} = \frac{p(r)}{\sqrt{2}}$ = root mean square of peak pressure in the modal and harmonic analysis

```
 ------------- r=1m, 0-100Hz ---------------
 |  Freq(Hz)  |  MECHANICAL APDL |  RATIO  |

  0.200000E+02      0.11416E+03    1.0000
  0.400000E+02      0.11884E+03    1.0000
  0.600000E+02      0.12078E+03    1.0000
  0.800000E+02      0.12173E+03    1.0000
  0.100000E+03      0.12225E+03    1.0000

-------------- r=15m, 0-100Hz -------------
|  Freq(Hz)  |  MECHANICAL APDL |  RATIO  |
```

```
     0.200000E+02      0.90631E+02    0.9999
     0.400000E+02      0.95316E+02    0.9999
     0.600000E+02      0.97252E+02    1.0000
     0.800000E+02      0.98203E+02    1.0000
     0.100000E+03      0.98726E+02    1.0000

   --------------- r=1m, 100-500Hz ------------
   |  Freq(Hz)  |  MECHANICAL APDL  |  RATIO  |

    0.200000E+03       0.12305E+03    1.0000
    0.300000E+03       0.12322E+03    1.0000
    0.400000E+03       0.12328E+03    1.0000
    0.500000E+03       0.12331E+03    1.0000

   -------------- r=15m, 100-500Hz ------------
   |  Freq(Hz)  |  MECHANICAL APDL  |  RATIO  |

    0.200000E+03       0.99551E+02     1.0002
    0.300000E+03       0.99703E+02     1.0000
    0.400000E+03       0.99798E+02     1.0004
    0.500000E+03       0.99932E+02     1.0014
```

vmr083-CA1-221.dat

VMR083-CA2: Sound Radiation of a Cylinder with Vibrating Lateral Surface

Test Description

A cylinder with radius R = 1 m and length l = 4 m is given. The cylinder is radiating sound into the exterior unbounded domain.

Geometric Properties	Material Properties	Loading
Cylinder radius, R = 1 m Length, l = 4 m	Density of Air, ρ = 1.225 kg/m^3 Speed of Sound, c = 340 m/s	Uniform radial velocity of v_n = 1.0 m/s on the lateral surface for wave number k = 1 and k =2. The end surfaces are rigid, v_n = 0

Results

The distribution of normalized sound pressure level in the YZ-plane (φ = 90° in the spherical coordinate system) is calculated at distance r = 100 m from the origin of the coordinate system for 0° to 90°, or from θ = 90° to 0° in the spherical coordinate system. The sound pressure is normalized with respect to the sound pressure at r = 100 and θ = 90°. The normalized sound pressure levels obtained for k =1 and k = 2 are compared to the NADwork Version 3.2 results given in the NAFEMS article.

A numerical reference solution can be found in A.F. Seybert, B. Soenarko, F.J. Rizzo, and D.J. Shippy, "An advanced computational method for radiation and scattering of acoustic waves in three dimensions", *J. Acous. Soc. Am.*, 77(2), 1985.

```
 ------------- Pn (k = 1) ---------------
 |  THETA  |  Mechanical APDL  |  RATIO  |

     0          0.772            1.003
     10         0.782            1.002
     20         0.807            1.009
     30         0.844            1.004
     40         0.884            1.005
     50         0.923            1.003
     60         0.955            1.005
     70         0.979            0.989
     80         0.995            0.995
     90         1.000            1.000

 ------------- Pn (k = 2) ---------------
 |  THETA  |  Mechanical APDL  |  RATIO  |

     0          0.469             1.019
     10         0.424             1.033
     20         0.293             1.009
     30         0.099             0.989
     40         0.163             1.019
     50         0.389             0.998
     60         0.593             0.988
     70         0.781             0.988
     80         0.937             1.007
     90         1.000             1.000
```

vmr083-CA2-221.dat

Part V: NRC Piping Benchmarks

Chapter 1: NRC Piping Benchmarks Overview

The following section contains Mechanical APDL solutions to NRC piping benchmark problems taken from publications NUREG/CR1677, Volumes 1 & 2 and NUREG/CR6645. The piping benchmark solutions given in NRC publications were obtained by using a computer program EPIPE which is a modification of the widely available program SAP IV specifically prepared to perform piping analyses.

The problems solved in this section range from simple to complex nuclear piping systems. The dynamic loading in these problems are induced by uniform earthquake type excitation in the three spatial directions. The solutions are determined by using the response spectrum method.

The test case description for each problem includes the element types, analysis types, input files, problem sketch, brief description of the problem and its geometry, material properties, and loadings. A results table is included at the end of the description of each test case.

1.1. Piping Benchmarks using Archived Elements

The first set of piping benchmark problems is solved using archived pipe elements PIPE16 and PIPE18. The system natural frequency and the element and nodal results obtained from Mechanical APDL solutions using these elements are verified against the NRC benchmark solutions.

Piping Benchmarks using Archived Elements:

1.2. Piping Benchmarks using Current Technology Elements

The second set of piping benchmark problems is solved using current technology pipe elements PIPE289 and ELBOW290. The straight and curved piping segments are discretized with PIPE289 and ELBOW290 respectively. In order to better model the ovalization carry over from the curved pipe elements to the straight pipe elements, the **ELBOW** command is used to automatically convert some straight PIPE289 elements near the pipe bends into ELBOW290 elements. A finer mesh compared to the NUREG model is used with PIPE289 and ELBOW290 elements so that the subtended angle in each ELBOW290 element does not exceed 45 degrees.

PIPE289 element is based on the extended Timoshenko beam theory with the inclusion of pipe wall expansion degrees of freedoms. PIPE289 supports both plane stress (thin pipe) and 3-D stress (thick pipe) states and is effective for modeling straight pipes. Based on 3-D finite strain shell theory, ELBOW290 element uses Fourier series for explicitly modeling the cross-section deformation (i.e., non-uniform radial expansion, ovalization, and warping). These arbitrary section deformation modes are commonly observed in curved pipes under loading.

In contrast, PIPE16 and PIPE18 adopt legacy technologies that limit their ability to model piping systems accurately. For instance, PIPE16 and PIPE18 have no way to model the section ovalization between them in a continuous manner; PIPE18 may fail to capture the stiffness and localized stress distribution on a pipe bend under general loading, due to its outdated flexibility factor technology method (published in 1959). The NUREG results come from a computer program that employs a flexibility factor technology method, and the results are not based on analytical calculations. For these reasons, the results obtained from current technology elements are not compared against NUREG results.

Piping Benchmarks using Current Technology Elements:

The results obtained using current technology elements are more accurate and match more closely to the results obtained from the equivalent 3-D model. To confirm this, three demonstration problems are included, where the results obtained from the piping model meshed with current technology pipe elements are compared against the piping model meshed with 3-D, 8-node SHELL281 elements.

1.3. Demonstration Problem 1

Problem Description

A cantilevered bend pipe is modeled with a ratio of outer radius to wall thickness equal to 45.36. Single point response spectrum analysis is performed on the model with base excitation along the global X, Y and Z directions.

The input files for this problem are listed below:

demonstration-problem1-290 Input Listing (p. 2899)
demonstration-problem1-281 Input Listing (p. 2903)
demonstration-problem1-18 Input Listing (p. 2907)

Material Properties:

Young's modulus = 24e6 psi
Poisson's ratio = 0.3
Density = 0.000125 lb-sec^2/in^4

Geometric Properties:

Outer diameter = 10.932 inches
Wall thickness = 0.1205 inches
Radius of curvature = 36.30 inches

Loading:

Acceleration response spectrum curve is input on the **SV** and **FREQ** commands.

Results

Figure 1.1: Nodal Equivalent Stress Plot Obtained from PIPE18 Elements

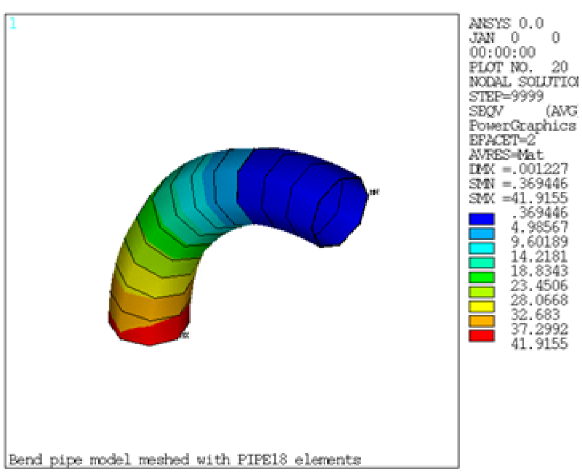


Figure 1.2: Nodal Equivalent Stress Plot Obtained from ELBOW290 Elements

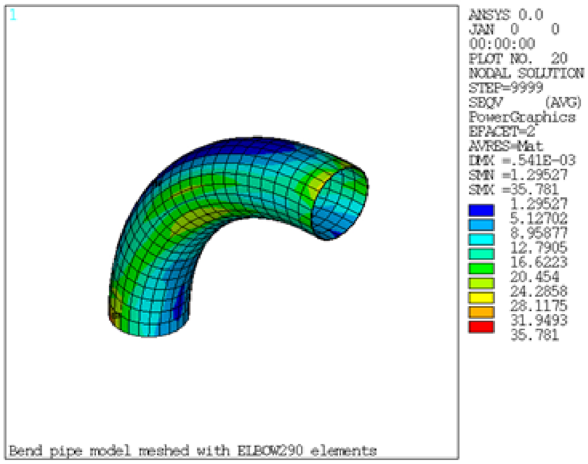
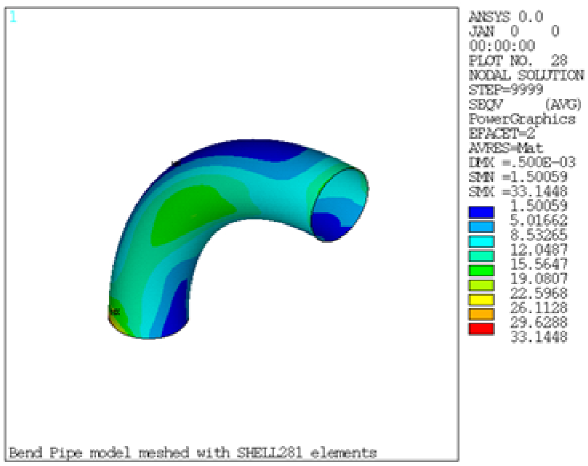


Figure 1.3: Nodal Equivalent Stress Plot Obtained from SHELL281 Elements



Results Comparison

Table 1.1: Frequencies Obtained from Modal Solution

Mode	Results from SHELL281 (A)	Results from PIPE18 (B)	Results from ELBOW290 (C)	Ratio between A and B	Ratio between A and C
1	145.554	90.588	145.641	1.606	0.999
2	149.530	100.503	149.613	1.487	0.999
3	315.404	418.040	315.392	0.754	1.000
4	319.433	480.193	319.425	0.665	1.000
5	575.655	1241.493	575.845	0.463	0.999
6	604.193	1335.526	604.387	0.452	0.999
7	757.127	2260.454	757.039	0.334	1.000
8	760.925	2505.754	760.827	0.303	1.000
9	947.803	2771.559	948.182	0.341	0.999
10	982.926	3852.258	983.168	0.255	0.999

Mode	Results from SHELL281 (A)	Results from PIPE18 (B)	Results from ELBOW290 (C)	Ratio between A and B	Ratio between A and C
11	1001.878	3852.333	1001.868	0.260	1.000
12	1242.305	5223.342	1242.931	0.237	0.999
13	1271.296	5279.894	1271.867	0.240	0.999
14	1369.966	6010.645	1368.740	0.227	1.000
15	1411.341	6673.827	1411.654	0.211	0.999

Table 1.2: Displacements and Stresses Obtained from Spectrum Solution

Result Quantities	Results from SHELL281 (A)	Results from PIPE18 (B)	Results from ELBOW290 (C)	Ratio between A and B	Ratio between A and C
Maximum displacement Vector Sum	5.00e-04	1.23e-03	4.94e-04	0.407	1.012
Maximum equivalent stress	33.144	41.915	27.633	0.790	1.199

Conclusion

The result comparison table and Figure 1.1: Nodal Equivalent Stress Plot Obtained from PIPE18 Elements (p. 1027), Figure 1.2: Nodal Equivalent Stress Plot Obtained from ELBOW290 Elements (p. 1028), and Figure 1.3: Nodal Equivalent Stress Plot Obtained from SHELL281 Elements (p. 1028) show that the results obtained from modal and spectrum analyses with ELBOW290 elements closely match with the results obtained from SHELL281 elements. The results obtained from PIPE18 elements are off by more than 50% when compared with SHELL281 results due to the limitations explained in Piping Benchmarks using Current Technology Elements (p. 1026).

1.4. Demonstration Problem 2

Problem Description

A simple piping model made up of straight and bend pipe elements between two fixed anchors is solved. This problem is similar to the problem specified in NRC1677-Volume 1, Problem 1. Single point response spectrum analysis is performed on the model with base excitation along global X, Y and Z directions.

The input files for this problem are listed below:

demonstration-problem2-290 Input Listing (p. 2910)
demonstration-problem2-281 Input Listing (p. 2913)
demonstration-problem2-16-18 Input Listing (p. 2917)

Material Properties:

Young's modulus = 24e6 psi
Poisson's ratio = 0.3
Density = 0.000125 lb-sec^2/in^4

Geometric Properties:

Outer diameter = 10.932 inches
Wall thickness = 0.241 inches
Radius of curvature (for bend pipes) = 36.30 inches

Loading:

Acceleration response spectrum curve is input on the **SV** and **FREQ** commands.

Modeling Notes:

When modeling the piping problem with current technology elements, the straight elements are also modeled using ELBOW290 elements in order to better capture the ovalization from the curved pipe elements to straight pipe elements.

Results

Figure 1.4: Nodal Equivalent Stress Plot Obtained from PIPE16 and PIPE18 Elements

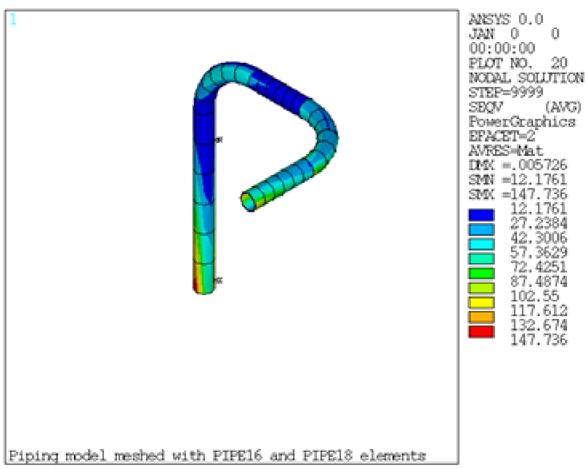


Figure 1.5: Nodal Equivalent Stress Plot Obtained from ELBOW290 Elements

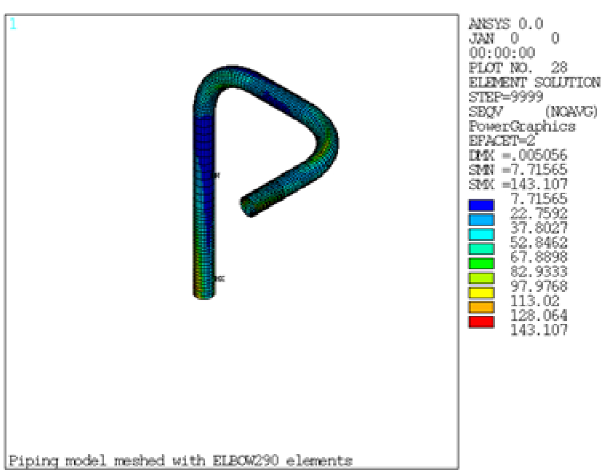
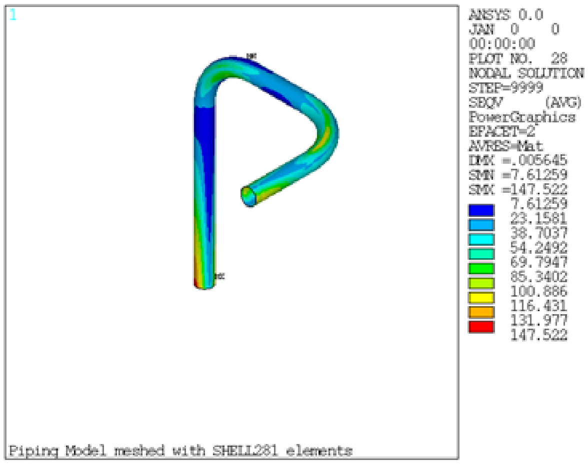


Figure 1.6: Nodal Equivalent Stress Plot Obtained from SHELL281 Elements



Results Comparison

Table 1.3: Frequencies Obtained from Modal Solution

Mode	Results from SHELL281 (A)	Results from PIPE18 and PIPE16 (B)	Results from ELBOW290 (C)	Ratio between A and B	Ratio between A and C
1	45.457	44.673	45.460	1.017	0.999
2	83.403	80.632	83.454	1.034	0.999
3	108.235	103.566	108.532	1.045	0.997
4	202.668	193.109	202.808	1.049	0.999
5	219.772	210.178	219.878	1.045	0.999
6	338.843	329.211	338.765	1.029	1.000
7	344.744	336.523	345.216	1.024	0.998
8	431.890	457.355	431.528	0.944	1.000
9	441.304	466.377	440.802	0.946	1.000
10	491.536	693.369	491.493	0.708	1.000
11	491.876	745.125	491.838	0.660	1.000
12	528.549	763.789	528.446	0.692	1.000
13	563.018	801.945	562.924	0.702	1.000
14	563.899	932.173	563.795	0.604	1.000
15	593.071	947.206	592.365	0.626	1.000

Table 1.4: Displacements and Stresses Obtained from Spectrum Solution

Result Quantities	Results from SHELL281 (A)	Results from PIPE18 and PIPE16 (B)	Results from ELBOW290 (C)	Ratio between A and B	Ratio between A and C
Maximum displacement Vector Sum	5.65e-03	5.72e-03	5.65e-03	1.106	1.000

Result Quantities	Results from SHELL281 (A)	Results from PIPE18 and PIPE16 (B)	Results from ELBOW290 (C)	Ratio between A and B	Ratio between A and C
Maximum equivalent stress	147.522	147.736	160.106	1.024	0.921

Conclusion

The result comparison table and Figure 1.4: Nodal Equivalent Stress Plot Obtained from PIPE16 and PIPE18 Elements (p. 1030), Figure 1.5: Nodal Equivalent Stress Plot Obtained from ELBOW290 Elements (p. 1030), and Figure 1.6: Nodal Equivalent Stress Plot Obtained from SHELL281 Elements (p. 1031) show that the results obtained from modal and spectrum analyses with ELBOW290 elements closely match with the results obtained from SHELL281 elements. The higher modes computed from PIPE16 and PIPE18 elements are off by more than 30% when compared with SHELL281 elements. Since only the lower modes contribute to the spectrum solution, the results obtained from spectrum solution with PIPE16 and PIPE18 elements and the results obtained withELBOW290 and SHELL281 elements are all relatively close.

1.5. Demonstration Problem 3

Problem Description

This problem is taken from NRC 1677- Volume 2, Problem 1. This problem simulates a 3.5 inch diameter water line extending between two elevations that has two anchors and numerous intermediate supports. Single point response spectrum analysis is performed on the model with base excitation along global X and Y directions.

The input files for this problem are listed below:

demonstration-problem3-281 Input Listing (p. 2929)
demonstration-problem3-16-18 Input Listing (p. 2942)
demonstration_problem3-289-290 Input Listing (p. 2921)

Material Properties:

Young's modulus = 0.258e8 psi
Poisson's ratio = 0.3
Shear modulus = 0.992e7 psi
Density = 0.000125 lb-sec^2/in^4
Set 1:
Stiffness of the longitudinal spring-damper element (UX degree of freedom) = 0.2e8 lb/in
Stiffness of the longitudinal spring-damper element (UY degree of freedom) = 0.2e8 lb/in
Stiffness of the longitudinal spring-damper element (UZ degree of freedom) = 0.2e8 lb/in
Set 2:
Stiffness of the longitudinal spring-damper element (UX degree of freedom) = 0.2e5 lb/in
Stiffness of the longitudinal spring-damper element (UY degree of freedom) = 0.2e5 lb/in

Geometric Properties:

Outer diameter = 3.5 inches
Wall thickness = 0.216 inches
Radius of curvature (for bend pipes) = 48.003 inches

Loading:

Acceleration response spectrum curve is input on the **SV** and **FREQ** commands.

Modeling Notes:

In the piping model using SHELL281 elements, all the rotational degrees of freedom at the end nodes are constrained. In order to simulate the same boundary conditions with pipe elements, the end elements are modeled with ELBOW290 elements. In addition to constraining the nodal degrees of freedom, the ELBOW290 element can also constrain the pipe cross-sections that are not possible with PIPE289 elements, such as warping, ovalization, radial expansion, and shell normal rotations. CONTA175 and TARGE170 elements are used to establish contact between spring-damper elements (COMBIN14) and shell elements (SHELL281).

Results

Figure 1.7: Nodal Equivalent Stress Plot fromPIPE16/PIPE18 Elements

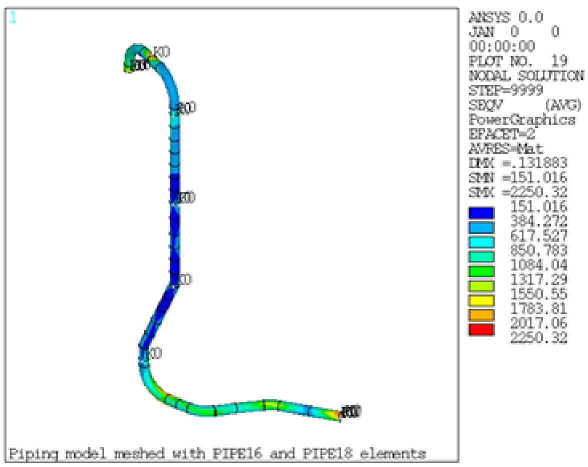


Figure 1.8: Nodal Equivalent Stress Plot fromPIPE289/ELBOW290 Elements

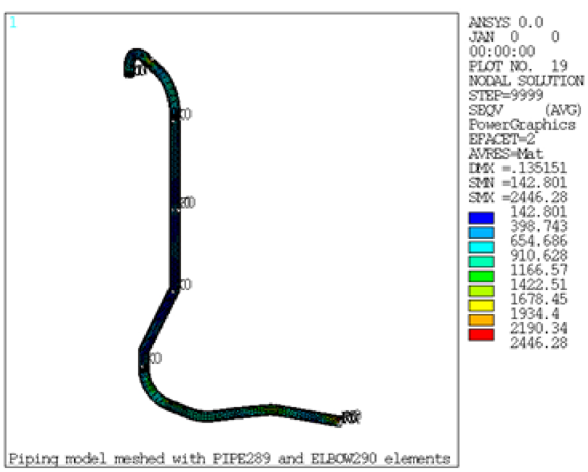
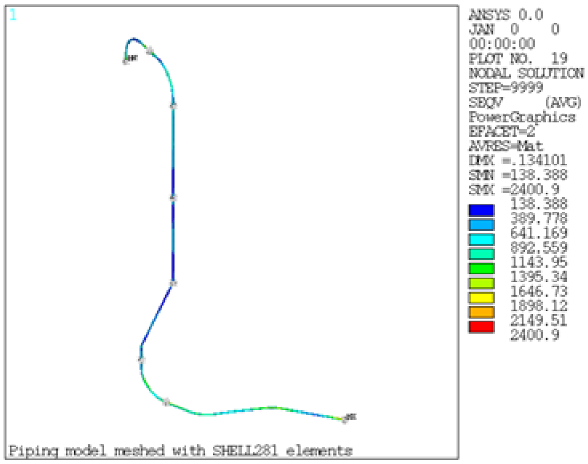


Figure 1.9: Nodal Equivalent Stress Plot from SHELL281 Elements



Results Comparison

Table 1.5: Frequencies Obtained from Modal Solution

Mode	Results from SHELL281 (A)	Results from PIPE18 and PIPE16 (B)	Results from ELBOW290 (C)	Ratio between A and B	Ratio between A and C
1	5.989	6.047	6.113	0.990	0.979
2	6.230	6.269	6.353	0.993	0.980
3	7.893	7.759	7.766	1.017	1.016
4	8.800	8.922	8.793	0.986	1.000
5	12.259	12.441	12.185	0.985	1.000
6	12.758	12.830	12.627	0.994	1.010
7	13.917	14.297	13.956	0.973	0.997
8	15.363	15.484	14.866	0.992	1.033
9	16.096	16.369	15.987	0.983	1.006
10	18.218	18.540	18.061	0.982	1.008
11	18.888	19.496	18.921	0.968	0.998
12	21.943	23.223	21.609	0.944	1.015
13	22.973	24.080	22.958	0.954	1.000
14	25.390	32.634	24.942	0.778	1.017
15	31.411	33.749	31.874	0.930	0.985

Table 1.6: Displacements and Stresses Obtained from Spectrum Solution

Result Quantities	Results from SHELL281 (A)	Results from PIPE18 and PIPE16 (B)	Results from ELBOW290 (C)	Ratio between A and B	Ratio between A and C
Maximum displacement Vector Sum	0.134	0.131	0.135	1.022	0.992

Result Quantities	Results from SHELL281 (A)	Results from PIPE18 and PIPE16 (B)	Results from ELBOW290 (C)	Ratio between A and B	Ratio between A and C
Maximum equivalent stress	2400.901	2250.316	2446.511	1.066	0.981

Conclusion

The result comparison table and figures Figure 1.7: Nodal Equivalent Stress Plot from PIPE16/PIPE18 Elements (p. 1033), Figure 1.8: Nodal Equivalent Stress Plot from PIPE289/ELBOW290 Elements (p. 1033), and Figure 1.9: Nodal Equivalent Stress Plot from SHELL281 Elements (p. 1034) show that the results obtained from modal and spectrum analyses with PIPE289 and ELBOW290 elements closely match with the results obtained from SHELL281 elements. The higher modes computed from PIPE16 and PIPE18 elements are off by more than 5% when compared with SHELL281 elements. Since only the lower modes are contributing to the spectrum solution, the results obtained from spectrum solution with PIPE16 and PIPE18 elements, PIPE289 and ELBOW290 elements, and SHELL281 elements are all relatively close.

VM-NR1677-01-1-a: NUREG/CR-1677: Volume 1, Benchmark Problem No. 1

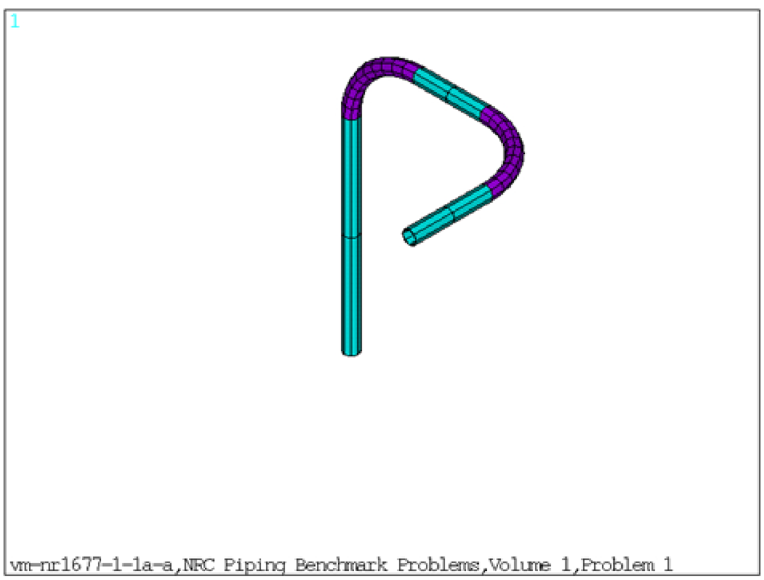
Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic Analysis of Uniform Support Motion Response Spectrum Method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 1, Pages 24-47.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Elastic straight pipe elements (PIPE16) Elastic curved pipe elements (PIPE18) Structural Mass element (MASS21)
Input Listing:	vm-nr1677-1-1a-a.dat

Test Case

This benchmark problem contains three straight sections, two bends, and two fixed anchors (refer to Figure VM-NR1677-01-1-a.1: FE Model of Benchmark Problem (p. 1037)). The total mass of the system is represented by structural mass element (MASS21) specified at individual nodes. Modal and response spectrum analysis is performed on the piping model. Frequencies obtained from modal solve and the nodal/element solution obtained from spectrum solve are compared against reference results.

Figure VM-NR1677-01-1-a.1: FE Model of Benchmark Problem



Material Properties	Geometric Properties	Loading
Pipe Elements: E = 24.00 x 10^6 psi Nu = 0.3 **3-D mass (lb-sec^2/in):**	**Straight Pipe:** Type 1, real 1 Outer Diameter = 7.288 in Wall Thickness = 0.241 in	Acceleration response spectrum curve defined by **SV** and **FREQ** commands.

Material Properties	Geometric Properties	Loading
Mass @ node 2 = 0.0398 Mass @ node 3 = 0.0503 Mass @ node 4 = 0.02088 Mass @ node 5 = 0.0169 Mass @ node 6 = 0.0130 Mass @ node 7 = 0.0169 Mass @ node 8 = 0.0104 Mass @ node 9 = 0.0179 Mass @ node 10 = 0.0150	**Bend Pipe:** Outer Diameter = 7.288 in Wall Thickness = 0.241 in Radius of Curvature = 36.30 in	

Results Comparison

Table VM-NR1677-01-1-a.1: Frequencies Obtained from Modal Solution

Mode	Target	Mechanical APDL	Ratio
1	28.530	28.534	1.00
2	55.770	55.771	1.00
3	81.500	81.499	1.00
4	141.700	141.739	1.00
5	162.800	162.816	1.00

Table VM-NR1677-01-1-a.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node5	0.0078	0.0078	0.999
UY at node7	0.0025	0.0025	1.00
UZ at node4	0.0174	0.0174	1.00
ROTX at node3	0.0002	0.0002	1.00
ROTY at node7	0.0002	0.0002	1.00

Result Node	Target	Mechanical APDL	Ratio
ROTZ at node3	0.0001	0.001	1.00

Table VM-NR1677-01-1-a.3: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	4.964	4.958	1.001
VY(I)	17.879	17.880	1.000
VZ(I)	36.436	36.430	1.000
TX(I)	629.715	629.600	1.000
MY(I)	3226.871	3227.000	1.000
MZ(I)	1393.841	1394.000	1.000
PX(J)	4.964	4.958	1.001
VY(J)	17.879	17.880	1.000
VZ(J)	36.436	36.430	1.000
TX(J)	629.715	629.600	1.000
MY(J)	1259.879	1260.000	1.000
MZ(J)	473.244	474.200	0.998
Element 10			
PX(I)	24.022	24.020	1.000
VY(I)	7.478	7.472	1.001
VZ(I)	34.800	34.780	1.001
TX(I)	112.957	113.000	1.000
MY(I)	1871.654	1871.000	1.000
MZ(I)	650.273	650.100	1.000
PX(J)	24.022	24.020	1.000
VY(J)	7.478	7.472	1.001
VZ(J)	34.800	34.780	1.001
TX(J)	112.957	113.000	1.000
MY(J)	2477.415	2477.000	1.000
MZ(J)	774.763	774.500	1.000
Element 4			
PX(I)	9.304	9.300	1.000
VY(I)	10.635	10.630	1.000
VZ(I)	9.245	9.239	1.001
TX(I)	142.101	142.100	1.000

Result	Target	Mechanical APDL	Ratio
MY(I)	289.991	289.900	1.000
MZ(I)	828.470	828.400	1.000
PX(J)	12.388	12.38	1.001
VY(J)	10.635	10.63	1.000
VZ(J)	4.310	4.305	1.001
TX(J)	423.720	423.7	1.000
MY(J)	261.350	261.3	1.000
MZ(J)	541.933	541.9	1.000

Note

PX (I) and PX (J) = Section axial force at node I and J.

VY (I) and VY (J) = Section shear forces along Y direction at node I and J.

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J.

TX (I) and TX (J) = Section torsional moment at node I and J.

MY (I) and MY (J) = Section bending moments along Y direction at node I and J.

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J.

The element forces and moments along Y and Z directions are flipped between Mechanical APDL and NRC results.

VM-NR1677-01-2-a: NUREG/CR-1677: Volume 1, Benchmark Problem No. 2

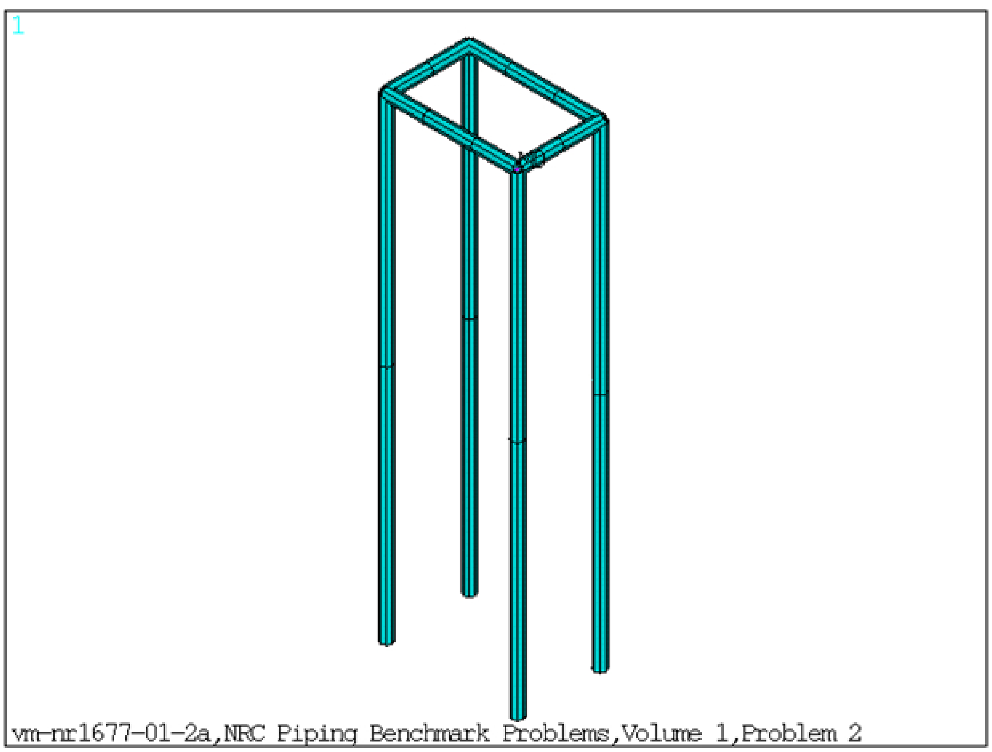
Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic Analysis of Uniform Support Motion Response Spectrum Method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 2, Pages 48-80.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Elastic straight pipe elements (PIPE16) Structural Mass element (MASS21)
Input Listing:	vm-nr1677-1-2a-a.dat

Test Case

This benchmark problem contains three-dimensional multi-branched piping systems (refer to Figure VM-NR1677-01-2-a.1: FE model of the Benchmark Problem (p. 1041)). The total mass of the system is represented by structural mass element (MASS21) specified at individual nodes. Modal and response spectrum analysis is performed on the piping model. Frequencies obtained from modal solve and the nodal/element solution obtained from spectrum solve are compared against reference results. The NUREG intermodal/interspatial results are used for comparison.

Figure VM-NR1677-01-2-a.1: FE model of the Benchmark Problem



Material Properties	Geometric Properties	Loading
Pipe Elements: E = 27.8999 x 10^6 psi. Nu = 0.3 Density = 2.587991718e-10 lb-sec^2/in^4 **Mass Elements (lb-sec^2/in):** (Mass is isotropic) Mass @ node 1: M = 0.447000518e-01 Mass @ node 2: M = 0.447000518e-01 Mass @ node 3: M = 0.447000518e-01 Mass @ node 4: M = 0.447000518e-01 Mass @ node 5: M = 0.432699275e-01 Mass @ node 6: M = 0.893995859e-02 Mass @ node 7: M = 0.432699275e-01 Mass @ node 8: M = 0.893995859e-02 Mass @ node 9: M = 0.893995859e-02 Mass @ node 10: M = 0.432699275e-01 Mass @ node 11: M = 0.893995859e-02 Mass @ node 12: M = 0.432699275e-01 Mass @ node 13: M = 0.893995859e-02 Mass @ node 14: M = 0.893995859e-02	**Straight Pipe:** Outer Diameter = 2.375 in Wall Thickness = 0.154 in	Acceleration response spectrum curve defined by **SV** and **FREQ** commands

Results Comparison

Table VM-NR1677-01-2-a.1: Frequencies Obtained from Modal Solution

Mode	Target	Mechanical APDL	Ratio
1	8.712	8.711	1.00

Mode	Target	Mechanical APDL	Ratio
2	8.806	8.806	1.00
3	17.510	17.507	1.00
4	40.370	40.366	1.00
5	41.630	41.625	1.00

Table VM-NR1677-01-2-a.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node6	0.461	0.461	1.000
UY at node8	0.002	0.002	1.006
UZ at node8	0.446	0.450	1.009
ROTX at node1	0.006	0.006	1.009
ROTY at node9	0.000	0.000	1.009
ROTZ at node1	0.006	0.006	1.00

Table VM-NR1677-01-2-a.3: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	555.400	558.987	1.006
VY(I)	108.200	109.274	1.010
VZ(I)	109.300	109.239	0.999
TX(I)	1.610	1.6233	1.008
MY(I)	5135.000	5182.557	1.009
MZ(I)	5229.000	5228.602	1.000
PX(J)	555.400	558.987	1.006
VY(J)	108.800	109.274	1.004
VZ(J)	109.300	109.239	0.999
TX(J)	1.610	1.6233	1.008
MY(J)	276.900	279.413	1.009
MZ(J)	235.100	235.111	1.000
Element 18			
PX(I)	14.000	14.031	1.002
VY(I)	297.200	297.157	1.000
VZ(I)	12.280	12.390	1.009

Result	Target	Mechanical APDL	Ratio
TX(I)	0.0141	0.014	1.000
MY(I)	47.710	48.141	1.009
MZ(I)	1480.000	1486.025	1.004
PX(J)	14.000	14.031	1.002
VY(J)	297.200	297.157	1.000
VZ(J)	12.280	12.390	1.009
TX(J)	0.0141	0.014	1.000
MY(J)	60.430	60.936	1.008
MZ(J)	4049.00	4049.004	1.000

Note

PX (I) and PX (J) = Section axial force at node I and J.

VY (I) and VY (J) = Section shear forces along Y direction at node I and J.

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J.

TX (I) and TX (J) = Section torsional moment at node I and J.

MY (I) and MY (J) = Section bending moments along Y direction at node I and J.

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J.

The element forces and moments along Y and Z directions are flipped between Mechanical APDL and NRC results.

VM-NR1677-01-3-a: NUREG/CR-1677: Volume 1, Benchmark Problem No. 3

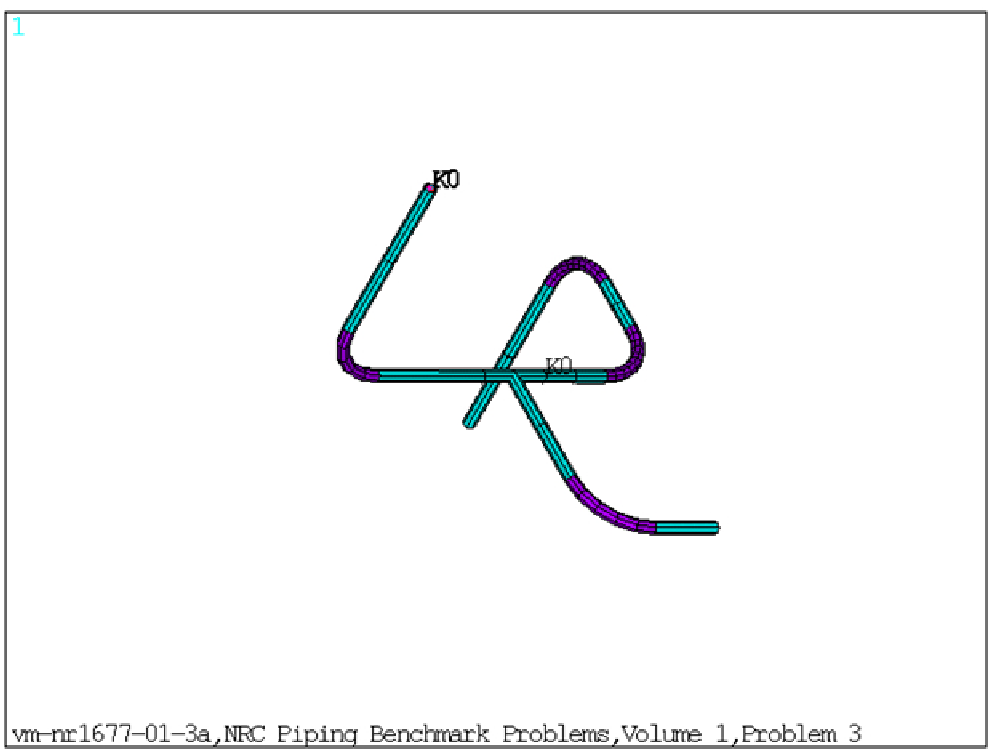
Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic Analysis of Uniform Support Motion Response Spectrum Method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 3, Pages 81-121.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Elastic straight pipe elements (PIPE16) Elastic curved pipe elements (PIPE18) Spring-Damper Element (COMBIN14) Structural Mass element (MASS21)
Input Listing:	vm-nr1677-1-3a-a.dat

Test Case

This benchmark problem is an expanded version of VM-NR1677-01-1 (p. 1131) (refer to Figure VM-NR1677-01-3-a.1: FE Model of the Benchmark Problem (p. 1045)). The problem contains several anchors and branch connection representing a real piping system. The problem also has intermediate spring supports to simulate hangers and snubbers. Modal and response spectrum analysis is performed on the piping model. Frequencies obtained from modal solve and the nodal/element solution obtained from spectrum solve are compared against reference results.

Figure VM-NR1677-01-3-a.1: FE Model of the Benchmark Problem



Material Properties	Geometric Properties	Loading
Pipe Elements: $E = 24 \times 10^6$ psi Nu = 0.3 Density = 0.001057 lb-sec^2/in^4 **Mass Elements (lb-sec^2/in):** Mass @ Node 18 = 1.518 lb **Spring-Damper Elements (lb/in):** Because there are multiple Spring Supports at different locations, the Stiffness for the Spring Damper Elements are listed based on real constant set number. Set 3: $K = 0.1 \times 10^5$ Set 4: $K = 0.1 \times 10^4$ Set 5: $K = 0.1 \times 10^{11}$	**Straight Pipe:** Outer Diameter = 7.288 in Wall Thickness = 0.241 in **Bend Pipe:** Outer Diameter = 7.288 in Wall Thickness = 0.241 in Radius of Curvature = 36.30 in	Internal Pressure on Pipe Elements: 350 psi Acceleration Response Spectrum Curve defined by **FREQ** and **SV** commands

Results Comparison

Table VM-NR1677-01-3-a.1: Frequencies Obtained from Modal Solution:

Mode	Target	Mechanical APDL	Ratio
1	9.360	9.359	1.00
2	12.710	12.705	1.00
3	15.380	15.376	1.00
4	17.800	17.796	1.00
5	21.600	21.602	1.00
6	25.100	25.097	1.00
7	32.030	32.033	1.00
8	38.070	38.067	1.00
9	40.290	40.291	1.00

Mode	Target	Mechanical APDL	Ratio
10	48.900	48.895	1.00

Table VM-NR1677-01-3-a.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node14	0.229	0.220	0.964
UY at node8	0.098	0.095	0.971
UZ at node9	0.166	0.163	0.985
ROTX at node3	0.002	0.002	0.985
ROTY at node7	0.005	0.004	0.985
ROTZ at node17	0.002	0.002	0.985

Table VM-NR1677-01-3-a.3: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	154.400	150.944	0.978
VY(I)	209.200	206.317	0.986
VZ(I)	463.300	457.647	0.988
TX(I)	13090.000	13297.217	1.016
MY(I)	43130.000	42520.777	0.986
MZ(I)	18060.000	17807.561	0.986
PX(J)	154.400	150.944	0.978
VY(J)	209.200	206.317	0.986
VZ(J)	463.300	457.647	0.988
TX(J)	13090.000	13297.217	1.016
MY(J)	18760.000	18477.803	0.985
MZ(J)	8095.000	7975.593	0.985
Element 20			
PX(I)	633.300	630.070	0.995
VY(I)	471.200	448.778	0.952
VZ(I)	1012.000	1010.454	0.998
TX(I)	5724.000	5437.012	0.950
MY(I)	9985.000	9858.470	0.987
MZ(I)	8126.000	7745.946	0.953

Result	Target	Mechanical APDL	Ratio
PX(J)	633.300	630.070	0.995
VY(J)	471.200	448.778	0.952
VZ(J)	1012.000	1010.454	0.998
TX(J)	5724.000	5437.012	0.950
MY(J)	44680.000	44642.850	0.999
MZ(J)	27570.000	26253.384	0.952
Element 7			
PX(I)	270.600	268.384	0.992
VY(I)	39.150	38.835	0.992
VZ(I)	1813.000	1788.540	0.987
TX(I)	5823.000	5729.957	0.984
MY(I)	20040.000	19858.360	0.991
MZ(I)	5439.000	5363.425	0.986
PX(J)	1200.000	1184.253	0.987
VY(J)	39.150	38.835	0.992
VZ(J)	1386.000	1366.913	0.986
TX(J)	7810.000	7688.175	0.984
MY(J)	31740.000	31295.523	0.986
MZ(J)	2256.000	2245.912	0.996

Note

PX (I) and PX (J) = Section axial force at node I and J.

VY (I) and VY (J) = Section shear forces along Y direction at node I and J.

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J.

TX (I) and TX (J) = Section torsional moment at node I and J.

MY (I) and MY (J) = Section bending moments along Y direction at node I and J.

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J.

The element forces and moments along Y and Z directions are flipped between Mechanical APDL and NRC results.

VM-NR1677-01-4-a: NUREG/CR-1677: Volume 1, Benchmark Problem No. 4

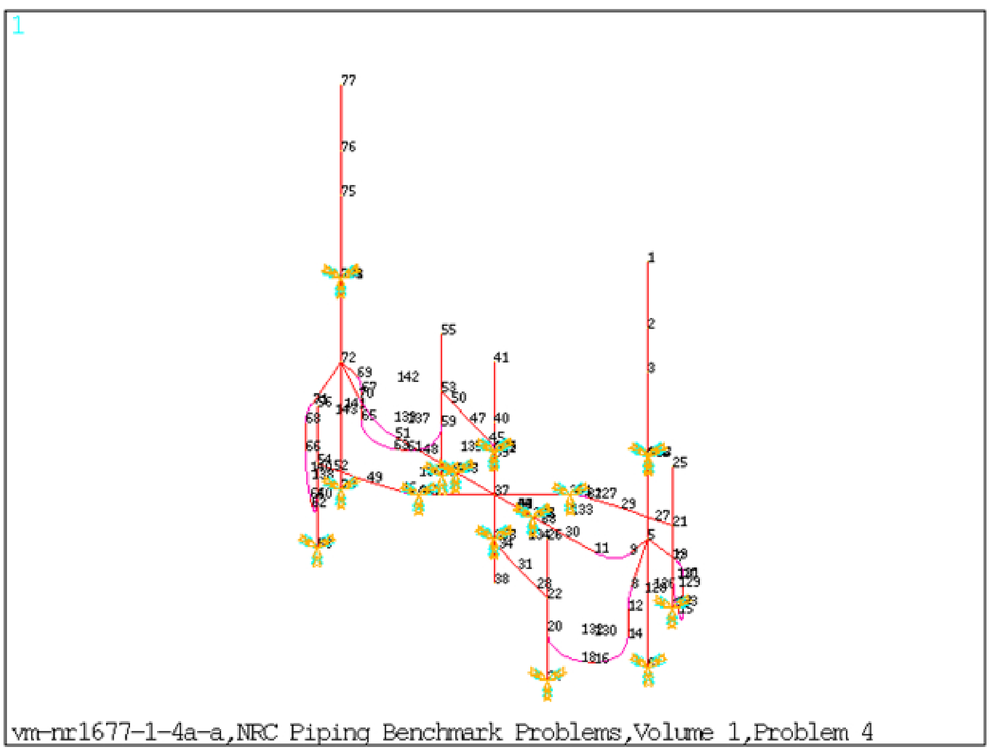
Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic Analysis of Uniform Support Motion Response Spectrum Method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 5, Pages 122-217.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Elastic straight pipe elements (PIPE16) Elastic curved pipe elements (PIPE18) Spring-Damper Element (COMBIN14) Structural Mass element (MASS21)
Input Listing:	vm-nr1677-1-4a-a.dat

Test Case

This benchmark problem is a three-dimensional multi-branched piping system. The system configuration resembles a two-loop reactor (refer to Figure VM-NR1677-01-4-a.1: FE Model of the Benchmark Problem (p. 1049)). The problem simulates an elastically supported reactor vessel, with two steam generators and four primary pumps connected by three and four foot diameter piping. The total mass of the system is represented by structural mass element (MASS21) specified at individual nodes. Modal and response spectrum analysis is performed on the piping model. Frequencies obtained from modal solve and the nodal/element solution obtained from spectrum solve are compared against reference results. The NUREG intermodal/interspatial results are used for comparison.

Figure VM-NR1677-01-4-a.1: FE Model of the Benchmark Problem



Material Properties	Geometric Properties	Loading
Pipe Elements: **Material ID 1:** E = 2.9 x 10^7 psi Nu = 0.3 **Density of the internal fluid Material ID 2:** Density = 0.28138E-03 lb-sec^2/in^4 **Material ID 3:** Density = 0.32972E-03 lb-sec^2/in^4 **Stiffness for Spring-Damper Elements (lb/in):** Since there are multiple Spring Supports at different locations, the Stiffness for the Spring Damper Elements are listed based on real constant set number. **Set 1:** K = 0.1 x 10^{11} **Set 2:** K = 0.5 x 10^8 **Set 3:** K = 0.1 x 10^8 **Mass Elements (lb-sec^2/in):** **Set 13:** Mass @ Node 1 = 518.0 Mass @ Node 40 = 518.0	**Straight Pipe:** Outer Diameter = 144.0 in Wall Thickness = 3 in **Set 5:** Outer Diameter = 36.0 in. Wall Thickness = 2.5 in. **Set 7:** Outer Diameter = 48.0 in. Wall Thickness = 3.75 in **Set 9:** Outer Diameter = 72.0 in. Wall Thickness = 4 in. **Set 10:** Outer Diameter = 192.0 in. Wall Thickness = 8 in. **Set 11:** Outer Diameter = 135.0 in. Wall Thickness = 0.4 in. **Set 12:** Outer Diameter = 100.0 in. Wall Thickness = 0.38 in. **Bend Pipe:** **Set 6:**	Surface Pressure = 2400 psi Surface Pressure = 2400 psi. Acceleration Response Spectrum Curve defined by **FREQ** and **SV** commands.

Material Properties	Geometric Properties	Loading
Mass @ Node 77 = 518.0 **Set 14:** Mass @ Node 2 = 259.0 Mass @ Node 3 = 259.0 Mass @ Node 75 = 259.0 Mass @ Node 76 = 259.0 **Set 15:** Mass @ Node 4 = 906.0 Mass @ Node 74 = 906.0 **Set 16:** Mass @ Node 5 = 233.0 Mass @ Node 72 = 233.0 **Set 16:** Mass @ Node 21 = 130.0 Mass @ Node 22 = 130.0 Mass @ Node 53 = 130.0 Mass @ Node 54 = 130.0 **Set 18:** Mass @ Node 25 = 389.0 Mass @ Node 26 = 389.0 Mass @ Node 41 = 389.0 Mass @ Node 55 = 389.0 Mass @ Node 56 = 389.0 **Set 19:**	Outer Diameter = 36.0 in Wall Thickness = 2.5 in Radius of Curvature = 60.0 in **Set 8:** Outer Diameter = 48.0 in Wall Thickness = 3.75 in Radius of Curvature = 117.900 in	

Material Properties	Geometric Properties	Loading
Mass @ Node 37 = 2073.0 **Set 20:** Mass @ Node 38 = 1943.0 **Set 21:** Mass @ Node 39 = 1295.0		

Results Comparison

Table VM-NR1677-01-4-a.1: Frequencies Obtained from Modal Solution:

Mode	Target	Mechanical APDL	Ratio
1	6.133	6.120	1.000
2	6.183	6.169	1.000
3	6.557	6.526	1.000
4	6.571	6.539	1.000
5	6.632	6.604	1.000
6	6.636	6.609	1.000
7	6.722	6.712	1.000
8	7.984	7.978	1.000
9	10.21	10.198	1.000
10	11.73	11.715	1.000
11	13.4	13.371	1.000
12	13.89	13.871	1.000
13	14.25	14.231	1.000
14	14.5	14.466	1.000
15	14.71	14.685	1.000
16	15.57	15.557	1.000
17	17.1	17.066	1.000
18	18.9	18.884	1.000
19	28.29	28.155	1.000
20	28.31	28.177	1.000
21	29.52	29.479	1.000
22	29.8	29.723	1.000
23	30.32	30.266	1.000
24	30.49	30.423	1.000

Mode	Target	Mechanical APDL	Ratio
25	30.5	30.429	1.000
26	31.83	31.599	0.990
27	31.86	31.612	0.990
28	39.5	39.181	0.990
29	40.42	40.155	0.990
30	40.73	40.436	0.990

Table VM-NR1677-01-4-a.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node55	0.454	0.460	1.012
UY at node77	0.076	0.076	1.006
UZ at node55	0.950	0.973	1.023
ROTX at node55	0.004	0.004	1.022
ROTY at node47	0.002	0.002	1.026
ROTZ at node55	0.002	0.002	1.011

Table VM-NR1677-01-4-a.3: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	315400.000	315781.292	1.001
VY(I)	633000.000	639475.958	1.010
VZ(I)	638200.000	659264.753	1.033
PX(J)	315300.000	315781.292	1.002
VY(J)	633000.000	639475.958	1.010
VZ(J)	638100.000	659264.753	1.033
Element 80			
PX(I)	315400.000	315812.135	1.001
VY(I)	633000.000	639459.663	1.010
VZ(I)	638200.000	659350.137	1.033
PX(J)	315400.000	315812.135	1.001
VY(J)	633000.000	639459.663	1.010

Result	Target	Mechanical APDL	Ratio
VZ(J)	638200.000	659350.137	1.033

Note

PX (I) and PX (J) = Section axial force at node I and J.

VY (I) and VY (J) = Section shear forces along Y direction at node I and J.

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J.

TX (I) and TX (J) = Section torsional moment at node I and J.

MY (I) and MY (J) = Section bending moments along Y direction at node I and J.

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J.

The element forces and moments along Y and Z directions are flipped between Mechanical APDL and NRC results.

VM-NR1677-01-5-a: NUREG/CR-1677: Volume 1, Benchmark Problem No. 5

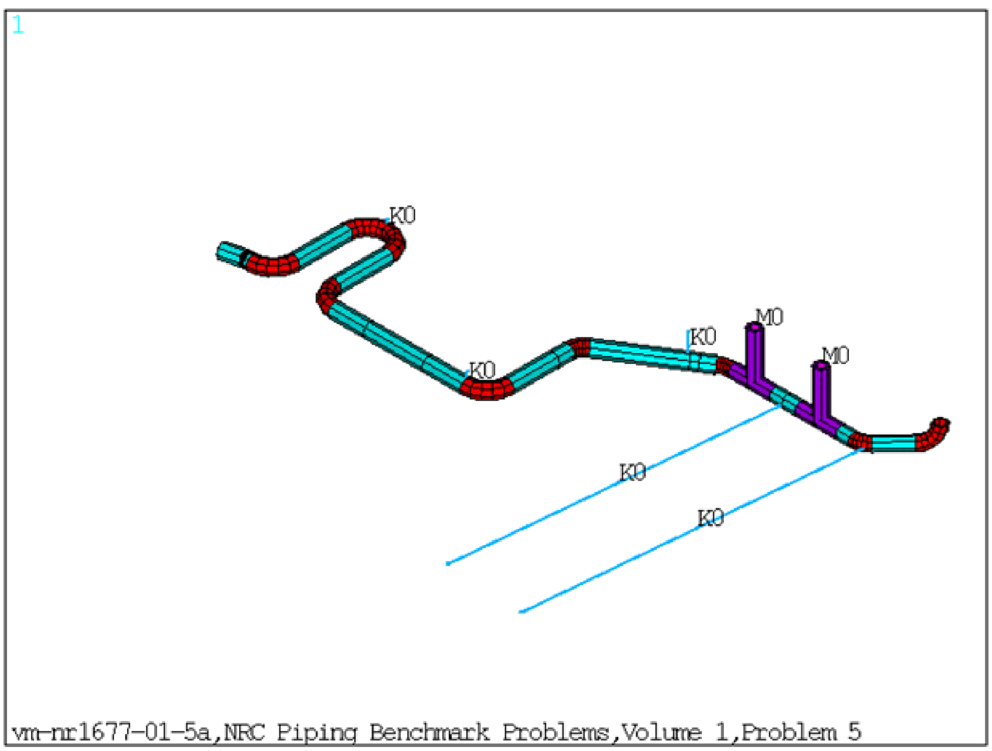
Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic Analysis of Uniform Support Motion Response Spectrum Method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 1, Pages 218-262.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Elastic straight pipe elements (PIPE16) Elastic curved pipe elements (PIPE18) Spring-Damper Element (COMBIN14) Structural Mass element (MASS21)
Input Listing:	vm-nr1677-1-5a-a.dat

Test Case

This benchmark problem is an in-line structure between two anchors. The system configuration is shown in Figure VM-NR1677-01-5-a.1: FE Model of the Benchmark Problem (p. 1055). The total mass of the system is represented by structural mass element (MASS21) specified at individual nodes. Modal and response spectrum analysis is performed on the piping model. Frequencies obtained from modal solve and the nodal/element solution obtained from spectrum solve are compared against reference results.

Figure VM-NR1677-01-5-a.1: FE Model of the Benchmark Problem



Material Properties	Geometric Properties	Loading
Pipe Elements: **Material ID 1:** $E = 2.62 \times 10^7$ psi Nu = 0.3 **Material ID 2:** $E = 7.56 \times 10^7$ psi Nu = 0.3 **Material ID 3:** $E = 2.52 \times 10^7$ psi Nu = 0.3 **Stiffness for Spring-Damper Elements (lb/in):** Since there are multiple Spring Supports at different locations, the Stiffness for the Spring Damper Elements are listed based on real constant set number. **Set 1:** $K = 1 \times 10^7$ **Set 2:** K = 450.0 **Set 3:** K = 800.0 **Set 4:** K = 600.0 **Mass Elements (lb-sec^2/in):** (Isotropic Mass) **Set 11:**	**Straight Pipe:** **Set 5:** Outer Diameter = 14.0 in Wall Thickness = 0.4380 in **Set 8:** Outer Diameter = 12.750 in Wall Thickness = 1.3120 in **Set 10:** Outer Diameter = 12.750 in Wall Thickness = 2.0 in **Bend Pipe:** **Set 6:** Outer Diameter = 14.0 in Wall Thickness = 0.4380 in Radius of Curvature = 21.0 in. **Set 7:** Outer Diameter = 12.750 in Wall Thickness = 0.3750 in Radius of Curvature = 18.0 in **Set 9:** Outer Diameter = 12.750 in Wall Thickness = 1.3120 in Radius of Curvature = 18.0 in	Acceleration Response Spectrum Curve defined by **FREQ** and **SV** commands.

Material Properties	Geometric Properties	Loading
Mass @ Node 4 = 2.8116 **Set 12:** Mass @ Node 7 = 4.0432 **Set 13:** Mass @ Node 10 = 2.5489 **Set 14:** Mass @ Node 11 = 1.4063 **Set 15:** Mass @ Node 12 = 1.4503 **Set 16:** Mass @ Node 13 = 1.8685 **Set 17:** Mass @ Node 15 = 2.8566 **Set 18:** Mass @ Node 18 = 2.0246 **Set 19:** Mass @ Node 22 = 6.7857 **Set 20:** Mass @ Node 24 = 0.63406 Mass @ Node 29 = 0.63406 **Set 21:** Mass @ Node 25 = 0.59369		

Material Properties	Geometric Properties	Loading
Set 22: Mass @ Node 27 = 6.95390 **Set 23:** Mass @ Node 31 = 3.73960		

Results Comparison

Table VM-NR1677-01-5-a.1: Frequencies Obtained from Modal Solution

Mode	Target	Mechanical APDL	Ratio
1	4.036	4.035	1.000
2	4.257	4.257	1.000
3	9.116	9.115	1.000
4	11.19	11.187	1.000
5	17.11	17.106	1.000
6	18.17	18.171	1.000
7	22.38	22.375	1.000
8	27.19	27.193	1.000
9	28.01	28.011	1.000
10	37.98	37.976	1.000
11	40.97	40.968	1.000

Table VM-NR1677-01-5-a.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node7	0.0976	0.0981	1.005
UY at node13	0.0601	0.0614	1.022
UZ at node10	0.0466	0.047	1.008
ROTX at node14	0.0004	0.0004	1.015
ROTY at node6	0.0011	0.0011	1.005
ROTZ at node8	0.0002	0.0002	1.029

Table VM-NR1677-01-5-a.3: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	473.600	477.753	1.009

Result	Target	Mechanical APDL	Ratio
VY(I)	120.900	123.832	1.024
VZ(I)	463.600	475.143	1.025
TX(I)	3979.000	4100.777	1.031
MY(I)	52390.000	52745.642	1.007
MZ(I)	9741.000	10003.363	1.027
PX(J)	473.600	477.753	1.009
VY(J)	120.900	123.832	1.024
VZ(J)	403.600	475.143	1.177
TX(J)	3479.000	4100.777	1.179
MY(J)	44110.000	44355.237	1.006
MZ(J)	7434.000	7639.033	1.028
Element 31			
PX(I)	525.900	576.546	1.096
VY(I)	233.800	256.697	1.098
VZ(I)	497.200	507.714	1.021
TX(I)	15180.000	15744.687	1.037
MY(I)	11900.000	13365.014	1.123
MZ(I)	7325.000	7246.545	0.989
PX(J)	525.900	576.546	1.096
VY(J)	233.800	256.697	1.098
VZ(J)	497.200	507.714	1.021
TX(J)	15180.000	15744.687	1.037
MY(J)	11900.000	11974.064	1.006
MZ(J)	7326.000	7719.677	1.054
Element 20			
PX(I)	418.400	423.098	1.011
VY(I)	262.600	247.341	0.942
VZ(I)	215.400	238.600	1.108
TX(I)	9940.000	10477.617	1.054
MY(I)	23180.000	23160.617	0.999
MZ(I)	12000.000	11999.284	1.000
PX(J)	316.800	322.541	1.018
VY(J)	215.400	247.341	1.148
VZ(J)	346.200	362.396	1.047
TX(J)	15060.000	15407.310	1.023
MY(J)	22180.000	22248.102	1.003

Result	Target	Mechanical APDL	Ratio
MZ(J)	4918.000	4876.276	0.992

Note

PX (I) and PX (J) = Section axial force at node I and J.

VY (I) and VY (J) = Section shear forces along Y direction at node I and J.

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J.

TX (I) and TX (J) = Section torsional moment at node I and J.

MY (I) and MY (J) = Section bending moments along Y direction at node I and J.

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J.

The element forces and moments along Y and Z directions are flipped between Mechanical APDL and NRC results.

VM-NR1677-01-6-a: NUREG/CR-1677: Volume 1, Benchmark Problem No. 6

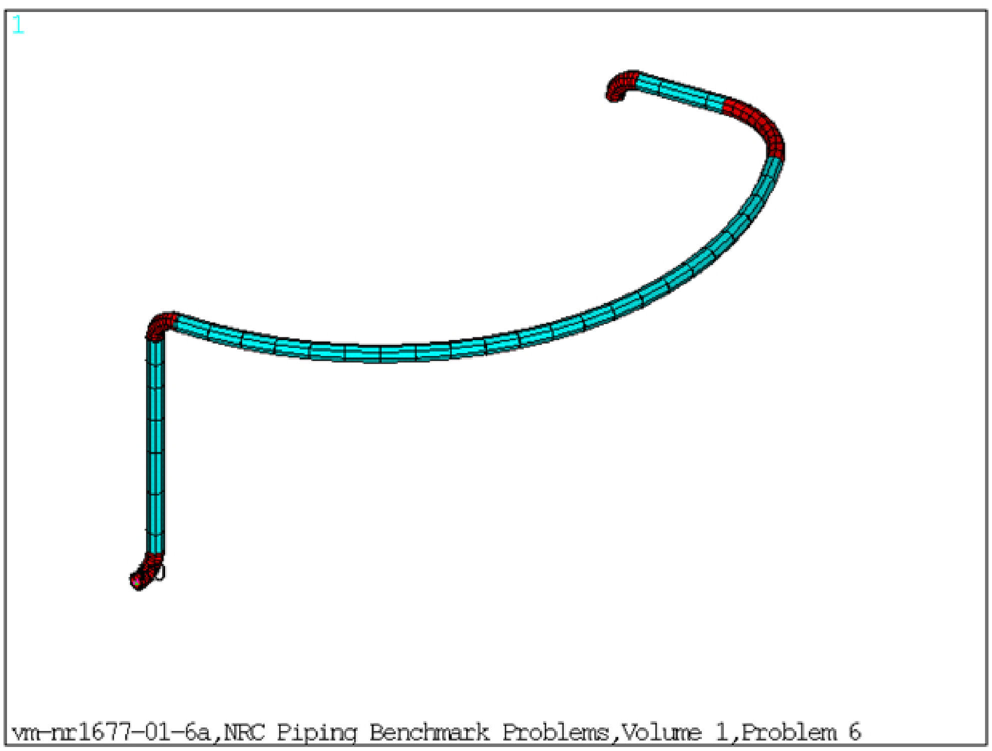
Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic Analysis of Uniform Support Motion Response Spectrum Method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 2, Pages 48-80.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Elastic straight pipe elements (PIPE16) Elastic curved pipe elements (PIPE18) Spring-Damper Element (COMBIN14) Structural Mass element (MASS21)
Input Listing:	vm-nr1677-1-6a-a.dat

Test Case

This benchmark problem contains three-dimensional multi-branched piping systems (refer to Figure VM-NR1677-01-6-a.1: FE Model of the Benchmark Problem (p. 1061)). The total mass of the system is represented by structural mass element (MASS21) specified at individual nodes. Modal and response spectrum analysis is performed on the piping model. Frequencies obtained from modal solve and the nodal/element solution obtained from spectrum solve are compared against reference results. The NUREG intermodal/interspatial results are used for comparison.

Figure VM-NR1677-01-6-a.1: FE Model of the Benchmark Problem



Material Properties	Geometric Properties	Loading
Pipe Elements: **Material ID 1:** E = 2.99 x 10^8 psi Nu = 0.3 **Stiffness for Spring-Damper Elements (lb/in):** Since there are multiple Spring Supports at different locations, the Stiffness for the Spring Damper Elements are listed based on real constant set number. **Set 101:** K= 0.1 x 10^{20} **Set 102:** K= 0.1 x 10^7 **Set 103:** K= 0.25 x 10^6 **Set 104:** K= 0.2 x 10^7 **Set 105:** K= 0.45 x 10^6 **Set 106:** K= 0.8 x 10^6 **Set 107:** K= 0.1 x 10^{10} **Set 108:** K= 0.1 x 10^{12}	**Straight Pipe Elements:** **Set 6:** Outer Diameter = 30.0 in Wall Thickness = 0.85 in **Set 8:** Outer Diameter = 32.0 in Wall Thickness = 0.905 in **Bend Pipe Elements:** **Set 7:** Outer Diameter = 30.0 in Wall Thickness = 0.85 in Radius of Curvature = 45.0 in **Set 9:** Outer Diameter = 32.0 in Wall Thickness = 0.905 in Radius of Curvature = 45.0 in **Set 10:** Outer Diameter = 30.0 in Wall Thickness = 0.85 in Radius of Curvature = 150 in	Acceleration Response Spectrum Curve defined by **FREQ** and **SV** commands.

Material Properties	Geometric Properties	Loading
Mass Elements (lb-sec^2/in): (Isotropic Mass) **Set 11:** Mass @ Node 5 = 9.925 **Set 12:** Mass @ Node 6 = 5.453 **Set 13:** Mass @ Node 7 = 4.888 **Set 14:** Mass @ Node 8 = 5.888 **Set 15:** Mass @ Node 10 = 5.373 **Set 16:** Mass @ Node 12 = 3.95 **Set 17:** Mass @ Node 13 = 2.43 **Set 18:** Mass @ Node 15 = 3.941 **Set 19:** Mass @ Node 17 = 7.6092 Mass @ Node 19 = 7.6092 **Set 20:**		

Material Properties	Geometric Properties	Loading
Mass @ Node 21 = 7.612 **Set 21:** Mass @ Node 23 = 7.6111 Mass @ Node 25 = 7.6111 Mass @ Node 27 = 7.6111 Mass @ Node 29 = 7.6111 Mass @ Node 31 = 7.6111 Mass @ Node 33 = 7.6111 **Set 22:** Mass @ Node 35 = 7.601 **Set 23:** Mass @ Node 37 = 10.293 **Set 24:** Mass @ Node 38 = 7.518 **Set 25:** Mass @ Node 40 = 3.877 **Set 26:** Mass @ Node 41 = 10.528		

Results Comparison

Table VM-NR1677-01-6-a.1: Frequencies Obtained from Modal Solution:

Mode	Target	Mechanical APDL	Ratio
1	6.391	6.391	1.000
2	9.993	9.993	1.000
3	13.270	13.274	1.000

Mode	Target	Mechanical APDL	Ratio
4	14.490	14.484	1.000
5	15.330	15.327	1.000
6	17.500	17.499	1.000
7	19.090	19.090	1.000
8	19.620	19.623	1.000
9	21.440	21.436	1.000
10	28.710	28.707	1.000
11	29.860	29.867	1.000
12	31.480	31.484	1.000
13	32.010	32.009	1.000
14	36.370	36.365	1.000
15	40.980	40.980	1.000
16	41.370	41.367	1.000
17	47.390	47.391	1.000
18	49.770	49.765	1.000
19	50.130	50.123	1.000
20	52.930	52.928	1.000
21	56.900	56.898	1.000
22	58.510	58.506	1.000
23	67.470	67.464	1.000
24	70.460	70.457	1.000
25	75.410	75.405	1.000
26	79.180	79.179	1.000
27	80.740	80.738	1.000
28	86.110	86.099	1.000
29	88.280	88.280	1.000
30	92.740	92.730	1.000
31	99.360	99.353	1.000

Table VM-NR1677-01-6-a.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node33	0.0236	0.0236	0.999
UYat node39	0.0894	0.0894	1.000
UZ at node38	0.0151	0.0151	0.999
ROTX at node37	0.0003	0.0003	1.000
ROTY at node37	0.0001	0.0001	0.999

Result Node	Target	Mechanical APDL	Ratio
ROTZ at node41	0.0003	0.0003	1.000

Table VM-NR1677-01-6-a.3: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	1171	1058.375	0.904
VY(I)	2398	2293.319	0.956
VZ(I)	1265	1181.920	0.934
TX(I)	68260	63128.296	0.925
MY(I)	48070	46262.894	0.962
MZ(I)	91740	84887.397	0.925
PX(J)	1171	1058.375	0.904
VY(J)	2398	2293.319	0.956
VZ(J)	1265	1181.920	0.934
TX(J)	68260	63128.296	0.925
MY(J)	46640	44930.270	0.963
MZ(J)	89260	82495.914	0.924
Element 44			
PX(I)	1749.000	1742.686	0.996
VY(I)	1990.000	1966.478	0.988
VZ(I)	946.500	928.701	0.981
TX(I)	100400.000	100095.784	0.997
MY(I)	132700.000	132608.345	0.999
MZ(I)	165900.000	165698.922	0.999
PX(J)	1749.000	1742.686	0.996
VY(J)	1990.000	1966.478	0.988
VZ(J)	946.500	928.701	0.981
TX(J)	100400.000	100095.784	0.997
MY(J)	132700.000	132612.979	0.999
MZ(J)	165900.000	165716.979	0.999
Element 37			
PX(I)	682.900	666.336	0.976
VY(I)	258.100	250.243	0.970
VZ(I)	1262.700	1257.777	0.996
TX(I)	92360.000	92342.330	1.000

Result	Target	Mechanical APDL	Ratio
MY(I)	49120.000	48078.085	0.979
MZ(I)	108700.000	108509.140	0.998
PX(J)	1187.000	1177.966	0.992
VY(J)	258.100	250.243	0.970
VZ(J)	804.200	796.851	0.991
TX(J)	19480.000	19308.964	0.991
MY(J)	78220.000	78152.238	0.999
MZ(J)	134100.000	134143.972	1.000

Note

PX (I) and PX (J) = Section axial force at node I and J.

VY (I) and VY (J) = Section shear forces along Y direction at node I and J.

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J.

TX (I) and TX (J) = Section torsional moment at node I and J.

MY (I) and MY (J) = Section bending moments along Y direction at node I and J.

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J.

The element forces and moments along Y and Z directions are flipped between Mechanical APDL and NRC results.

VM-NR1677-01-7-a: NUREG/CR-1677: Volume 1, Benchmark Problem No. 7

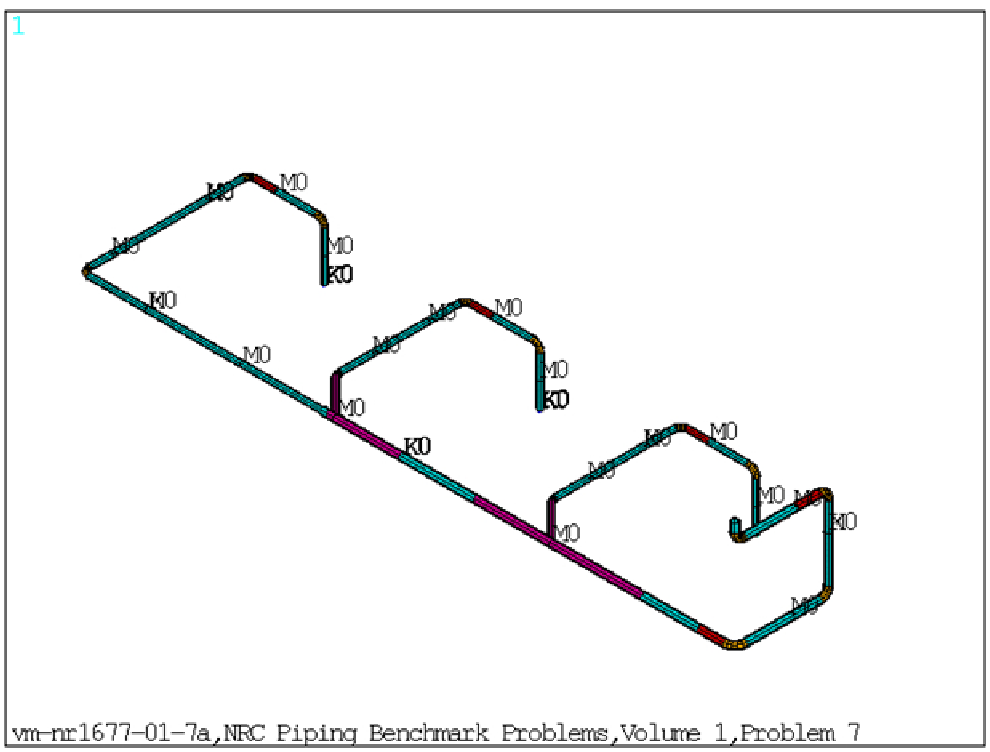
Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic Analysis of Uniform Support Motion Response Spectrum Method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 1, Pages 328-402
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Elastic straight pipe elements (PIPE16) Elastic curved pipe elements (PIPE18) Spring-Damper Element (COMBIN14) Structural Mass element (MASS21)
Input Listing:	vm-nr1677-1-7a-a.dat

Test Case

This benchmark problem is a multi-branched configuration containing four anchor points. The problem represents an actual piping system as shown in Figure VM-NR1677-01-7-a.1: FE Model of the Benchmark Problem (p. 1069). Modal and response spectrum analysis is performed on the piping model. The input excitation consists of two distinct sets of excitation spectra. Frequencies obtained from modal solve and the nodal/element solution obtained from spectrum solve are compared against reference results.

Figure VM-NR1677-01-7-a.1: FE Model of the Benchmark Problem



Material Properties	Geometric Properties	Loading
Pipe Elements: **Material ID 1:** E = 2.7 x 10^7 psi Nu = 0.3 **Material ID 2:** E = 8.1 x 10^7 psi Nu = 0.3 **Stiffness for Spring –Damper Elements (lb/in):** Since there are multiple Spring Supports at different locations, the Stiffness for the Spring Damper Elements are listed based on real constant set number. **Set 1:** K = 1.0 **Set 23:** K = 1.0 x 10^9 **Set 24:** K = 1.0 x 10^{11} **Mass Elements (lb-sec^2/in):** (Isotropic Mass) **Set 6:** Mass @ Node 4 = 0.47179 **Set 7:** Mass @ Node 7 = 0.37604 **Set 8:**	**Straight Pipe:** **Set 2:** Outer Diameter = 4.5 in Wall Thickness = 0.337 in **Set 4:** Outer Diameter = 3.5 in Wall Thickness = 0.3 in **Bend Pipe:** **Set 3:** Outer Diameter = 4.5 in Wall Thickness = 0.337 in Radius of Curvature = 6.0 in **Set 5:** Outer Diameter = 3.5 in Wall Thickness = 0.3 in Radius of Curvature = 4.5 in	Acceleration response spectrum curve defined by **SV** and **FREQ** commands.

Material Properties	Geometric Properties	Loading
Mass @ Node 10 = 0.40399 **Set 9:** Mass @ Node 13 = 0.35016 **Set 10:** Mass @ Node 14 = 0.22179 **Set 11:** Mass @ Node 15 = 0.33799 Mass @ Node 34 = 0.33799 **Set 12:** Mass @ Node 19 = 0.14441 Mass @ Node 33 = 0.14441 **Set 13:** Mass @ Node 20 = 0.26889 **Set 14:** Mass @ Node 23 = 0.29011 Mass @ Node 37 = 0.29011 **Set 15:** Mass @ Node 26 = 0.12733 Mass @ Node 40 = 0.12733 **Set 16:** Mass @ Node 16 = 0.22386 **Set 17:**		

Material Properties	Geometric Properties	Loading
Mass @ Node 28 = 0.20990 **Set 18:** Mass @ Node 29 = 0.28620 **Set 19:** Mass @ Node 43 = 0.19358 **Set 20:** Mass @ Node 47 = 0.18737 Mass @ Node 44 = 0.18737 **Set 21:** Mass @ Node 48 = 0.31366 **Set 22:** Mass @ Node 51 = 0.29736		

Results Comparison

Table VM-NR1677-01-7-a.1: Frequencies Obtained from Modal Solution

Mode	Target	Mechanical APDL	Ratio
1	5.034	5.033	1.000
2	7.813	7.812	1.000
3	8.193	8.192	1.000
4	8.977	8.977	1.000
5	9.312	9.312	1.000
6	9.895	9.895	1.000
7	13.220	13.221	1.000
8	14.960	14.956	1.000
9	15.070	15.066	1.000
10	17.750	17.754	1.000
11	18.210	18.208	1.000
12	22.900	22.899	1.000

Mode	Target	Mechanical APDL	Ratio
13	25.020	25.022	1.000
14	25.850	25.854	1.000
15	26.940	26.941	1.000
16	28.130	28.131	1.000
17	30.300	30.297	1.000
18	35.220	35.218	1.000
19	37.100	37.095	1.000
20	42.610	42.612	1.000
21	44.420	44.415	1.000
22	48.090	48.086	1.000

Table VM-NR1677-01-7-a.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node8	0.0847	0.0847	1.000
UY at node8	0.2434	0.2434	1.000
UZ at node11	0.3421	0.3421	1.000
ROTX at node7	0.0058	0.0058	1.000
ROTY at node14	0.0021	0.0021	1.000
ROTZ at node50	0.0012	0.0012	1.000

Table VM-NR1677-01-7-a.3: Element Forces and Moments Obtained from Spectrum Solve

Res-ult	Target	Mechanical AP-DL	Ra-tio
Element 1			
PX(I)	236.400	236.401	1.000
VY(I)	80.7200	80.574	0.998
VZ(I)	260.5000	266.003	1.021
TX(I)	4947.000	4938.015	0.998
MY(I)	22170.000	22128.503	0.998
MZ(I)	2106.000	2102.161	0.998
PX(J)	236.000	236.401	1.002
VY(J)	80.720	80.574	0.998
VZ(J)	266.500	266.003	0.998
TX(J)	4947.000	4938.015	0.998
MY(J)	20590.000	20548.191	0.998
MZ(J)	1656.000	1653.184	0.998

Result	Target	Mechanical APDL	Ratio
Element 38			
PX(I)	50.360	50.222	0.997
VY(I)	27.620	27.588	0.999
VZ(I)	28.530	26.563	0.931
TX(I)	482.000	473.398	0.982
MY(I)	96.690	92.848	0.960
MZ(I)	1625.000	1640.961	1.010
PX(J)	50.360	50.222	0.997
VY(J)	27.620	27.588	0.999
VZ(J)	28.530	26.563	0.931
TX(J)	462.000	473.398	1.025
MY(J)	428.000	420.239	0.982
MZ(J)	1796.000	1790.638	0.997
Element 49			
PX(I)	94.270	92.742	0.984
VY(I)	35.290	34.212	0.969
VZ(I)	26.370	25.380	0.962
TX(I)	235.400	230.264	0.978
MY(I)	2491.000	2447.900	0.983
MZ(I)	446.600	441.965	0.990
PX(J)	26.070	25.380	0.974
VY(J)	35.290	34.212	0.969
VZ(J)	94.270	92.742	0.984
TX(J)	469.200	457.142	0.974
MY(J)	2176.000	2133.047	0.980
MZ(J)	134.000	136.211	1.017

Note

PX (I) and PX (J) = Section axial force at node I and J.

VY (I) and VY (J) = Section shear forces along Y direction at node I and J.

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J.

TX (I) and TX (J) = Section torsional moment at node I and J.

MY (I) and MY (J) = Section bending moments along Y direction at node I and J.

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J.

The element forces and moments along Y and Z directions are flipped between Mechanical APDL and NRC results.

VM-NR1677-02-1-a: NUREG/CR-1677: Volume 2, Benchmark Problem No. 1

Overview

Reference:	NUREG/CR-1677 Volume II Piping Benchmark Problems, Dynamic Analysis Independent Support Motion Response Spectrum Method, P. Bezler, M. Subudhi & M. Hartzman of Brookhaven National Laboratory, prepared for the U.S. Nuclear Regulatory Commission, August 1985, Problem 1, pages 18-76.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Elastic straight pipe elements (PIPE16) Elastic curved pipe elements (PIPE18) Spring-Damper Element (COMBIN14)
Input Listing:	vm-nr1677-2-1a-a.dat vm-nr1677-2-1b-a.dat vm-nr1677-2-1c-a.dat

Test Case

This benchmark problem simulates a 3.5 inch diameter water line extending between two elevations and having two anchors and numerous intermediate supports. The system configuration is shown in Figure VM-NR1677-02-1-a.1: FE Model of the Benchmark Problem (p. 1078). Modal and response spectrum analysis is performed on the piping model. Each solution has a fifteen frequency approximation with appropriate spectra and spectrum weighting factors of 1.0, 0.667, and 0.0 in the X, Y, and Z global directions respectively. Response spectrum solutions are done for three cases:

- Case 1: Envelope spectrum excitation
- Case 2: Independent support excitation with SRSS combination
- Case 3: Independent support excitation with absolute sum combination

Frequencies obtained from modal solve and the nodal/element solution obtained from spectrum solve are compared against reference results.

Figure VM-NR1677-02-1-a.1: FE Model of the Benchmark Problem

Material Properties	Geometric Properties	Loading
Pipe Elements: **Material ID 1:** E = 0.258 x 10^8 psi Nu = 0.3 G = 0.992x 10^7 psi Density =1.042868 x 10^{-3} lb-sec^2/in^4 **Stiffness for Spring-Damper Elements (lb/in):** Since there are multiple Spring Supports at different locations, the Stiffness for the Spring Damper Elements are listed based on real constant set number. **Set 3:** K = 0.2 x 10^8 **Set 4:**	**Straight Pipe:** **Set 1:** Outer Diameter = 3.5 in Wall Thickness = 0.216 in **Bend Pipe:** **Set 2:** Outer Diameter = 3.5 in Wall Thickness = 0.216 in Radius of Curvature = 48.003 in	**Case 1:** Acceleration Response Spectrum Curve defined by **FREQ** and **SV** commands. **Case 2:** Acceleration Response Spectrum Curve defined by **SPVAL** and **SPFREQ** commands. **Case 3:** Acceleration Response Spectrum Curve defined by **SPVAL** and **SPFREQ** commands.

Material Properties	Geometric Properties	Loading
$K = 0.2 \times 10^8$ **Set 5:** $K = 0.2 \times 10^8$ **Set 6:** $K = 0.2 \times 10^5$ **Set 7:** $K = 0.2 \times 10^5$		

Results Comparison

Table VM-NR1677-02-1-a.1: Frequencies Obtained from Modal Solution:

Mode	Target	Mechanical APDL	Ratio
1	6.042	6.0476	1.000
2	6.256	6.2692	1.000
3	7.760	7.7593	1.000
4	8.943	8.9227	1.000
5	12.444	12.4419	1.000
6	12.830	12.8300	1.000
7	14.303	14.2974	1.000
8	15.486	15.4842	1.000
9	16.371	16.3691	1.000
10	18.543	18.5402	1.000
11	19.499	19.4966	1.000
12	23.243	23.2237	1.000
13	24.105	24.0804	1.000
14	32.636	32.6346	1.000
15	33.837	33.7491	1.000

Case 1: Envelope Spectrum Excitation

Table VM-NR1677-02-1-a.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node5	0.0586	0.0581	0.992
UY at node33	0.1127	0.1121	0.994

Result Node	Target	Mechanical APDL	Ratio
UZ at node15	0.0103	0.0102	0.994
ROTX at node32	0.0015	0.0015	1.008
ROTY at node32	0.0011	0.0011	1.009
ROTZ at node5	0.0013	0.0013	1.002

Table VM-NR1677-02-1-a.3: Reaction forces Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
FY at node38	107.000	108.032	1.010
FX at node40	234.000	237.377	1.014
FY at node46	78.000	77.756	0.997
FY at node50	89.000	89.503	1.006
FZ at node53	56.000	55.954	0.999

Table VM-NR1677-02-1-a.4: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 35			
PX(I)	119.900	120.779	1.007
VY(I)	56.630	55.832	0.986
VZ(I)	55.950	55.953	1.000
TX(I)	595.800	600.438	1.008
MY(I)	675.000	662.530	0.982
MZ(I)	606.200	600.380	0.990
PX(J)	119.900	120.779	1.007
VY(J)	56.630	55.832	0.986
VZ(J)	55.950	55.953	1.000
TX(J)	595.800	600.438	1.008
MY(J)	2685.000	2684.495	1.000
MZ(J)	3329.000	3294.761	0.990
Element 27			
PX(I)	183.700	183.104	0.997

Result	Target	Mechanical APDL	Ratio
VY(I)	26.740	26.836	1.004
VZ(I)	120.400	118.901	0.988
TX(I)	265.800	261.024	0.982
MY(I)	1308.000	1310.954	1.002
MZ(I)	398.200	387.454	0.973
PX(J)	120.400	118.922	0.988
VY(J)	26.740	26.836	1.004
VZ(J)	183.700	183.091	0.997
TX(J)	1123.000	1131.198	1.007
MY(J)	3095.000	3099.150	1.001
MZ(J)	1496.000	1497.427	1.001

Case 2: Independent Support Excitation with SRSS Combination

Table VM-NR1677-02-1-a.5: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node5	0.0783	0.0777	0.992
UY at node32	0.1899	0.1821	0.959
UZ at node32	0.1987	0.1915	0.964
ROTX at node5	0.0015	0.0015	1.000
ROTY at node30	0.0022	0.0022	0.967
ROTZ at node30	0.0021	0.002	0.956

Table VM-NR1677-02-1-a.6: Reaction forces Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
FX at node37	86.000	87.554	1.018
FX at node43	34.000	33.854	0.996
FX at node47	53.000	53.104	1.002
FY at node50	95.000	94.883	0.999

Result Node	Target	Mechanical APDL	Ratio
FZ at node53	74.000	73.685	0.996

Table VM-NR1677-02-1-a.7: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	92.710	94.458	1.019
VY(I)	86.430	87.553	1.013
VZ(I)	81.500	82.851	1.017
TX(I)	1318.000	1307.260	0.992
MY(I)	2885.000	2869.256	0.995
MZ(I)	2775.000	2779.451	1.002
PX(J)	92.710	94.458	1.019
VY(J)	86.430	87.553	1.013
VZ(J)	81.500	82.851	1.017
TX(J)	1318.000	1307.260	0.992
MY(J)	2041.000	2039.996	1.000
MZ(J)	1907.00	1900.633	0.997
Element 35			
PX(I)	84.200	89.526	1.063
VY(I)	66.720	65.634	0.984
VZ(I)	74.270	73.684	0.992
TX(I)	431.300	449.133	1.041
MY(I)	1169.000	1134.734	0.971
MZ(I)	1119.000	1072.024	0.958
PX(J)	84.200	89.526	1.063
VY(J)	66.720	65.634	0.984
VZ(J)	74.270	73.684	0.992
TX(J)	431.300	449.133	1.041
MY(J)	4724.000	4634.807	0.981
MZ(J)	4484.000	4376.956	0.976
Element 27			
PX(I)	121.700	129.333	1.063
VY(I)	30.010	30.084	1.002
VZ(I)	90.720	92.932	1.024

Result	Target	Mechanical APDL	Ratio
TX(I)	556.200	536.885	0.965
MY(I)	1036.000	1063.432	1.026
MZ(I)	989.200	945.928	0.956
PX(J)	90.720	92.946	1.025
VY(J)	30.010	30.084	1.002
VZ(J)	121.700	129.323	1.063
TX(J)	755.700	813.088	1.076
MY(J)	2681.000	2751.404	1.026
MZ(J)	1948.000	1928.135	0.990

Case 3: Independent Support Excitation with Absolute Sum Combination

Table VM-NR1677-02-1-a.8: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node5	0.0908	0.0907	0.999
UY at node32	0.2634	0.2533	0.962
UZ at node32	0.2759	0.2668	0.967
ROTX at node28	0.0015	0.0015	0.97
ROTY at node30	0.0031	0.003	0.97
ROTZ at node30	0.0028	0.0027	0.959

Table VM-NR1677-02-1-a.9: Reaction forces Obtained from Spectrum Solution

Result Node	Target	Mechanical APDL	Ratio
FX at node37	117.000	117.844	1.007
FY at node38	128.000	129.484	1.012
FZ at node39	109.000	110.605	1.015
FY at node40	278.000	281.675	1.013
FZ at node41	100.000	100.743	1.007

Result Node	Target	Mechanical APDL	Ratio
FX at node42	113.000	114.585	1.014
FZ at node43	44.000	44.200	1.005
FX at node 44	65.000	70.472	1.084
FZ at node45	35.000	34.880	0.997
FX at node46	63.000	71.970	1.142
FZ at node47	72.000	72.137	1.002
FX at node48	185.000	187.520	1.014
FY at node49	204.000	213.458	1.046
FZ at node50	131.000	130.683	0.998
FX at node51	116.000	121.992	1.052
FY at node52	92.000	90.226	0.981
FZ at node53	103.000	101.880	0.989

Table VM-NR1677-02-1-a.10: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	127.700	129.483	1.014
VY(I)	116.500	117.843	1.012
VZ(I)	109.000	110.604	1.015
TX(I)	1522.000	1520.961	0.999
MY(I)	3548.000	3580.852	1.009
MZ(I)	3503.000	3521.743	1.005
PX(J)	127.700	129.483	1.014
VY(J)	116.500	117.843	1.012
VZ(J)	109.000	110.604	1.015
TX(J)	1522.000	1520.961	0.999
MY(J)	2450.000	2462.909	1.005

Result	Target	Mechanical APDL	Ratio
MZ(J)	2316.000	2320.998	1.002
Element 35			
PX(I)	115.600	121.991	1.055
VY(I)	91.810	90.225	0.983
VZ(I)	102.600	101.879	0.993
TX(I)	582.500	601.775	1.033
MY(I)	1615.000	1572.491	0.974
MZ(I)	1544.000	1482.208	0.960
PX(J)	115.600	121.991	1.055
VY(J)	91.810	90.225	0.983
VZ(J)	102.600	101.879	0.993
TX(J)	582.500	601.775	1.033
MY(J)	6548.000	6438.979	0.983
MZ(J)	6198.000	6052.192	0.976
Element 27			
PX(I)	163.900	172.478	1.052
VY(I)	41.340	41.401	1.001
VZ(I)	123.300	125.815	1.020
TX(I)	769.100	744.446	0.968
MY(I)	1399.000	1427.547	1.020
MZ(I)	1365.000	1309.761	0.960
PX(J)	123.300	125.833	1.021
VY(J)	41.340	41.401	1.001
VZ(J)	163.900	172.464	1.052
TX(J)	1034.000	1103.573	1.067
MY(J)	3666.000	3740.442	1.020
MZ(J)	2692.000	2664.208	0.990

Note

PX (I) and PX (J) = Section axial force at node I and J.

VY (I) and VY (J) = Section shear forces along Y direction at node I and J.

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J.

TX (I) and TX (J) = Section torsional moment at node I and J.

MY (I) and MY (J) = Section bending moments along Y direction at node I and J.

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J.

The element forces and moments along Y and Z directions are flipped between Mechanical APDL and NRC results.

VM-NR1677-02-2-a: NUREG/CR-1677: Volume 2, Benchmark Problem No. 2

Overview

Reference:	NUREG/CR-1677 Volume II Piping Benchmark Problems, Dynamic Analysis Independent Support Motion Response Spectrum Method, P. Bezler, M. Subudhi & M. Hartzman of Brookhaven National Laboratory, prepared for the U.S. Nuclear Regulatory Commission, August 1985, Problem 2, pages 77-137.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Elastic straight pipe elements (PIPE16) Elastic curved pipe elements (PIPE18) Spring-Damper Element (COMBIN14) Structural Mass Element (MASS21)
Input Listing:	vm-nr1677-2-2a-a.dat vm-nr1677-2-2b-a.dat vm-nr1677-2-2c-a.dat

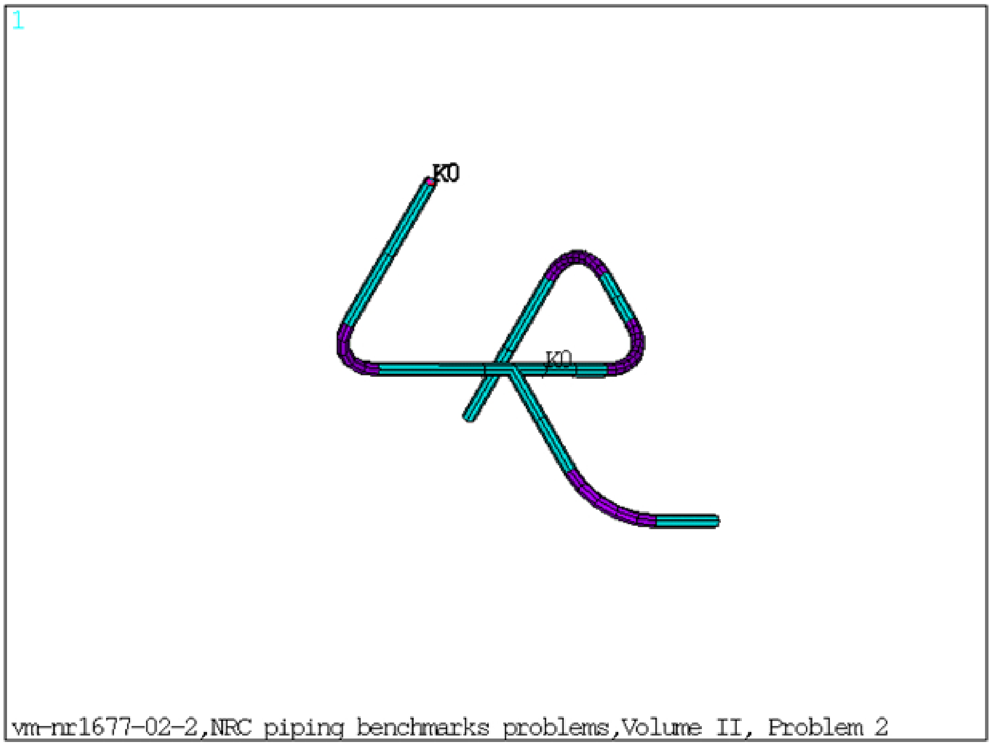
Test Case

This benchmark problem is a three-branch configuration as shown in Figure VM-NR1677-02-2-a.1: FE model of the Benchmark Problem (p. 1088). The support elements were divided into four groups corresponding to four distinct excitation sets. Modal and response spectrum analysis is performed on the model. Each solution had a twenty-five frequency approximation with various spectrum weighting factors. Response spectrum solutions are done for three cases:

- Case 1: Envelope spectrum excitation
- Case 2: Independent support excitation with SRSS combination
- Case 3: Independent support excitation with absolute sum combination

Frequencies obtained from modal solve and the nodal/element solution obtained from spectrum solve are compared against reference results.

Figure VM-NR1677-02-2-a.1: FE model of the Benchmark Problem



Material Properties	Geometric Properties	Loading
Pipe Element: **Material ID 1:** E = 0.240 x 10^8 psi Nu = 0.3 G = 0.923 x 10^7 psi **Material ID 2:** E = 0.240 x 10^8 psi Nu = 0.3 G = 9230769.230 psi **Mass Element (lb-sec^2/in):** (Isotropic Mass) **Set 6:** Mass @ Node 18 = 1.518	**Straight Pipe:** **Set 1:** Outer Diameter = 7.288 in Wall Thickness = 0.241 in **Set 2:** Outer Diameter = 7.288 in Wall Thickness = 0.241 in Radius of Curvature = 36.3 in	Internal Pressure = 350 psi is applied internally on PIPE elements. **Case 1:** Acceleration Response Spectrum Curve defined by **FREQ** and **SV** commands. **Case 2:** Acceleration Response Spectrum Curve defined by **SPVAL** and **SPFREQ** commands. **Case 3:** Acceleration Response Spectrum Curve defined by

Material Properties	Geometric Properties	Loading
Stiffness for Spring-Damper Elements (lb/in): Since there are multiple Spring Supports at different locations, the Stiffness for the Spring Damper Elements are listed based on real constant set number. **Set 3:** K = 0.1 x 10^5 **Set 4:** K = 0.1 x 10^9 **Set 5:** K = 0.1 x 10^{11}		**SPVAL** and **SPFREQ** commands.

Results Comparison

Table VM-NR1677-02-2-a.1: Frequencies Obtained from Modal Solution:

Mode	Target	Mechanical APDL	Ratio
1	9.360	9.1655	0.980
2	12.706	12.6533	1.000
3	15.377	15.1847	0.990
4	17.797	17.4952	0.980
5	21.603	21.2461	0.980
6	25.098	24.7136	0.980
7	32.035	31.771	0.990
8	38.069	37.7442	0.990
9	40.293	39.9244	0.990
10	48.898	48.2221	0.990
11	57.515	57.0146	0.990
12	61.500	61.0477	0.990
13	62.541	62.0268	0.990
14	69.348	68.4341	0.990
15	77.444	76.179	0.980
16	78.881	77.7516	0.990

Mode	Target	Mechanical APDL	Ratio
17	101.715	99.622	0.980
18	103.583	101.6221	0.980
19	107.966	106.1587	0.980
20	115.098	112.7788	0.980
21	135.244	132.6403	0.980
22	155.220	153.8602	0.990
23	160.601	158.8719	0.990
24	203.789	200.4281	0.980
25	209.925	206.9838	0.990

Case 1: Envelope Spectrum Excitation

Table VM-NR1677-02-2-a.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node14	0.0849	0.0913	1.075
UY at node8	0.0379	0.0393	1.037
UZ at node4	0.0907	0.0972	1.072
ROTX at node3	0.001	0.0011	1.073
ROTY at node7	0.0019	0.002	1.076
ROTZ at node17	0.0009	0.001	1.071

Table VM-NR1677-02-2-a.3: Reaction forces Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
FY at node23	65.000	64.858	0.998
FX at node26	446.000	448.117	1.005
FY at node28	164.000	165.698	1.010
FX at node33	378.000	381.136	1.008

Result Node	Target	Mechanical APDL	Ratio
FY at node34	192.000	193.067	1.006

Table VM-NR1677-02-2-a.4: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	64.960	64.858	0.998
VY(I)	90.500	93.048	1.028
VZ(I)	177.400	184.917	1.042
TX(I)	5110.000	5301.549	1.037
MY(I)	16350.000	17315.366	1.059
MZ(I)	7002.000	7418.061	1.059
PX(J)	64.960	64.858	0.998
VY(J)	90.500	93.048	1.028
VZ(J)	177.400	184.917	1.042
TX(J)	5110.000	5301.549	1.037
MY(J)	7138.000	7680.016	1.076
MZ(J)	3188.000	3382.535	1.061
Element 20			
PX(I)	245.100	246.391	1.005
VY(I)	191.600	193.067	1.008
VZ(I)	377.900	381.136	1.009
TX(I)	2314.000	2383.259	1.030
MY(I)	3823.000	4009.387	1.049
MZ(I)	3268.000	3271.878	1.001
PX(J)	245.100	246.391	1.005
VY(J)	191.600	193.067	1.008
VZ(J)	377.900	381.136	1.009
TX(J)	2314.000	2383.259	1.030
MY(J)	16600.000	17087.900	1.029
MZ(J)	11140.000	11205.551	1.006
Element 8			
PX(I)	446.300	461.294	1.034

Result	Target	Mechanical APDL	Ratio
VY(I)	32.560	33.799	1.038
VZ(I)	517.800	532.454	1.028
TX(I)	2967.000	3065.565	1.033
MY(I)	12020.000	12115.559	1.008
MZ(I)	798.600	804.853	1.008
PX(J)	664.800	686.096	1.032
VY(J)	32.560	33.799	1.038
VZ(J)	159.100	159.911	1.005
TX(J)	2021.000	2071.720	1.025
MY(J)	20520.000	20840.868	1.016
MZ(J)	2487.000	2574.882	1.035

Case 2: Independent Support Excitation with SRSS Combination

Table VM-NR1677-02-2-a.5: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node14	0.0530	0.0574	1.082
UY at node7	0.0242	0.0252	1.043
UZ at node4	0.0574	0.0619	1.078
ROTX at node3	0.0006	0.0007	1.08
ROTY at node7	0.0012	0.0013	1.082
ROTZ at node17	0.0006	0.0006	1.078

Table VM-NR1677-02-2-a.6: Reaction forces Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
FY at node23	46.000	46.533	1.012
FY at node28	98.000	99.526	1.016

Result Node	Target	Mechanical APDL	Ratio
FZ at node35	116.000	115.203	0.993

Table VM-NR1677-02-2-a.7: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	46.1600	46.5337	1.008
VY(I)	53.0500	54.7907	1.033
VZ(I)	112.9000	117.7437	1.043
TX(I)	3230.0000	3369.8260	1.043
MY(I)	10340.0000	11008.9986	1.065
MZ(I)	4209.0000	4485.8240	1.066
PX(J)	46.1600	46.5337	1.008
VY(J)	53.0500	54.7907	1.033
VZ(J)	112.9000	117.7437	1.043
TX(J)	3230.0000	3369.8260	1.043
MY(J)	4529.0000	4898.8517	1.082
MZ(J)	2005.0000	2141.7982	1.068
Element 20			
PX(I)	115.5000	115.2037	0.997
VY(I)	114.0000	115.4438	1.013
VZ(I)	103.2000	100.8049	0.977
TX(I)	1361.0000	1408.4573	1.035
MY(I)	2302.0000	2391.9304	1.039
MZ(I)	1960.0000	1974.6510	1.007
PX(J)	115.5	115.2037	0.997
VY(J)	114.00	115.4438	1.013
VZ(J)	103.200	100.8049	0.977
TX(J)	1361.00	1408.4573	1.035
MY(J)	4038.0000	4167.3920	1.032
MZ(J)	6632.0000	6706.0262	1.011
Element 8			
PX(I)	265.00	275.8397	1.041
VY(I)	22.82	23.8785	1.046

Result	Target	Mechanical APDL	Ratio
VZ(I)	327.2	338.6018	1.035
TX(I)	1884.00	1958.7920	1.04
MY(I)	7379.0000	7503.3873	1.017
MZ(I)	763.8000	766.6107	1.004
PX(J)	411.6000	427.9288	1.040
VY(J)	22.8200	23.8785	1.046
VZ(J)	89.0400	87.2679	0.98
TX(J)	1346.00	1384.6321	1.029
MY(J)	12880.00	13181.8828	1.023
MZ(J)	1569.00	1637.1861	1.043

Case 3: Independent Support Excitation with Absolute Sum Combination

Table VM-NR1677-02-2-a.8: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node14	0.0741	0.0797	1.076
UY at node8	0.0355	0.0369	1.039
UZ at node4	0.08	0.0858	1.072
ROTX at node3	0.0009	0.0010	1.074
ROTY at node7	0.0017	0.0018	1.076
ROTZ at node17	0.0008	0.0009	1.072

Table VM-NR1677-02-2-a.9: Reaction forces Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
FX at node1	76.000	78.580	1.03
FY at node1	70.000	69.809	1.00
FZ at node1	156.000	161.944	1.04
FZ at node7	607.000	629.228	1.04
FX at node9	350.000	352.638	1.01
FY at node11	184.000	187.426	1.02
FY at node 13	146.000	147.613	1.01

Result	Target	Mechanical APDL	Ratio
FX at node 15	301.000	305.961	1.02
FX at node17	45.000	46.520	1.03
FY at node17	169.000	171.561	1.02
FZ at node17	91.000	92.568	1.02
FX at node21	152.000	148.172	0.97
FY at node21	170.000	171.553	1.01
FZ at node21	158.000	156.957	0.99

Table VM-NR1677-02-2-a.10: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	69.61	69.809	1.003
VY(I)	76.39	78.580	1.029
VZ(I)	155.6	161.944	1.041
TX(I)	4498	4667.308	1.038
MY(I)	14380	15231.297	1.059
MZ(I)	5959	6310.483	1.059
PX(J)	69.61	69.809	1.003
VY(J)	76.39	78.580	1.029
VZ(J)	155.6	161.944	1.041
TX(J)	4498	4667.308	1.038
MY(J)	6317	6795.559	1.076
MZ(J)	2787	2964.103	1.064
Element 20			
PX(I)	157.6	156.957	0.996
VY(I)	169.9	171.554	1.01
VZ(I)	151.7	148.172	0.977
TX(I)	2041	2103.856	1.031
MY(I)	3192	3304.303	1.035
MZ(I)	2935	2946.545	1.004

Result	Target	Mechanical APDL	Ratio
PX(J)	157.6	156.957	0.996
VY(J)	169.9	171.554	1.01
VZ(J)	151.7	148.172	0.977
TX(J)	2041	2103.856	1.031
MY(J)	6079	6239.911	1.026
MZ(J)	9904	9984.300	1.008
Element 8			
PX(I)	368.6	382.363	1.037
VY(I)	33.77	35.351	1.047
VZ(I)	453.2	466.924	1.03
TX(I)	2643	2723.367	1.03
MY(I)	10310	10419.421	1.011
MZ(I)	1268	1273.659	1.004
PX(J)	571.7	591.776	1.035
VY(J)	33.77	35.351	1.047
VZ(J)	120	118.409	0.987
TX(J)	1937	1981.184	1.023
MY(J)	17940	18258.859	1.018
MZ(J)	2187	2268.179	1.037

Note

PX (I) and PX (J) = Section axial force at node I and J.

VY (I) and VY (J) = Section shear forces along Y direction at node I and J.

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J.

TX (I) and TX (J) = Section torsional moment at node I and J.

MY (I) and MY (J) = Section bending moments along Y direction at node I and J.

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J.

The element forces and moments along Y and Z directions are flipped between Mechanical APDL and NRC results.

VM-NR1677-02-3-a: NUREG/CR-1677: Volume 2, Benchmark Problem No. 3

Overview

Reference:	NUREG/CR-1677 Volume II Piping Benchmark Problems, Dynamic Analysis Independent Support Motion Response Spectrum Method, P. Bezler, M. Subudhi & M. Hartzman of Brookhaven National Laboratory, prepared for the U.S. Nuclear Regulatory Commission, August 1985, Problem 3, pages 138-243.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Elastic Straight Pipe Elements (PIPE16) Elastic Curved Pipe Elements (PIPE18) Spring-Damper Element (COMBIN14)
Input Listing:	vm-nr1677-2-3a-a.dat vm-nr1677-2-3b-a.dat vm-nr1677-2-3c-a.dat

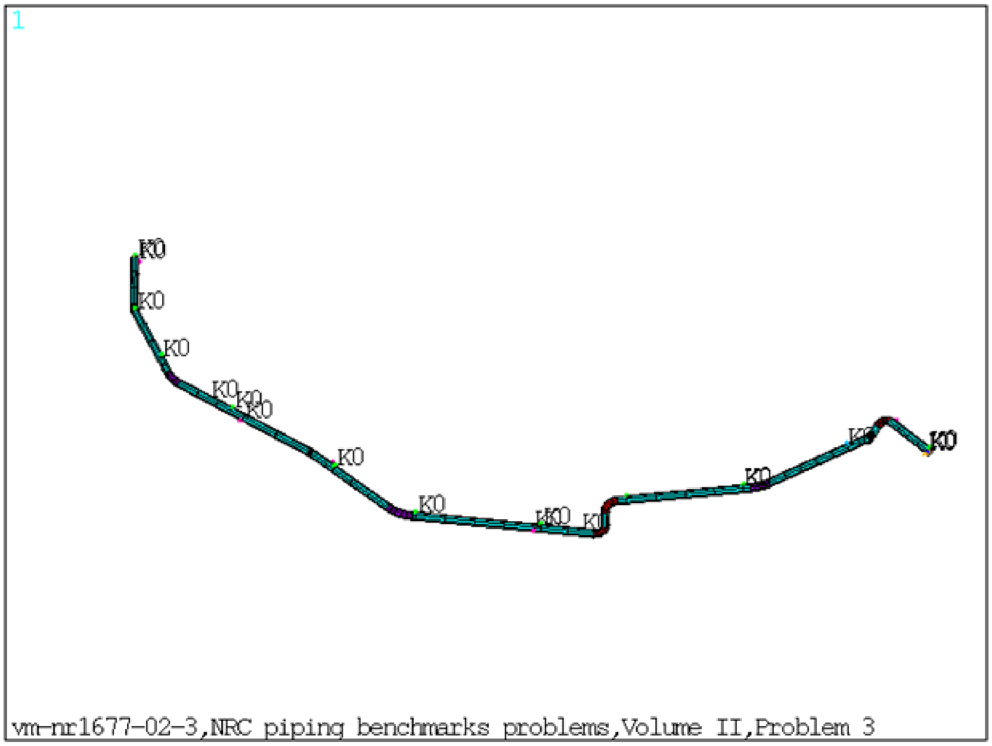
Test Case

This benchmark problem is a two-anchor configuration simulating safety injection piping of a nuclear power plant as shown in Figure VM-NR1677-02-3-a.1: FE Model of the Benchmark Problem (p. 1098). The support elements were a combination of spring and snubber elements. Modal and response spectrum analysis is performed on the piping model. The input excitation consisted of four spectra sets with the vertical component of excitation varying from set to set while the horizontal components of excitation are identical for all supports. Each solution has a fifteen natural frequency approximation with various spectra and spectrum weighting factors.

Response spectrum solutions are done for three cases:

- Case 1: Envelope spectrum excitation
- Case 2: Independent support excitation with SRSS combination
- Case 3: Independent support excitation with absolute sum combination

Figure VM-NR1677-02-3-a.1: FE Model of the Benchmark Problem



Material Properties	Geometric Properties	Loading
Pipe Elements: **Material ID 1:** E = 0.277 x 10^8 psi Nu = 0.3 G = 10653846.15384 psi **Material ID 2:** E = 0.277 x 10^8 psi Nu = 0.3 G = 10653846.15384 psi **Material ID 3:** E = 0.277 x 10^8 psi Nu = 0.3 G = 10653846.15384 psi **Stiffness for Spring-Damper Elements (lb/in):**	**Straight Pipe:** **Set 1:** Outer Diameter = 12.750 in Wall Thickness = 0.3750 in **Bend Pipe:** **Set 2:** Outer Diameter = 12.750 in Wall Thickness = 0.3750 in Radius of Curvature = 60 in **Set 3:** Outer Diameter = 12.750 in Wall Thickness = 0.3750 in Radius of Curvature = 18 in	Temperature = 400 F applied as body force. Pressure = 615 psi. applied as surface pressure. **Case 1:** Acceleration Response Spectrum Curve defined by **FREQ** and **SV** commands. **Case 2:** Acceleration Response Spectrum Curve defined by **SPVAL** and **SPFREQ** commands. **Case 3:** Acceleration Response Spectrum

Material Properties	Geometric Properties	Loading
Since there are multiple Spring Supports at different locations, the Stiffness for the Spring Damper Elements are listed based on real constant set number. **Set 4:** $K = 0.1 \times 10^{2}$ **Set 5:** $K = 0.1 \times 10^{13}$ **Set 6:** $K = 0.1 \times 10^{13}$ **Set 7:** $K = 0.1 \times 10^{13}$ **Set 8:** $K = 0.1 \times 10^{13}$ **Set 9:** $K = 0.1 \times 10^{13}$ **Set 10:** $K = 0.1 \times 10^{13}$		Curve defined by **SPVAL** and **SPFREQ** commands.

Results Comparison

Table VM-NR1677-02-3-a.1: Frequencies Obtained from Modal Solution:

Mode	Target	Mechanical APDL	Ratio
1	7.238	7.2431	1.000
2	10.145	10.1497	1.000
3	14.579	14.6066	1.000
4	15.991	16.0215	1.000
5	17.198	17.177	1.000
6	17.987	17.9922	1.000
7	22.282	22.274	1.000

Mode	Target	Mechanical APDL	Ratio
8	23.632	23.6365	1.000
9	27.864	27.8631	1.000
10	29.211	29.207	1.000
11	29.514	29.4711	1.000
12	31.554	31.5635	1.000
13	34.018	34.0245	1.000
14	34.778	34.7638	1.000
15	35.122	35.1169	1.000

Case 1: Envelope spectrum excitation

Table VM-NR1677-02-3-a.2: Maximum Displacements and Rotations

Result Node	Target	Mechanical APDL	Ratio
UX at node36	0.6114	0.6054	0.990
UY at node51	1.1035	1.1039	1.000
UZ at node20	0.0062	0.0062	0.999
ROTX at node44	0.0093	0.0093	1.000
ROTY at node31	0.006	0.006	0.997
ROTZ at node53	0.0133	0.0133	1.000

Table VM-NR1677-02-3-a.3: Element Forces and Moments

Result	Target	Mechanical APDL	Ratio
FY at node65	11.000	10.852	0.987
FX at node66	7837.000	7783.639	0.993
FX at node67	4472.000	4447.907	0.995
FY at node75	8931.000	8936.619	1.001
FY at node68	359.000	357.420	0.996
FY at node69	729.000	719.789	0.987
FY at node70	784.000	792.5824	1.011

Result	Target	Mechanical APDL	Ratio
FY at node71	1043.000	1025.413	0.983
FY at node72	1378.000	1361.234	0.988
FY at node73	3408.000	3381.375	0.992
FY at node74	1448.000	1435.296	0.991
FX at node101	1685.000	1672.272	0.992
FY at node102	87.000	87.303	1.003
FZ at node103	1370.000	1363.138	0.995
FX at node591	3031.000	2994.254	0.988
FY at node592	15859.000	15871.962	1.001
FZ at node593	896.000	886.978	0.990
FX at node120	6792.000	6773.652	0.997
FX at node310	11991.000	11957.218	0.997
FX at node61	801.000	800.657	1.000
FX at node62	303.000	303.116	1.000
FX at node63	7447.000	7420.509	0.996

Table VM-NR1677-02-3-a.4: Element Forces and Moments

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	2014.000	1997.825	0.992
VY(I)	86.890	87.303	1.005
VZ(I)	813.200	814.444	1.002
TX(I)	14130.000	13970.555	0.989
MY(I)	58340.000	58552.903	1.004
MZ(I)	3861.000	3879.502	1.005

Result	Target	Mechanical APDL	Ratio
PX(J)	2014.000	1997.825	0.992
VY(J)	86.89000	87.303	1.005
VZ(J)	813.2000	814.444	1.002
TX(J)	14130.000	13970.555	0.989
MY(J)	24430.000	24567.022	1.006
MZ(J)	535.000	525.835	0.983
Element 17			
PX(I)	6286.000	6272.340	0.998
VY(I)	752.300	742.262	0.987
VZ(I)	873.300	871.734	0.998
TX(I)	22430.000	22143.624	0.987
MY(I)	8460.000	8491.516	1.004
MZ(I)	29590.000	29012.529	0.980
PX(J)	6286.000	6272.340	0.998
VY(J)	752.300	742.262	0.987
VZ(J)	873.300	871.734	0.998
TX(J)	22430.000	22143.624	0.987
MY(J)	43530.000	43483.765	0.999
MZ(J)	23500.000	22462.707	0.956
Element 50			
PX(I)	1739.000	1726.048	0.993
VY(I)	395.300	387.095	0.979
VZ(I)	773.000	775.102	1.003
TX(I)	14640.000	14416.888	0.985
MY(I)	22240.000	22272.039	1.001
MZ(I)	16520.000	16382.506	0.992
PX(J)	1879.000	1868.924	0.995
VY(J)	395.300	387.095	0.979
VZ(J)	300.000	295.205	0.984
TX(J)	20260.000	20011.374	0.988
MY(J)	29470.000	29597.765	1.004
MZ(J)	16330.000	16300.507	0.998

Case 2: Independent support excitation with SRSS combination

Table VM-NR1677-02-3-a.5: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node36	0.5674	0.5620	0.990
UY at node51	0.3888	0.3854	0.991
UZ at node36	0.5219	0.5163	0.989
ROTX at node22	0.0028	0.0028	0.989
ROTY at node22	0.0001	0.0001	0.997
ROTZ at node35	0.0071	0.0070	0.990

Table VM-NR1677-02-3-a.6: Reaction forces Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
FY at node65	4.000	3.838	0.960
FX at node66	6845.000	6813.770	0.995
FX at node67	3100.000	3082.6893	0.994
FY at node75	2923.000	2900.109	0.992
FY at node68	524.000	521.904	0.996
FY at node69	1144.000	1138.868	0.996
FY at node70	1068.000	1070.123	1.002
FY at node71	1416.000	1405.368	0.992
FY at node72	1666.000	1653.069	0.992
FY at node73	2776.000	2759.1665	0.994
FY at node74	1738.000	1725.100	0.993
FX at node101	3160.000	3112.999	0.985
FY at node102	109.000	109.196	1.002

Result Node	Target	Mechanical APDL	Ratio
FZ at node103	2408.000	2375.430	0.986
FX at node591	2834.000	2800.740	0.988
FY at node592	4923.000	4890.870	0.993
FZ at node593	803.000	798.011	0.994
FX at node120	4953.000	4890.178	0.987
FX at node61	831.000	826.212	0.994
FX at node62	312.000	309.944	0.993
FX at node63	4411.000	4373.316	0.991
FX at node310	5898.000	5860.060	0.994

Table VM-NR1677-02-3-a.7: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	3807.000	3748.970	0.985
VY(I)	109.100	109.196	1.001
VZ(I)	1139.000	1130.767	0.993
TX(I)	17220.000	17067.318	0.991
MY(I)	77410.000	77027.059	0.995
MZ(I)	5027.000	5033.468	1.001
PX(J)	3807.000	3748.970	0.985
VY(J)	109.100	109.196	1.001
VZ(J)	1139.000	1130.767	0.993
TX(J)	17220.000	17067.318	0.991
MY(J)	30930.000	30861.332	0.998
MZ(J)	775.300	768.536	0.991
Element 17			
PX(I)	3539.000	3507.254	0.991
VY(I)	933.300	925.705	0.992
VZ(I)	533.100	529.442	0.993

Result	Target	Mechanical APDL	Ratio
TX(I)	26390.000	26106.583	0.989
MY(I)	9809.000	9800.492	0.999
MZ(I)	41630.000	41290.283	0.992
PX(J)	3539.000	3507.254	0.991
VY(J)	933.300	925.705	0.992
VZ(J)	533.100	529.442	0.993
TX(J)	26390.000	26106.583	0.989
MY(J)	29000.000	28900.249	0.997
MZ(J)	41980.000	41379.964	0.986
Element 50			
PX(I)	3150.000	3101.322	0.985
VY(I)	649.600	645.286	0.993
VZ(I)	1386.000	1379.109	0.995
TX(I)	17480.000	17252.674	0.987
MY(I)	28130.000	27958.296	0.994
MZ(I)	19150.000	18998.162	0.992
PX(J)	3413.000	3366.752	0.986
VY(J)	649.600	645.286	0.993
VZ(J)	444.200	430.259	0.969
TX(J)	23510.000	23242.522	0.989
MY(J)	38990.000	38842.244	0.996
MZ(J)	23530.000	23533.252	1.000

Case 3: Independent support excitation with absolute sum combination

Table VM-NR1677-02-3-a.8: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanical APDL	Ratio
UX at node36	0.8272	0.8198	0.991
UY at node51	0.5475	0.5452	0.996
UZ at node36	0.7619	0.754	0.990
ROTX at node12	0.0019	0.0019	0.990
ROTY at node12	0.0002	0.0002	1.000

Result Node	Target	Mechanical APDL	Ratio
ROTZ at node35	0.0103	0.0102	0.990

Table VM-NR1677-02-3-a.9: Reaction forces Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
FY at node49	5.000	5.432	1.09
FX at node55	9479.000	9411.998	0.99
FX at node41	4250.000	4215.067	0.99
FY at node41	4011.000	3999.962	1.00
FY at node5	832.000	828.354	1.00
FY at node8	1828.000	1818.031	0.99
FY at node14	1689.000	1692.251	1.00
FY at node20	2149.000	2131.734	0.99
FY at node25	2467.000	2447.640	0.99
FY at node290	4062.000	4039.442	0.99
FY at node37	2537.000	2521.378	0.99
FX at node1	4353.000	4303.772	0.99
FY at node1	168.000	168.192	1.00
FZ at node1	3376.000	3343.400	0.99
FX at node59	3937.000	3885.033	0.99
FY at node59	6819.000	6813.123	1.00
FZ at node59	1069.000	1057.741	0.99
FX at node13	6866.000	6796.337	0.99
FX at node140	1276.000	1273.302	1.00
FX at node18	492.544	490.815	1.00

Result	Target	Mechanical APDL	Ratio
FX at node29	6332.010	6286.316	0.99
FX at node32	8415.285	8375.552	1.00

Table VM-NR1677-02-3-a.10: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanical APDL	Ratio
Element 1			
PX(I)	5223.000	5162.199	0.988
VY(I)	167.900	168.192	1.002
VZ(I)	1753.000	1747.118	0.997
TX(I)	25590.000	25371.812	0.991
MY(I)	122100.000	121964.224	0.999
MZ(I)	7826.000	7836.310	1.001
PX(J)	5223.000	5162.199	0.988
VY(J)	167.900	168.192	1.002
VZ(J)	1753.000	1747.118	0.997
TX(J)	25590.000	25371.812	0.991
MY(J)	49880.000	49950.709	1.001
MZ(J)	1213.000	1202.718	0.992
Element 17			
PX(I)	4944.000	4905.012	0.992
VY(I)	1380.000	1368.650	0.992
VZ(I)	741.600	737.391	0.994
TX(I)	38460.000	38055.473	0.989
MY(I)	15200.000	15209.516	1.001
MZ(I)	63740.000	63190.025	0.991
PX(J)	4944.000	4905.012	0.992
VY(J)	1380.000	1368.650	0.992
VZ(J)	741.600	737.391	0.994
TX(J)	38460.000	38055.473	0.989
MY(J)	40840.000	40736.452	0.997
MZ(J)	67620.000	66625.670	0.985
Element 50			

Result	Target	Mechanical APDL	Ratio
PX(I)	4365.000	4314.227	0.988
VY(I)	1042.000	1034.289	0.993
VZ(I)	1942.000	1939.515	0.999
TX(I)	25740.000	25414.899	0.987
MY(I)	45220.000	45105.706	0.997
MZ(I)	27970.000	27760.288	0.993
PX(J)	4738.000	4692.080	0.990
VY(J)	1042.000	1034.289	0.993
VZ(J)	615.900	598.878	0.972
TX(J)	34210.000	33823.295	0.989
MY(J)	61630.000	61625.412	1.000
MZ(J)	37150.000	37130.922	0.999

Note

PX (I) and PX (J) = Section axial force at node I and J.

VY (I) and VY (J) = Section shear forces along Y direction at node I and J.

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J.

TX (I) and TX (J) = Section torsional moment at node I and J.

MY (I) and MY (J) = Section bending moments along Y direction at node I and J.

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J.

The element forces and moments along Y and Z directions are flipped between Mechanical APDL and NRC results.

VM-NR1677-02-4-a: NUREG/CR-1677: Volume 2, Benchmark Problem No. 4

Overview

Reference:	NUREG/CR-1677 Volume II Piping Benchmark Problems, Dynamic Analysis Independent Support Motion Response Spectrum Method, P. Bezler, M. Subudhi & M. Hartzman of Brookhaven National Laboratory, prepared for the U.S. Nuclear Regulatory Commission, August 1985, Problem 1, pages 244-445
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Elastic straight pipe elements (PIPE16) Elastic curved pipe elements (PIPE18) Spring-Damper Element (COMBIN14) tructural Mass Elements (MASS21)
Input Listing:	vm-nr1677-2-4a-a.dat vm-nr1677-2-4c-a.dat

Test Case

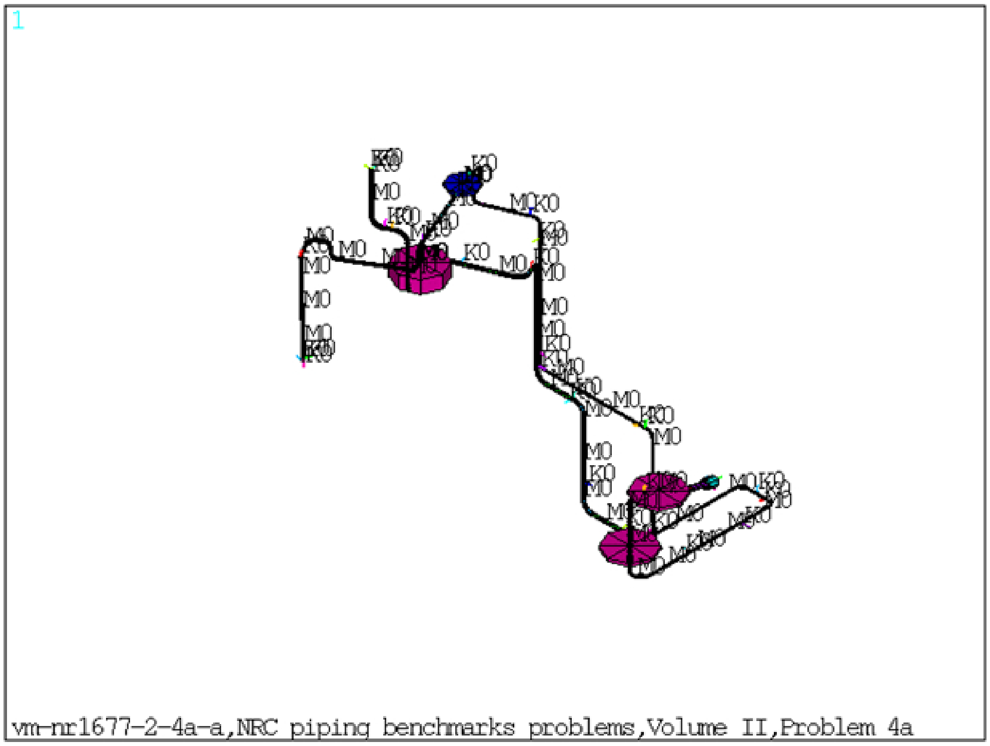
This benchmark problem is a three-branch, three-anchor piping subsystem from an actual nuclear power plant. The system configuration is shown in Figure VM-NR1677-02-4-a.1: FE Model of the Benchmark Problem (p. 1110). The boundary or spring support elements ranged in stiffness from relatively soft to virtually rigid. Modal and response spectrum analysis is performed on the piping model. The input excitation consisted of four different excitation spectra sets developed for the actual system and show variations for elevation and extent. Each solution had a fifty natural frequency approximation with various spectra and spectrum weighting factors.

Response spectrum solutions are done for two cases:

- Case 1: Envelope spectrum excitation
- Case 2: Independent support excitation with absolute sum combination.

Frequencies obtained from modal solve and the nodal/element solution obtained from spectrum solve are compared against reference results.

Figure VM-NR1677-02-4-a.1: FE Model of the Benchmark Problem



Material Properties	Geometric Properties	Loading
Pipe Elements: $E = 0.283 \times 10^8$ psi Nu = 0.3 $G = 0.108 \times 10^8$ psi $K = 0.911 \times 10^{-5}$ **Stiffness for Spring-Damper Elements (lb/in):** Since there are multiple Spring Supports at different locations, the Stiffness for Spring Damper Elements are listed based on the real constant set number. **Set 48:** $K = 0.1 \times 10^9$ **Set 49:**	**Straight Pipe:** **Set 1:** Outer Diameter = 32.35 in Wall Thickness = 2.25 in **Set 2:** Outer Diameter = 15.625 in Wall Thickness = 3.44 in **Set 3:** Outer Diameter = 10.75 in Wall Thickness = 1.0 in **Set 4:** Outer Diameter = 16.03 in	**Case 1:** Acceleration Response Spectrum Curve defined by **FREQ** and **SV** commands. **Case 2:** Acceleration Response Spectrum Curve defined by **SPVAL** and **SPFREQ** commands.

Material Properties	Geometric Properties	Loading
$K = 0.1 \times 10^9$ **Set 50:** $K = 0.1 \times 10^9$ **Set 51:** $K = 0.1080 \times 10^4$ **Set 52:** $K = 0.6001 \times 10^5$ **Set 53:** $K = 0.6001 \times 10^5$ **Set 55:** $K = 0.7541 \times 10^6$ **Set 58:** $K = 0.6000 \times 10^3$ **Set 60:** $K = 0.7601 \times 10^5$ **Set 62:** $K = 0.8000 \times 10^3$ **Set 63:** $K = 0.6001 \times 10^5$ **Set 64:** $K = 0.1000 \times 10^9$ **Set 65:** $K = 0.1000 \times 10^9$ **Set 66:** $K = 0.1000 \times 10^9$ **Set 67:**	Wall Thickness = 2.64 in **Set 5:** Outer Diameter = 160.3 in Wall Thickness = 74.775 in **Set 6:** Outer Diameter = 10.75 in Wall Thickness = 2.64 in **Set 7:** Outer Diameter = 16.03 in Wall Thickness = 2.64 in **Set 8:** Outer Diameter = 6.625 in. Wall Thickness = 0.7180 in **Set 9:** Outer Diameter = 9.87 in Wall Thickness = 1.62 in **Set 10:** Outer Diameter = 98.7 in Wall Thickness = 46.035 in **Set 11:** Outer Diameter = 6.625 in Wall Thickness = 0.7180 in **Set 12:**	

Material Properties	Geometric Properties	Loading
$K = 0.2600 \times 10^3$ **Set 68:** $K = 0.5901 \times 10^5$ **Set 70:** $K = 0.7601 \times 10^5$ **Set 72:** $K = 0.2460 \times 10^6$ **Set 75:** $K = 0.7501 \times 10^5$ **Set 76:** $K = 0.4660 \times 10^6$ **Set 77:** $K = 0.3400 \times 10^3$ **Set 79:** $K = 0.5000 \times 10^6$ **Set 80:** $K = 0.5000 \times 10^6$ **Set 81:** $K = 0.1000 \times 10^9$ **Set 82:** $K = 0.1000 \times 10^9$ **Set 83:** $K = 0.1000 \times 10^9$ **Mass Elements (lb-sec^2/in):** (Isotropic Mass)	Outer Diameter = 8.625 in Wall Thickness = 0.906 in **Set 13:** Outer Diameter = 10.75 in Wall Thickness = 0.365 in **Bend Pipe Elements:** **Set 14:** Outer Diameter = 10.75 in Wall Thickness = 1.0 in Radius of Curvature = 15.0 in **Set 15:** Outer Diameter = 10.75 in Wall Thickness = 1.0 in Radius of Curvature = 15.0 in **Set 16:** Outer Diameter = 10.75 in Wall Thickness = 1.0 in Radius of Curvature = 14.9 in **Set 17:** Outer Diameter = 10.75 in Wall Thickness = 0.365 in Radius of Curvature = 15.0 in **Set 18:**	

Material Properties	Geometric Properties	Loading
Set 23: Mass @ Node 12 = 1.69306 Mass @ Node 21 = 1.69306 Mass @ Node 25 = 1.69306 **Set 24:** Mass @ Node 15 = 5.07505 **Set 25:** Mass @ Node 33 = 4.96894 **Set 26:** Mass @ Node 34 = 1.20212 **Set 27:** Mass @ Node 39 = 1.42495 Mass @ Node 42 = 1.42495 **Set 28:** Mass @ Node 45 = 1.88768 Mass @ Node 46 = 1.88768 **Set 29:** Mass @ Node 53 = 2.18323 **Set 30:** Mass @ Node 58 = 2.4397 Mass @ Node 59 = 2.4397 **Set 31:** Mass @ Node 66 = 2.98188	Outer Diameter = 10.75 in Wall Thickness = 0.365 in Radius of Curvature = 14.9 in **Set 19:** Outer Diameter = 6.625 in Wall Thickness = 0.7180 in Radius of Curvature = 9.0 in **Set 20:** Outer Diameter = 8.625 in. Wall Thickness = 0.906 in Radius of Curvature = 12.0 in **Set 21:** Outer Diameter = 8.625 in Wall Thickness = 0.906 in Radius of Curvature = 40.0 in **Set 22:** Outer Diameter = 8.625 in Wall Thickness = 0.906 in Radius of Curvature = 8.0 in	

Material Properties	Geometric Properties	Loading
Set 32: Mass @ Node 69 = 1.41874 **Set 33:** Mass @ Node 78 = 0.104943 **Set 34:** Mass @ Node 79 = 0.930124 Mass @ Node 83 = 0.930124 Mass @ Node 84 = 0.930124 **Set 35:** Mass @ Node 93 = 1.6118 **Set 36:** Mass @ Node 102 = 0.6744 Mass @ Node 104 = 0.6744 Mass @ Node 107 = 0.674 **Set 37:** Mass @ Node 110 = 0.643 Mass @ Node 111 = 0.643 **Set 38:** Mass @ Node 114 = 1.06962 **Set 39:** Mass @ Node 123 = 1.20549 Mass @ Node 124 = 1.20549 **Set 40:**		

Material Properties	Geometric Properties	Loading
Mass @ Node 129 = 1.05642 Mass @ Node 130 = 1.05642 **Set 41:** Mass @ Node 137 = 1.25388 Mass @ Node 138 = 1.25388 **Set 42:** Mass @ Node 143 = 1.3543 Mass @ Node 144 = 1.3543 **Set 43:** Mass @ Node 151 = 0.666149 Mass @ Node 154 = 0.666149 Mass @ Node 160 = 0.666149 **Set 44:** Mass @ Node 162 = 2.27769 **Set 45:** Mass @ Node 167 = 1.15217 Mass @ Node 168 = 1.15217 **Set 46:** Mass @ Node 173 = 1.23214 Mass @ Node 176 = 1.23214 Mass @ Node 178 = 1.23214 Mass @ Node 185 = 1.23214 **Set 47:**		

Material Properties	Geometric Properties	Loading
Mass @ Node 189 = 1.52976 Mass @ Node 190 = 1.52976 Mass @ Node 191 = 1.52976		

Results Comparison

Table VM-NR1677-02-4-a.1: Frequencies Obtained from Modal Solution

Mode	Target	Mechanial APDL	Ratio
1	2.612	2.610	1.000
2	2.914	2.914	1.000
3	4.337	4.336	1.000
4	4.660	4.660	1.000
5	5.734	5.723	1.000
6	5.833	5.832	1.000
7	7.359	7.358	1.000
8	7.769	7.768	1.000
9	9.952	9.956	1.000
10	10.329	10.327	1.000
11	10.679	10.676	1.000
12	10.943	10.945	1.000
13	12.030	12.021	1.000
14	12.286	12.298	1.000
15	13.251	13.250	1.000
16	13.407	13.404	1.000
17	14.429	14.426	1.000
18	14.720	14.717	1.000
19	15.253	15.252	1.000
20	15.553	15.549	1.000
21	16.172	16.166	1.000
22	16.797	16.803	1.000
23	17.230	17.230	1.000
24	17.275	17.273	1.000
25	17.453	17.453	1.000
26	18.710	18.702	1.000
27	18.898	18.896	1.000
28	19.993	19.982	1.000

Mode	Target	Mechanial APDL	Ratio
29	21.460	21.455	1.000
30	21.523	21.522	1.000
31	22.736	22.733	1.000
32	23.281	23.298	1.000
33	24.067	24.064	1.000
34	24.593	24.595	1.000
35	25.117	25.105	1.000
36	26.516	26.513	1.000
37	26.935	26.943	1.000
38	27.509	27.503	1.000
39	28.662	28.659	1.000
40	29.542	29.537	1.000
41	30.596	30.603	1.000
42	31.274	31.261	1.000
43	32.283	32.274	1.000
44	35.484	35.465	1.000
45	36.022	36.042	1.000
46	36.394	36.343	1.000
47	36.769	36.736	1.000
48	38.000	37.992	1.000
49	38.420	38.328	1.000
50	40.185	40.173	1.000

Case 1: Envelope Spectrum Excitation

Table VM-NR1677-02-4-a.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanial APDL	Ratio
UX at node81	0.929	0.930	1.001
UY at node155	0.319	0.295	0.925
UZ at node61	0.618	0.618	1.000
ROTX at node143	0.006	0.005	0.972
ROTY at node149	0.010	0.009	0.966

Result Node	Target	Mechanial APDL	Ratio
ROTZ at node84	0.0092	0.009	1.001

Table VM-NR1677-02-4-a.3: Reaction forces Obtained from Spectrum Solve

Result Node	Target	Mechanial APDL	Ratio
FX at node1	3724.000	3689.557	0.990
FY at node1	2390.000	2378.323	0.995
FZ at node1	2156.000	2150.482	0.997
FY at node17	42.000	41.866	0.996
FY at node29	2466.000	2446.638	0.992
FZ at node37	4850.000	4829.495	0.995
FX at node43	4765.000	4740.622	0.994
FY at node49	3835.000	3571.352	0.931
FZ at node51	3482.000	3415.523	0.980
FX at node56	2101.000	2063.547	0.982
FY at node62	61.000	57.640	0.944
FZ at node67	6860.000	6625.256	0.965
FY at node72	2669.000	2647.903	0.992
FZ at node74	6554.000	6543.720	0.998
FY at node87	109.000	109.018	1.000
FY at node89	5015.000	5013.799	0.999
FX at node94	3334.000	3332.158	0.999
FY at node94	4739.000	4740.105	1.000

Result Node	Target	Mechanial APDL	Ratio
FZ at node94	861.000	852.660	0.990
FY at node108	64.000	62.142	0.971
FX at node112	2312.000	2295.611	0.992
FZ at node117	2079.000	2058.463	0.990
FY at node119	1153.000	1131.719	0.981
FZ at node127	1829.000	1812.821	0.991
FY at node133	886.000	880.659	0.994
FZ at node135	889.000	865.222	0.973
FX at node141	1858.000	1843.740	0.992
FZ at node145	2571.000	2486.985	0.967
FY at node149	1349.000	1319.100	0.977
FY at node157	106.000	98.521	0.929
FX at node165	4370.000	4308.793	0.986
FY at node169	1340.000	1305.014	0.973
FY at node188	1170.000	1165.614	0.996
FX at node192	970.000	939.963	0.969
FY at node192	749.000	749.140	1.000
FZ at node192	2952.000	2849.996	0.965

Table VM-NR1677-02-4-a.4: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanial APDL	Ratio
Element 1			
PX(I)	2273.000	2267.620	0.998

Result	Target	Mechanial APDL	Ratio
VY(I)	3719.000	3544.193	0.953
VZ(I)	2287.000	2488.055	1.088
TX(I)	105000.000	103993.519	0.990
MY(I)	229900.000	240284.895	1.045
MZ(I)	351600.000	340778.624	0.969
PX(J)	2273.000	2267.620	0.998
VY(J)	3719.000	3544.193	0.953
VZ(J)	2287.000	2488.055	1.088
TX(J)	105000.000	103993.519	0.990
MY(J)	198700.000	205919.646	1.036
MZ(J)	292000.000	283741.889	0.972

Case 2: Independent Support Excitation with Absolute Sum Combination

Table VM-NR1677-02-4-a.5: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result Node	Target	Mechanial APDL	Ratio
UX at node182	0.6884	0.6851	0.995
UY at node155	0.259	0.2547	0.983
UZ at node143	0.6247	0.6312	1.010
ROTX at node143	0.0053	0.0054	1.011
ROTY at node149	0.0079	0.0079	0.999
ROTZ at node155	0.0028	0.0028	0.980

Table VM-NR1677-02-4-a.6: Reaction forces Obtained from Spectrum Solve

Result Node	Target	Mechanial APDL	Ratio
FX at node1	3033.000	2979.648	0.982
FY at node1	2119.000	2081.495	0.982
FZ at node1	1917.000	1886.063	0.983
FY at node17	34.000	32.889	0.967

Result Node	Target	Mechanial APDL	Ratio
FY at node29	2018.000	1972.229	0.977
FZ at node37	3482.000	3384.218	0.971
FX at node43	4132.177	4098.492	0.991
FY at node49	2970.000	2914.793	0.981
FZ at node51	2882.485	2763.316	0.958
FX at node56	1739.497	1704.352	0.979
FY at node62	47.000	45.592	0.970
FZ at node67	6205.159	5879.702	0.947
FY at node72	2469.000	2400.031	0.972
FZ at node74	6490.198	6246.645	0.962
FY at node87	97.000	87.5166	0.902
FY at node89	4444.000	4025.096	0.905
FX at node94	2944.000	2653.078	0.901
FY at node94	4206.000	3789.072	0.900
FZ at node94	823.000	789.087	0.958
FY at node108	51.000	49.034	0.961
FX at node112	1887.000	1855.151	0.983
FZ at node117	1752.225	1719.744	0.981
FY at node119	914.000	884.858	0.968
FZ at node127	1258.628	1214.817	0.965
FY at node133	703.000	684.570	0.973

Result Node	Target	Mechanial APDL	Ratio
FZ at node135	626.592	612.336	0.977
FX at node141	1363.724	1310.226	0.960
FZ at node145	2031.000	2024.344	0.996
FY at node149	1182.000	1159.275	0.980
FY at node157	86.000	84.787	0.985
FX at node165	3972.166	3899.844	0.981
FY at node169	1058.000	1046.958	0.989
FY at node188	665.000	652.613	0.981
FX at node192	834.000	806.000	0.966
FY at node192	431.000	428.392	0.993
FZ at node192	2296.000	2286.566	0.995

Table VM-NR1677-02-4-a.7: Element Forces and Moments Obtained from Spectrum Solve

Result	Target	Mechanial APDL	Ratio
Element 1			
PX(I)	2021.000	2000.590	0.990
VY(I)	3016.000	2851.298	0.945
VZ(I)	2045.000	2153.117	1.053
TX(I)	82260.000	80273.621	0.976
MY(I)	200700.000	209122.092	1.042
MZ(I)	290200.000	277198.313	0.955
PX(J)	2021.000	2000.590	0.990
VY(J)	3016.000	2851.298	0.945
VZ(J)	2045.000	2153.117	1.053
TX(J)	82260.000	80273.621	0.976
MY(J)	172100.000	178506.798	1.037

Result	Target	Mechanial APDL	Ratio
MZ(J)	241800.000	231289.882	0.957

Note

PX (I) and PX (J) = Section axial force at node I and J.

VY (I) and VY (J) = Section shear forces along Y direction at node I and J.

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J.

TX (I) and TX (J) = Section torsional moment at node I and J.

MY (I) and MY (J) = Section bending moments along Y direction at node I and J.

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J.

The element forces and moments along Y and Z directions are flipped between Mechanical APDL and NRC results.

VM-NR6645-01-1: VM-NR6645-01-1-a

Overview

Reference:	Reevaluation of Regulatory Guidance on modal response combination methods for seismic response spectrum analysis NUREC/CR-6645, Brookhaven National Laboratory, December 1999.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Spring-Damper Element (COMBIN14) Elastic Straight Pipe Element (PIPE16) Elastic Curved Pipe Element (PIPE18)
Input Listing:	vm-nr6645-1-1a-a.dat vm-nr6645-1-2a-a.dat

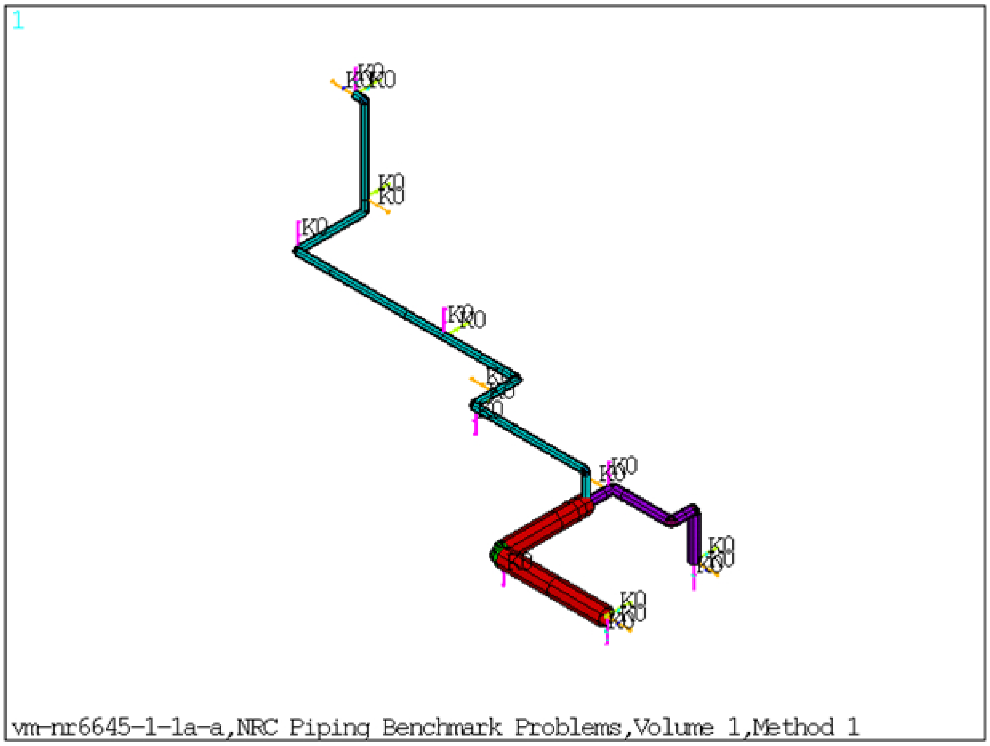
Test Case

The schematic of the BM3 piping model is shown in Figure VM-NR1677-01-1-a.1: FE Model of Benchmark Problem (p. 1037). The piping model is supported by means of elastic spring-damped elements. Modal and spectrum analysis is performed on the piping model. Lumped mass matrix formulation is used in the analysis. The first 14 modes obtained from modal solve is used in the subsequent spectrum analysis which is performed with an acceleration input spectra defined by 75 points. The model is excited in global X direction and the modes are combined using SRSS combination method. The spectrum solution is performed for two cases.

Spectrum solutions are performed for two cases:

- Case 1: With missing mass effect (ZPA = 0.54g)
- Case 2: With missing mass effect (ZPA = 0.54g) and rigid responses effect (Lindley method) Frequencies obtained from modal solve and reaction forces obtained from spectrum solve are compared against reference results.

Figure VM-NR6645-01-1-a.1: FE Model of the Benchmark Problem



Material Properties	Geometric Properties	Loading
Pipe Elements: E = 0.2.9 x 10^7 psi Nu = 0.3 G = 0.111 x 10^8 psi **Density for different material ID:** **Material ID 1:** Density = 1.043 x 10^{-3} lb-sec^2/in^4 **Material ID 2:** Density = 1.107 x 10^{-3} lb-sec^2/in^4 **Material ID 3:** Density = 1.253 x 10^{-3} lb-sec^2/in^4	**Straight Pipe:** **Set 1:** Outer Diameter = 3.5 in. Wall Thickness = 0..2160 in. **Set 2:** Outer Diameter = 4.5 in. Wall Thickness = 0.2370 in. **Set 3:** Outer Diameter = 8.625 in. Wall Thickness = 0.3220 in. **Bend Pipe Elements:** **Set 4:**	Acceleration response spectrum curve defined by **SV** and **FREQ** commands.

Material Properties	Geometric Properties	Loading
Material ID 4: Density = 1.043×10^{-3} lb-sec^2/in^4 **Material ID 5:** Density = 1.107×10^{-3} lb-sec^2/in^4 **Material ID 6:** Density = 1.253×10^{-3} lb-sec^2/in^4 **Stiffness for Spring-Damper Element: (lb/in)** Since there are multiple Spring Supports at different locations, the Stiffness for the Spring Damper Elements are listed based on real constant set number. **Set 7:** K = 1.0×10^5 **Set 8:** K = 1.0×10^8 **Set 9:** K = 1.0×10^{11} **Set 10:** K = 1.0×10^{20} **Set 11:** K = 1.0×10^{20}	Outer Diameter = 3.5 in. Wall Thickness = 0.2160 in. Radius of Curvature = 4.5 in. **Set 5:** Outer Diameter = 4.5 in. Wall Thickness = 0.2370 in. Radius of Curvature = 6.0 in. **Set 6:** Outer Diameter = 8.625 in. Wall Thickness = 0.3220 in. Radius of Curvature = 12.0 in.	

Material Properties	Geometric Properties	Loading
Set 12: $K = 1.0 \times 10^{20}$		

Results Comparison

Table VM-NR6645-01-1-a.1: Frequencies Obtained from Modal Solution

Mode	Target	Mechanical APDL	Ratio
1	2.910	2.906	0.999
2	4.390	4.383	0.999
3	5.520	5.515	0.999
4	5.700	5.701	1.000
5	6.980	6.978	1.000
6	7.340	7.342	1.000
7	7.880	7.877	1.000
8	10.300	10.396	1.009
9	11.060	11.062	1.000
10	11.230	11.232	1.000
11	11.500	11.532	1.003
12	12.430	12.455	1.002
13	13.880	13.964	1.006
14	16.120	16.092	0.998

Reaction Forces Obtained from Spectrum Solve

Table VM-NR6645-01-1-a.2: Case 1: With Missing Mass Effect (ZPA = 0.54g)

Force_Node	Target	Mechanical APDL	Ratio
Fx at node1	48.081	48.1800	1.002
Fy at node1	5.494	5.1448	0.937
Fz at node1	7.584	6.9158	0.912
Fx at node4	93.432	92.1492	0.986
Fz at node4	75.438	68.8216	0.912
Fy at node7	15.924	16.0453	1.008
Fy at node11	19.699	19.8697	1.009
Fz at node11	80.527	78.5385	0.975
Fx at node15	438.882	435.6856	0.993

Force_Node	Target	Mechanical APDL	Ratio
Fy at node17	48.896	48.9000	1.000
Fz at node17	79.739	79.0666	0.992
Fy at node36	90.112	94.9487	1.054
Fz at node36	85.082	87.6852	1.031
Fx at node38	651.640	621.1533	0.953
Fy at node38	52.562	53.3979	1.016
Fz at node38	41.930	40.0603	0.955
Fx at node23	264.782	260.2601	0.983
Fy at node23	105.363	112.0384	1.063
Fx at node31	50.646	50.1255	0.990
Fy at node31	24.798	24.6392	0.994
Fz at node31	31.678	30.9950	0.978

Table VM-NR6645-01-1-a.3: Case 2: With Missing Mass Effect (ZPA = 0.54g) and Rigid Responses Effect (Lindley Method)

Result	Target	Mechanical APDL	Ratio
Fx at node1	46.333	46.216	0.997
Fy at node1	3.706	3.5776	0.965
Fz at node1	3.536	3.2326	0.914
Fx at node4	93.432	104.6064	0.995
Fz at node4	36.218	33.2502	0.918
Fy at node7	13.934	13.9509	1.001
Fy at node11	15.173	15.2120	1.003
Fz at node11	70.766	70.1082	0.991
Fx at node15	592.491	586.3127	0.990

Result	Target	Mechanical APDL	Ratio
Fy at node17	36.352	36.3426	1.000
Fz at node17	63.399	62.8875	0.992
Fy at node36	63.032	66.0934	1.049
Fz at node36	53.914	54.4573	1.010
Fx at node38	768.789	746.3653	0.971
Fy at node38	47.784	48.0981	1.007
Fz at node38	38.037	36.5269	0.960
Fx at node23	342.659	338.8705	0.989
Fy at node23	55.811	60.6286	1.086
Fx at node31	56.151	56.6833	1.009
Fy at node31	17.854	17.8872	1.002
Fz at node31	22.994	22.4445	0.976

VM-NR1677-01-1: NUREG/CR-1677: Volume 1, Benchmark Problem No. 1

Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic Analysis of Uniform Support Motion Response Spectrum Method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 1, Pages 24-47.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Structural Mass Element (MASS21) 3-D 3-Node Pipe (PIPE289) 3-D 3-Node Elbow (ELBOW290)
Input Listing:	vm-nr1677-01-1a.dat

Test Case

For test case description, problem sketch, material properties, geometry properties and loadings refer to VM-NR1677-01-1-a (p. 1037)

Results Comparison

Table VM-NR1677-01-1.1: Frequencies Obtained from Modal Solution

Mode	Frequency
1	28.515
2	56.441
3	82.947
4	144.140
5	166.260

Table VM-NR1677-01-1.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node10	7.830E-03
UY at node36	2.648E-03
UZ at node28	1.748E-02
ROTX at node 9	1.867E-04
ROTY at node18	2.123E-04
ROTZ at node9	7.217E-05

Table VM-NR1677-01-1.3: Element Forces and Moments Obtained from Spectrum Solve

Result	MAPDL
Element 12	
PX(I)	24.019

Result	MAPDL
VY(I)	7.514
VZ(I)	34.728
TX(I)	123.39
MY(I)	2131.700
MZ(I)	722.790
PX(J)	24.018
VY(J)	7.514
VZ(J)	34.728
TX(J)	123.390
MY(J)	2442.700
MZ(J)	786.730
Element 14	
PX(I)	5.1505
VY(I)	7.2868
VZ(I)	7.899
TX(I)	450.42
MY(I)	675.58
MZ(I)	314.97
PX(J)	6.006
VY(J)	6.589
VZ(J)	7.8822
TX(J)	157.85
MY(J)	858.09
MZ(J)	302.94

Note

PX (I) and PX (J) = Section axial force at node I and J

VY (I) and VY (J) = Section shear forces along Y direction at node I and J

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J

TX (I) and TX (J) = Section torsional moment at node I and J

MY (I) and MY (J) = Section bending moments along Y direction at node I and J

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J

VM-NR1677-01-2: NUREG/CR-1677: Volume 1, Benchmark Problem No. 2

Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic Analysis of Uniform Support Motion Response Spectrum Method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 2, Pages 48-80.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Structural Mass element (MASS21) 3-D 2-Node pipe (PIPE288)
Input Listing:	vm-nr1677-01-2a.dat

Test Case

For test case description, problem sketch, material properties, geometry properties and loadings refer to VM-NR1677-01-2-a (p. 1041)

Results Comparison

Table VM-NR1677-01-2.1: Frequencies Obtained from Modal Solution

Mode	Frequency
1	8.711
2	8.806
3	17.508
4	40.367
5	41.627

Table VM-NR1677-01-2.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node6	0.461
UY at node8	2.368E-03
UZ at node8	0.450
ROTX at node1	6.597E-03
ROTY at node9	1.289E-05
ROTZ at node1	6.722E-03

Table VM-NR1677-01-2.3: Element Forces and Moments obtained from Spectrum Solve

Result	MAPDL
Element 1	
PX(I)	558.93
VY(I)	109.28

Result	MAPDL
VZ(I)	109.22
TX(I)	1.622
MY(I)	5181.6
MZ(I)	5228.600
PX(J)	558.93
VY(J)	109.28
VZ(J)	109.22
TX(J)	1.622
MY(J)	279.490
MZ(J)	235.190
Element 18	
PX(I)	14.031
VY(I)	297.170
VZ(I)	12.389
TX(I)	0.140E-01
MY(I)	48.124
MZ(I)	1486.100
PX(J)	14.031
VY(J)	297.170
VZ(J)	12.389
TX(J)	0.140E-01
MY(J)	60.936
MZ(J)	4049.1

Note

PX (I) and PX (J) = Section axial force at node I and J

VY (I) and VY (J) = Section shear forces along Y direction at node I and J

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J

TX (I) and TX (J) = Section torsional moment at node I and J

MY (I) and MY (J) = Section bending moments along Y direction at node I and J

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J

VM-NR1677-01-3: NUREG/CR-1677: Volume 1, Benchmark Problem No. 3

Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic Analysis of Uniform Support Motion Response Spectrum Method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 3, Pages 81-121.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	3-D 3-Node pipe (PIPE289) 3-D 3-Node elbow (ELBOW290) Spring-Damper Element (COMBIN14) Mass element (MASS21)
Input Listing:	vm-nr1677-01-3a.dat

Test Case

For test case description, problem sketch, material properties, geometry properties and loadings refer to VM-NR1677-01-3-a (p. 1045)

Results Comparison

Table VM-NR1677-01-3.1: Frequencies Obtained from Modal Solution

Mode	Frequency
1	8.2671
2	10.272
3	18.561
4	20.367
5	22.799
6	27.072
7	33.995
8	38.227
9	44.457
10	51.959

Table VM-NR1677-01-3.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node96	0.302
UY at node98	0.309
UZ at node40	0.340
ROTX at node84	4.079e-03
ROTY at node76	5.866e-03

Result_Node	Value
ROTZ at node10	4.249e-03

Table VM-NR1677-01-3.3: Element Forces and Moments obtained from Spectrum Solve

Result	MAPDL
Element 28	
PX(I)	280.23
VY(I)	281.60
VZ(I)	420.65
TX(I)	4672.7
MY(I)	7469.5
MZ(I)	9523.2
PX(J)	280.25
VY(J)	283.90
VZ(J)	422.04
TX(J)	4673.3
MY(J)	14867.
MZ(J)	14934.
Element 50	
PX(I)	457.01
VY(I)	127.86
VZ(I)	172.27
TX(I)	7340.4
MY(I)	3436.9
MZ(I)	11940
PX(J)	474.01
VY(J)	96.883
VZ(J)	207.85
TX(J)	6568.8
MY(J)	2731.6
MZ(J)	12369

Note

PX (I) and PX (J) = Section axial force at node I and J

VY (I) and VY (J) = Section shear forces along Y direction at node I and J

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J

TX (I) and TX (J) = Section torsional moment at node I and J

MY (I) and MY (J) = Section bending moments along Y direction at node I and J

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J

VM-NR1677-01-4: NUREG/CR-1677: Volume 1, Benchmark Problem No. 4

Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic Analysis of Uniform Support Motion Response Spectrum Method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 5, Pages 122-217.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	3-D 3-Node pipe (PIPE289) 3-D 3-Node elbow (ELBOW290) Spring-Damper Element (COMBIN14) Mass element (MASS21)
Input Listing:	vm-nr1677-01-4a.dat

Test Case

For test case description, problem sketch, material properties, geometry properties and loadings refer to VM-NR1677-01-4-a (p. 1049)

Results Comparison

Table VM-NR1677-01-4.1: Frequencies Obtained from Modal Solution

Mode	Frequency
1	6.158
2	6.204
3	6.563
4	6.572
5	6.636
6	6.641
7	6.757
8	7.998
9	10.327
10	11.807
11	13.535
12	14.050
13	14.595
14	14.828
15	14.926
16	15.581
17	17.696
18	18.974
19	30.130

Mode	Frequency
20	31.071
21	31.075
22	31.084
23	31.236
24	42.849
25	43.112
26	46.740
27	46.746
28	48.361
29	48.366
30	52.126

Table VM-NR1677-01-4.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node103	0.449
UY at node140	7.036E-2
UZ at node103	0.978
ROTX at node103	4.188E-3
ROTY at node57	2.602E-3
ROTZ at node103	2.091E-3

Table VM-NR1677-01-4.3: Element Forces and Moments obtained from Spectrum Solve

Result	MAPDL
Element 28	
PX(I)	0.131E6
VY(I)	0.125E6
VZ(I)	0.128E6
TX(I)	0.123E8
MY(I)	0.707E7
MZ(I)	0.117E8
PX(J)	0.131E6
VY(J)	0.125E6
VZ(J)	0.128E6
TX(J)	0.122E8
MY(J)	0.409E7
MZ(J)	0.973E7
Element 80	

Result	**MAPDL**
PX(I)	0.1570E6
VY(I)	0.1043E6
VZ(I)	0.127E6
TX(I)	0.154E8
MY(I)	0.129E7
MZ(I)	0.159E8
PX(J)	0.1304E6
VY(J)	0.1402E6
VZ(J)	0.1168E6
TX(J)	0.1356E8
MY(J)	0.534E7
MZ(J)	0.121E8

Note

PX (I) and PX (J) = Section axial force at node I and J

VY (I) and VY (J) = Section shear forces along Y direction at node I and J

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J

TX (I) and TX (J) = Section torsional moment at node I and J

MY (I) and MY (J) = Section bending moments along Y direction at node I and J

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J

VM-NR1677-01-5: NUREG/CR-1677: Volume 1, Benchmark Problem No. 5

Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic Analysis of Uniform Support Motion Response Spectrum Method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 1, Pages 218-262.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	3-D 3-Node pipe (PIPE289) 3-D 3-Node elbow (ELBOW290) Spring-Damper Element (COMBIN14) Mass element (MASS21)
Input Listing:	vm-nr1677-01-5a.dat

Test Case

For test case description, problem sketch, material properties, geometry properties and loadings refer to VM-NR1677-01-5-a (p. 1055)

Results Comparison

Table VM-NR1677-01-5.1: Frequencies Obtained from Modal Solution

Mode	Frequency
1	4.374
2	5.335
3	10.525
4	12.112
5	17.056
6	19.626
7	23.188
8	27.248
9	31.833
10	40.841
11	43.669

Table VM-NR1677-01-5.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node54	0.404
UY at node83	7.887e-02
UZ at node81	0.187
ROTX at node20	6.508e-04
ROTY at node8	4.695e-03

Result_Node	Value
ROTZ at node10	2.426e-04

Table VM-NR1677-01-5.3: Element Forces and Moments obtained from Spectrum Solve

Result	MAPDL
Element 20	
PX(I)	2476.8
VY(I)	303.12
VZ(I)	500.91
TX(I)	20244
MY(I)	36322
MZ(I)	13030
PX(J)	68.889
VY(J)	4.8473
VZ(J)	0.513
TX(J)	0.423
MY(J)	6.751
MZ(J)	97.662
Element 50	
PX(I)	2531.8
VY(I)	313.55
VZ(I)	482.90
TX(I)	20648
MY(I)	31772
MZ(I)	10390
PX(J)	2124.0
VY(J)	1345.9
VZ(J)	528.01
TX(J)	23581
MY(J)	29556
MZ(J)	11987

Note

PX (I) and PX (J) = Section axial force at node I and J

VY (I) and VY (J) = Section shear forces along Y direction at node I and J

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J

TX (I) and TX (J) = Section torsional moment at node I and J

MY (I) and MY (J) = Section bending moments along Y direction at node I and J

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J

VM-NR1677-01-6: NUREG/CR-1677: Volume 1, Benchmark Problem No. 6

Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic analysis of uniform support motion response spectrum method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 1, Pages 263-327
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	3-D 3-Node pipe (PIPE289) 3-D 3-Node elbow (ELBOW290) Spring-Damper Element (COMBIN14) Mass element (MASS21)
Input Listing:	vm-nr1677-01-6a.dat

Test Case

For test case description, problem sketch, material properties, geometry properties and loadings refer to VM-NR1677-01-6-a (p. 1061)

Results Comparison

Table VM-NR1677-01-6.1: Frequencies Obtained from Modal Solution

Mode	Frequency
1	6.343
2	9.949
3	10.092
4	10.595
5	14.995
6	17.391
7	19.099
8	19.678
9	21.253
10	23.578
11	28.767
12	29.697
13	30.887
14	32.549
15	37.329
16	42.621
17	47.809
18	49.877
19	50.446

Mode	Frequency
20	53.446
21	56.732
22	58.951
23	67.542
24	70.246
25	74.189
26	79.824
27	80.667
28	89.019
29	90.993
30	93.536
31	100.38

Table VM-NR1677-01-6.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node58	2.999E-2
UY at node107	9.129E-2
UZ at node10	2.069E-2
ROTX at node1	2.917E-4
ROTY at node1	3.533E-4
ROTZ at node71	3.153E-4

Table VM-NR1677-01-6.3: Element Forces and Moments obtained from Spectrum Solve

Res-ult	Target
Element 28	
PX(I)	1089.200
VY(I)	2022.600
VZ(I)	600.640
TX(I)	53740.000
MY(I)	0.174E6
MZ(I)	0.396E6
PX(J)	1089.200
VY(J)	2022.6
VZ(J)	600.64
TX(J)	53740
MY(J)	0.205E6
MZ(J)	0.282E6

Res-ult	Target
Element 50	
PX(I)	1808.6
VY(I)	1831.1
VZ(I)	1487.6
TX(I)	95719
MY(I)	64400
MZ(I)	0.16524E6
PX(J)	1776.3
VY(J)	1848.2
VZ(J)	1492.7
TX(J)	0.1003E6
MY(J)	71717
MZ(J)	0.1788E6

Note

PX (I) and PX (J) = Section axial force at node I and J

VY (I) and VY (J) = Section shear forces along Y direction at node I and J

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J

TX (I) and TX (J) = Section torsional moment at node I and J

MY (I) and MY (J) = Section bending moments along Y direction at node I and J

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J

VM-NR1677-01-7: NUREG/CR-1677: Volume 1, Benchmark Problem No. 7

Overview

Reference:	P.Bezler, M. Hartzman & M. Reich, *Dynamic Analysis of Uniform Support Motion Response Spectrum Method*, (NUREG/CR-1677), Brookhaven National Laboratory, August 1980, Problem 1, Pages 328-402
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	3-D 3-Node pipe (PIPE289) 3-D 3-Node elbow (ELBOW290) Mass element (MASS21)
Input Listing:	vm-nr1677-01-7a.dat

Test Case

For test case description, problem sketch, material properties, geometry properties and loadings refer to VM-NR1677-01-7-a (p. 1069)

Results Comparison

Table VM-NR1677-01-7.1: Frequencies Obtained from Modal Solution

Mode	Frequency
1	5.264
2	8.003
3	8.382
4	9.272
5	9.518
6	10.100
7	13.754
8	15.278
9	15.374
10	17.931
11	19.060
12	23.292
13	25.599
14	26.055
15	27.514
16	28.968
17	30.846
18	35.705
19	37.484

Mode	Frequency
20	44.113
21	44.678
22	48.567

Table VM-NR1677-01-7.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node8	5.467E-2
UY at node8	0.206
UZ at node11	0.194
ROTX at node7	4.738E-3
ROTY at node14	1.145E-3
ROTZ at node50	9.839E-5

Table VM-NR1677-01-7.3: Element Forces and Moments obtained from Spectrum Solve

Result	MAPDL
Element 28	
PX(I)	32.973
VY(I)	17.923
VZ(I)	83.074
TX(I)	3735.5
MY(I)	2077.1
MZ(I)	991.86
PX(J)	32.973
VY(J)	17.923
VZ(J)	83.074
TX(J)	3735.5
MY(J)	3303.4
MZ(J)	732.58
Element 50	
PX(I)	214.36
VY(I)	28.649
VZ(I)	32.196
TX(I)	419.19
MY(I)	1047.6
MZ(I)	6256.2
PX(J)	201.57

Result	MAP-DL
VY(J)	34.862
VZ(J)	27.597
TX(J)	882.44
MY(J)	808.86
MZ(J)	6196.5

Note

PX (I) and PX (J) = Section axial force at node I and J

VY (I) and VY (J) = Section shear forces along Y direction at node I and J

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J

TX (I) and TX (J) = Section torsional moment at node I and J

MY (I) and MY (J) = Section bending moments along Y direction at node I and J

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J

VM-NR1677-02-1: NUREG/CR-1677: Volume 2, Benchmark Problem No. 1

Overview

Reference:	NUREG/CR-1677 Volume II Piping Benchmark Problems, Dynamic Analysis Independent Support Motion Response Spectrum Method, P. Bezler, M. Subudhi & M. Hartzman of Brookhaven National Laboratory, prepared for the U.S. Nuclear Regulatory Commission, August 1985, Problem 1, pages 18-76.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	3-D 3-Noded Elbow (ELBOW290) 3-D 3-Noded Pipe (PIPE289) Spring-Damper Element (COMBIN14)
Input Listing:	vm-nr1677-02-1a.dat vm-nr1677-02-1b.dat vm-nr1677-02-1c.dat

Test Case

For test case description, problem sketch, material properties, geometry properties and loadings refer to VM-NR1677-02-1-a (p. 1077)

Results Comparison

Table VM-NR1677-02-1.1: Frequencies Obtained from Modal Solution

Mode	Frequency
1	6.1125
2	6.3518
3	7.7648
4	8.7922
5	12.185
6	12.627
7	13.954
8	14.865
9	15.986
10	18.059
11	18.919
12	21.600
13	22.957
14	24.934
15	31.868

Case 1: Envelope Spectrum Excitation

Table VM-NR1677-02-1.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node19	6.154E-1
UY at node275	1.216E-1
UZ at node11	8.415E-2
ROTX at node220	1.503E-3
ROTY at node11	1.315E-3
ROTZ at node265	1.485E-3

Table VM-NR1677-02-1.3: Element Forces and Moments Obtained from Spectrum Solve

Result	MAPDL
Element 120	
PX(I)	119.450
VY(I)	61.769
VZ(I)	57.027
TX(I)	596.71
MY(I)	1849.5
MZ(I)	2815.8
PX(J)	119.450
VY(J)	61.897
VZ(J)	57.209
TX(J)	596.73
MY(J)	2572.5
MZ(J)	3609.9
Element 131	
PX(I)	230.51
VY(I)	63.425
VZ(I)	26.172
TX(I)	281.33
MY(I)	1037
MZ(I)	2216.7
PX(J)	193.2
VY(J)	144.24
VZ(J)	22.136
TX(J)	662.31

Result	MAPDL
MY(J)	1316.9
MZ(J)	1146.6

Case 2: Independent Support Excitation with SRSS Combination

Table VM-NR1677-02-1.4: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node19	8.338E-2
UY at node226	1.949E-1
UZ at node224	1.835E-1
ROTX at node196	1.828E-3
ROTY at node208	2.168E-3
ROTZ at node211	2.058E-3

Table VM-NR1677-02-1.5: Element Forces and Moments Obtained from Spectrum Solve

Result	MAPDL
Element 120	
PX(I)	89.219
VY(I)	68.747
VZ(I)	68.736
TX(I)	445.59
MY(I)	3401.100
MZ(I)	3655.000
PX(J)	89.220
VY(J)	68.840
VZ(J)	68.851
TX(J)	445.61
MY(J)	4269.500
MZ(J)	4540.500
Element 131	
PX(I)	163.49
VY(I)	46.279
VZ(I)	29.814
TX(I)	699.60
MY(I)	919.42
MZ(I)	2275.1

Result	MAPDL
PX(J)	139.19
VY(J)	99.711
VZ(J)	26.523
TX(J)	549.10
MY(J)	1500.2
MZ(J)	1974.6

Case 3: Independent Support Excitation with Absolute Sum Combination

Table VM-NR1677-02-1.6: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node19	9.336E-2
UY at node229	1.497E-1
UZ at node11	1.277E-1
ROTX at node254	1.884E-3
ROTY at node11	1.998E-3
ROTZ at node254	1.767E-3

Table VM-NR1677-02-1.7: Element Forces and Moments Obtained from Spectrum Solve

Result	MAPDL
Element 120	
PX(I)	112.890
VY(I)	68.622
VZ(I)	62.717
TX(I)	654.090
MY(I)	2461.800
MZ(I)	3240.700
PX(J)	112.890
VY(J)	68.758
VZ(J)	62.887
TX(J)	654.120
MY(J)	3241.100
MZ(J)	4118.400
Element 131	
PX(I)	226.95
VY(I)	64.98
VZ(I)	28.212

Result	MAP-DL
TX(I)	496.04
MY(I)	1033.7
MZ(I)	2468.9
PX(J)	189.18
VY(J)	143.57
VZ(J)	24.531
TX(J)	672.32
MY(J)	1414.5
MZ(J)	1637.8

Note

PX (I) and PX (J) = Section axial force at node I and J

VY (I) and VY (J) = Section shear forces along Y direction at node I and J

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J

TX (I) and TX (J) = Section torsional moment at node I and J

MY (I) and MY (J) = Section bending moments along Y direction at node I and J

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J

VM-NR1677-02-2: NUREG/CR-1677: Volume 2, Benchmark Problem No. 2

Overview

Reference:	NUREG/CR-1677 Volume II Piping Benchmark Problems, Dynamic Analysis Independent Support Motion Response Spectrum Method, P. Bezler, M. Subudhi & M. Hartzman of Brookhaven National Laboratory, prepared for the U.S. Nuclear Regulatory Commission, August 1985, Problem 2, pages 77-137.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Structural Mass Element (MASS21) Spring-Damper Element (COMBIN14) 3-D 3-Noded Pipe (PIPE289) 3-D 3-Noded Elbow (ELBOW290)
Input Listing:	vm-nr1677-2-2a.dat vm-nr1677-2-2b.dat vm-nr1677-2-2c.dat

Test Case

For test case description, problem sketch, material properties, geometry properties and loadings refer to VM-NR1677-02-2-a (p. 1087)

Results Comparison

Table VM-NR1677-02-2.1: Frequencies Obtained from Modal Solution

Mode	Frequency
1	9.285
2	12.734
3	15.363
4	17.264
5	21.563
6	25.375
7	32.183
8	38.231
9	40.953
10	47.699
11	56.222
12	59.593
13	60.976
14	68.106
15	79.681
16	82.948

Mode	Frequency
17	99.141
18	118.660
19	124.250
20	126.730
21	131.230
22	136.750
23	140.370
24	170.460
25	190.260

Case 1: Envelope Spectrum Excitation

Table VM-NR1677-02-2.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node95	9.820E-2
UY at node84	4.020E-2
UZ at node40	1.090E-1
ROTX at node6	1.057E-3
ROTY at node79	1.972E-3
ROTZ at node45	8.993E-4

Table VM-NR1677-02-2.3: Element Forces and Moments Obtained from Spectrum Solve

Result	MAPDL
Element 1	
PX(I)	75. 044
VY(I)	93. 756
VZ(I)	187.19
TX(I)	5283.4
MY(I)	16943
MZ(I)	7023.9
PX(J)	74.932
VY(J)	91.282
VZ(J)	184.77
TX(J)	5282.4
MY(J)	12044
MZ(J)	4829.4
Element 41	
PX(I)	467.85

Result	MAPDL
VY(I)	533.21
VZ(I)	24.813
TX(I)	3066.1
MY(I)	856.66
MZ(I)	12294
PX(J)	547.67
VY(J)	440.21
VZ(J)	27.967
TX(J)	2992.1
MY(J)	1086.7
MZ(J)	15552

Case 2: Independent Support Excitation with SRSS Combination

Table VM-NR1677-02-2.4: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node95	6.160E-2
UY at node83	2.528E-2
UZ at node40	6.843E-2
ROTX at node6	6.627E-4
ROTY at node79	1.238E-3
ROTZ at node45	5.616E-4

Table VM-NR1677-02-2.5: Element Forces and Moments Obtained from Spectrum Solve

Result	MAPDL
Element 1	
PX(I)	53.296
VY(I)	52.622
VZ(I)	118.32
TX(I)	3308.4
MY(I)	10622
MZ(I)	4142.2
PX(J)	53.208
VY(J)	51.203
VZ(J)	116.67
TX(J)	3307.8
MY(J)	7544.9

Result	MAPDL
MZ(J)	2913.9
Element 41	
PX(I)	278.52
VY(I)	334.50
VZ(I)	16.711
TX(I)	1931.3
MY(I)	772.49
MZ(I)	7489.6
PX(J)	329.12
VY(J)	277.34
VZ(J)	19.226
TX(J)	1897.5
MY(J)	828.46
MZ(J)	9551.4

Case 3: Independent Support Excitation with Absolute Sum Combination

Table VM-NR1677-02-2.6: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node95	8.663E-2
UY at node84	3.731E-2
UZ at node40	9.622E-2
ROTX at node6	9.318E-4
ROTY at node79	1.741E-3
ROTZ at node45	7.897E-4

Table VM-NR1677-02-2.7: Element Forces and Moments Obtained from Spectrum Solve

Result	MAPDL
Element 1	
PX(I)	77.026
VY(I)	77.565
VZ(I)	164.28
TX(I)	4641.5
MY(I)	14876
MZ(I)	5923.9
PX(J)	76.933

Result	MAPDL
VY(J)	75.590
VZ(J)	162.090
TX(J)	4640.600
MY(J)	10590.000
MZ(J)	4122.400
Element 41	
PX(I)	387.53
VY(I)	466.17
VZ(I)	23.197
TX(I)	2717.8
MY(I)	1264.2
MZ(I)	10537
PX(J)	458.82
VY(J)	385.60
VZ(J)	28.199
TX(J)	2677.9
MY(J)	1296.6
MZ(J)	13430

Note

PX (I) and PX (J) = Section axial force at node I and J

VY (I) and VY (J) = Section shear forces along Y direction at node I and J

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J

TX (I) and TX (J) = Section torsional moment at node I and J

MY (I) and MY (J) = Section bending moments along Y direction at node I and J

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J

VM-NR1677-02-3: NUREG/CR-1677: Volume 2, Benchmark Problem No. 3

Overview

Reference:	NUREG/CR-1677 Volume II Piping Benchmark Problems, Dynamic Analysis Independent Support Motion Response Spectrum Method, P. Bezler, M. Subudhi & M. Hartzman of Brookhaven National Laboratory, prepared for the U.S. Nuclear Regulatory Commission, August 1985, Problem 3, pages 138-243.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Spring-Damper Elements (COMBIN14) 3-D 3-Noded Pipe Elements (PIPE289) 3-D 3-Noded Elbow Elements (ELBOW290)
Input Listing:	vm-nr1677-02-3a.dat vm-nr1677-02-3b.dat vm-nr1677-02-3c.dat

Test Case

For test case description, problem sketch, material properties, geometry properties and loadings refer to VM-NR1677-02-3-a (p. 1097)

Results Comparison

Table VM-NR1677-02-3.1: Frequencies Obtained from Modal Solution

Mode	Frequency
1	7.680
2	10.554
3	14.871
4	15.996
5	16.589
6	18.859
7	21.795
8	24.679
9	26.787
10	29.395
11	30.755
12	32.092
13	33.541
14	34.924
15	36.610

Case 1: Envelope Spectrum Excitation

Table VM-NR1677-02-3.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node151	0.607
UY at node87	0.963
UZ at node92	0.709
ROTX at node92	1.052E-2
ROTY at node72	9.991E-3
ROTZ at node160	1.217E-2

Table VM-NR1677-02-3.3: Element Forces and Moments Obtained from Spectrum Solve

Result	MAPDL
Element 1	
PX(I)	1.0505E5
VY(I)	74.696
VZ(I)	1296.4
TX(I)	15196
MY(I)	94990
MZ(I)	3232.8
PX(J)	1.0505E5
VY(J)	71.945
VZ(J)	1257.5
TX(J)	15176
MY(J)	40883
MZ(J)	552.37
Element 50	
PX(I)	2120.7
VY(I)	480.45
VZ(I)	50.816
TX(I)	15296
MY(I)	4421.8
MZ(I)	45147
PX(J)	2113.4
VY(J)	489.97
VZ(J)	50.813
TX(J)	15346
MY(J)	4295.6

Result	MAPDL
MZ(J)	45705

Case 2: Independent Support Excitation with SRSS Combination

Table VM-NR1677-02-3.4: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node63	5.416E-1
UY at node87	3.564E-1
UZ at node63	5.116E-1
ROTX at node58	8.109E-3
ROTY at node72	6.860E-3
ROTZ at node61	6.983E-3

Table VM-NR1677-02-3.5: Element Forces and Moments Obtained from Spectrum Solve

Result	MAPDL
Element 1	
PX(I)	6.4759E4
VY(I)	1.0495E2
VZ(I)	1.622E3
TX(I)	2.076E4
MY(I)	1.109E5
MZ(I)	4.9121E3
PX(J)	6.4758E4
VY(J)	1.0168E2
VZ(J)	1.5656E3
TX(J)	2.0729E4
MY(J)	4.5190E4
MZ(J)	9.6992E2
Element 50	
PX(I)	4648.6
VY(I)	582.45
VZ(I)	66.974
TX(I)	20650
MY(I)	6754.9
MZ(I)	62055
PX(J)	4635.3
VY(J)	648.45

Result	MAP-DL
VZ(J)	66.66
TX(J)	20664
MY(J)	6782.7
MZ(J)	62257

Case 3: Independent Support Excitation with Absolute Sum Combination

Table VM-NR1677-02-3.6: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node63	7.632E-1
UY at node87	4.772E-1
UZ at node63	7.228E-1
ROTX at node58	1.146E-2
ROTY at node52	9.350E-3
ROTZ at node61	9.866E-3

Table VM-NR1677-02-3.7: Element Forces and Moments Obtained from Spectrum Solve

Result	MAP-DL
Element 1	
PX(I)	9.0205E4
VY(I)	1.6169E2
VZ(I)	2.3389E3
TX(I)	3.0557E4
MY(I)	1.6159E5
MZ(I)	7.7189E3
PX(J)	9.0204E4
VY(J)	1.5636E2
VZ(J)	2.2591E3
TX(J)	3.0507E4
MY(J)	6.6443E4
MZ(J)	1.523E3
Element 50	
PX(I)	6375
VY(I)	843.63
VZ(I)	97.166
TX(I)	30219
MY(I)	10403

Result	MAPDL
MZ(I)	88387
PX(J)	6356.5
VY(J)	928.01
VZ(J)	96.616
TX(J)	30207
MY(J)	10538
MZ(J)	88772

Note

PX (I) and PX (J) = Section axial force at node I and J

VY (I) and VY (J) = Section shear forces along Y direction at node I and J

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J

TX (I) and TX (J) = Section torsional moment at node I and J

MY (I) and MY (J) = Section bending moments along Y direction at node I and J

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J

VM-NR1677-02-4: NUREG/CR-1677: Volume 2, Benchmark Problem No. 4

Overview

Reference:	NUREG/CR-1677 Volume II Piping Benchmark Problems, Dynamic Analysis Independent Support Motion Response Spectrum Method, P. Bezler, M. Subudhi & M. Hartzman of Brookhaven National Laboratory, prepared for the U.S. Nuclear Regulatory Commission, August 1985, Problem 1, pages 244-445.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Spring-Damper Elements (COMBIN14) Structural Mass Elements (MASS21) 3-D 3-Noded Pipe Elements (PIPE289) 3-D 3-Noded Elbow Elements (ELBOW290)
Input Listing:	vm-nr1677-02-4a.dat vm-nr1677-02-4cdat

Test Case

For test case description, problem sketch, material properties, geometry properties and loadings refer to VM-NR1677-02-4-a (p. 1109)

Results Comparison

Table VM-NR1677-02-4.1: Frequencies Obtained from Modal Solution

Mode	Frequency
1	2.632
2	2.917
3	4.570
4	4.708
5	5.749
6	5.893
7	7.465
8	7.871
9	10.011
10	10.276
11	10.738
12	10.979
13	12.433
14	12.624
15	13.328
16	13.977
17	14.495

Mode	Frequency
18	14.760
19	15.512
20	15.739
21	16.198
22	16.908
23	17.324
24	17.391
25	17.596
26	18.757
27	19.068
28	20.121
29	21.592
30	22.318
31	22.465
32	22.734
33	24.195
34	25.335
35	26.565
36	26.736
37	27.103
38	27.665
39	28.827
40	31.297
41	31.604
42	32.254
43	32.491
44	35.629
45	36.756
46	37.032
47	37.310
48	38.070
49	39.199
50	40.345

Case 1: Envelope Spectrum Excitation

Table VM-NR1677-02-4.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node470	0.861

Result_Node	Value
UY at node243	0.934
UZ at node425	1.094
ROTX at node172	6.277E-3
ROTY at node217	9.708E-3
ROTZ at node127	7.817E-3

Table VM-NR1677-02-4.3: Element Forces and Moments Obtained from Spectrum Solve

Result	MAPDL
Element 1	
PX(I)	2060.2
VY(I)	3667.3
VZ(I)	2519.6
TX(I)	0.102E6
MY(I)	0.2327E6
MZ(I)	0.339E6
PX(J)	2060.2
VY(J)	3667.3
VZ(J)	2519.6
TX(J)	0.109E6
MY(J)	0.1979E6
MZ(J)	0.280E6
Element 240	
PX(I)	2139.4
VY(I)	440.79
VZ(I)	591.38
TX(I)	25478
MY(I)	31215
MZ(I)	0.21133E6
PX(J)	2074.1
VY(J)	382.69
VZ(J)	594.76
TX(J)	16315
MY(J)	36765
MZ(J)	0.21079E6

Case 2: Independent Support Excitation with Absolute Sum Combination

Table VM-NR1677-02-4.4: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node470	0.687
UY at node243	0.743
UZ at node425	0.975
ROTX at node208	5.212E-3
ROTY at node217	7.822E-3
ROTZ at node175	5.041E-3

Table VM-NR1677-02-4.5: Element Forces and Moments Obtained from Spectrum Solve

Result	MAPDL
Element 1	
PX(I)	1987.6
VY(I)	2907.200
VZ(I)	2203.500
TX(I)	81008
MY(I)	0.209E6
MZ(I)	0.272E6
PX(J)	1987.6
VY(J)	2907.200
VZ(J)	2203.500
TX(J)	81008
MY(J)	0.177E6
MZ(J)	0.225E6
Element 240	
PX(I)	1750.2
VY(I)	361.53
VZ(I)	414.49
TX(I)	20977
MY(I)	25553
MZ(I)	0.16819E6
PX(J)	1707.7
VY(J)	281.94
VZ(J)	420.74
TX(J)	13449

Result	MAPDL
MY(J)	30221
MZ(J)	0.16779E6

Note

PX (I) and PX (J) = Section axial force at node I and J

VY (I) and VY (J) = Section shear forces along Y direction at node I and J

VZ (I) and VZ (J) = Section shear forces along Z direction at node I and J

TX (I) and TX (J) = Section torsional moment at node I and J

MY (I) and MY (J) = Section bending moments along Y direction at node I and J

MZ (I) and MZ (J) = Section bending moments along Z direction at node I and J

VM-NR6645-01-1: NUREG/CR-6645-01-1

Overview

Reference:	Reevaluation of Regulatory Guidance on modal response combination methods for seismic response spectrum analysis NUREC/CR-6645, Brookhaven National Laboratory, December 1999.
Analysis Type(s):	Modal analysis (**ANTYPE** = 2) Spectral analysis (**ANTYPE** = 8)
Element Type(s):	Spring-Damper Element (COMBIN14) 3-D 2-Noded Straight Pipe Element (PIPE288) 3-D 3-Noded Curved Pipe Element (ELBOW290)
Input Listing:	vm-nr6645-01-1a.dat vm-nr6645-01-2a.dat

Test Case

For test case description, problem sketch, material properties, geometry properties and loadings refer to VM-NR6645-01-1-a (p. 1125)

Results Comparison

Table VM-NR6645-01-1.1: Frequencies Obtained from Modal Solution

Mode	Frequency
1	2.912
2	4.439
3	4.819
4	4.976
5	6.837
6	7.401
7	7.851
8	10.858
9	10.975
10	11.422
11	11.652
12	13.837
13	14.052
14	14.145

Case 1: With missing mass effect (ZPA = 0.54g)

Table VM-NR6645-01-1.2: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node279	2.540E-1
UY at node105	1.597E-1
UZ at node50	2.261E-1
ROTX at node78	1.426E-3
ROTY at node82	5.475E-3
ROTZ at node113	3.112E-3

Table VM-NR6645-01-1.3: Element Forces and Moments Obtained from Spectrum Solve

Result	MAPDL
Element 1	
PX(I)	58.172
VY(I)	19.588
VZ(I)	28.124
TX(I)	863.48
MY(I)	937.49
MZ(I)	1814.8
PX(J)	57.364
VY(J)	19.585
VZ(J)	28.123
TX(J)	863.48
MY(J)	873.13
MZ(J)	1750.8
Element 28	
PX(I)	153.48
VY(I)	17.322
VZ(I)	41.263
TX(I)	184.21
MY(I)	932.95
MZ(I)	700.72
PX(J)	73.317
VY(J)	0.237e-05
VZ(J)	782.26
TX(J)	782.26
MY(J)	541.90

Result	MAPDL
MZ(J)	541.90

Case 2: With missing mass effect (ZPA = 0.54g) and rigid responses effect (Lindley method)

Table VM-NR6645-01-1.4: Maximum Displacements and Rotations Obtained from Spectrum Solve

Result_Node	Value
UX at node274	2.748E-1
UY at node105	1.410E-1
UZ at node50	2.088E-1
ROTX at node78	1.402E-3
ROTY at node81	5.986E-3
ROTZ at node113	2.920E-3

Table VM-NR6645-01-1.5: Element Forces and Moments Obtained from Spectrum Solve

Result	MAPDL
Element 1	
PX(I)	55.88
VY(I)	8.3028
VZ(I)	13.183
TX(I)	411.81
MY(I)	903.74
MZ(I)	1166.9
PX(J)	54.219
VY(J)	8.3021
VZ(J)	13.182
TX(J)	411.81
MY(J)	879.78
MZ(J)	1148.0
Element 28	
PX(I)	214.35
VY(I)	12.448
VZ(I)	33.906
TX(I)	175.49
MY(I)	1109
MZ(I)	642.83
PX(J)	101.92

Result	**MAPDL**
VY(J)	0.331E-5
VZ(J)	840.82
TX(J)	840.82
MY(J)	468.83
MZ(J)	468.83

Appendix A. Verification Test Case Input Listings

This appendix contains all of the input listings for the VM test cases documented in Part I: Verification Test Case Descriptions (p. 1).

VM1 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM1
/PREP7
/TITLE, VM1, STATICALLY INDETERMINATE REACTION FORCE ANALYSIS
C***      STR. OF MATL., TIMOSHENKO, PART 1, 3RD ED., PAGE 26, PROB.10
ANTYPE,STATIC                  ! STATIC ANALYSIS
ET,1,LINK180
SECTYPE,1,LINK
SECDATA,1            ! CROSS SECTIONAL AREA (ARBITRARY) = 1
MP,EX,1,30E6
N,1
N,2,,4
N,3,,7
N,4,,10
E,1,2                          ! DEFINE ELEMENTS
EGEN,3,1,1
D,1,ALL,,,4,3                  ! BOUNDARY CONDITIONS AND LOADING
F,2,FY,-500
F,3,FY,-1000
FINISH
/SOLU
OUTPR,BASIC,1
```

```
OUTPR,NLOAD,1
SOLVE
FINISH
/POST1
NSEL,S,LOC,Y,10
FSUM
*GET,REAC_1,FSUM,,ITEM,FY
NSEL,S,LOC,Y,0
FSUM
*GET,REAC_2,FSUM,,ITEM,FY

*DIM,LABEL,CHAR,2
*DIM,VALUE,,2,3
LABEL(1) = 'R1, lb','R2, lb '
*VFILL,VALUE(1,1),DATA,900.0,600.0
*VFILL,VALUE(1,2),DATA,ABS(REAC_1),ABS(REAC_2)
*VFILL,VALUE(1,3),DATA,ABS(REAC_1 / 900) ,ABS( REAC_2 / 600)
/OUT,vm1,vrt
/COM
/COM,------------------- VM1 RESULTS COMPARISON ---------------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.1,'  ',F10.1,'   ',1F5.3)
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vm1,vrt
```

VM2 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM2
/PREP7
MP,PRXY,,0.3
/TITLE, VM2, BEAM STRESSES AND DEFLECTIONS
C***         STR. OF MATL., TIMOSHENKO, PART 1, 3RD ED., PAGE 98, PROB. 4
ANTYPE,STATIC
ET,1,BEAM188
KEYOPT,1,9,3                  ! OUTPUT AT 9 INTERMEDIATE LOCATIONS
KEYOPT,1,3,3                  ! CUBIC SHAPE FUNCTION
SECT,1,BEAM,I
W_F=1.048394965
W_W=0.6856481
SECD,15,15,28+(2*W_F),W_F,W_F,W_W
MP,EX,1,30E6
N,1                           ! DEFINE NODES AND ELEMENTS
N,5,480
N,6,60,1 $ N,10,420,1
FILL,1,5
FILL,6,10
E,1,2,6
EGEN,4,1,1
D,2,UX,,,,,UY                 ! BOUNDARY CONDITIONS AND LOADING
D,4,UY
NSEL,S,LOC,Y,0
D,ALL,UZ
D,ALL,ROTX
D,ALL,ROTY
NALL
SFBEAM,1,1,PRES,(10000/12)
SFBEAM,4,1,PRES,(1E4/12)
FINISH
/SOLU
OUTPR,BASIC,1
/OUT,SCRATCH
SOLVE
```

```
FINISH
/POST1
SET,1,1
/OUT,
PRNSOL,U,COMP
PRNSOL,ROT,COMP
PLDISP,1
MID_NODE = NODE (240,,, )
*GET,DISP,NODE,MID_NODE,U,Y
MID_ELM = ENEARN (MID_NODE)
ETABLE,STRS,LS,1
*GET,STRSS,ELEM,MID_ELM,ETAB,STRS
*DIM,LABEL,CHAR,2
*DIM,VALUE,,2,3
LABEL(1) = 'STRS_psi','DEF_in'
*VFILL,VALUE(1,1),DATA,-11400,0.182
*VFILL,VALUE(1,2),DATA,STRSS,DISP
*VFILL,VALUE(1,3),DATA,ABS(STRSS /11400 ) ,ABS( DISP /0.182 )
/OUT,vm2,vrt
/COM
/COM,-------------------VM2 RESULTS COMPARISON ---------------------
/COM,
/COM,          |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vm2,vrt
```

VM3 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM3
/PREP7
/TITLE, VM3, THERMALLY LOADED SUPPORT STRUCTURE
C***      STR. OF MATL., TIMOSHENKO, PART 1, 3RD ED., PAGE 30, PROB. 9
ANTYPE,STATIC             ! STATIC ANALYSIS
ET,1,LINK180
SECTYPE,1,LINK
SECDATA,0.1
MP,EX,1,16E6
MP,ALPX,1,92E-7
MP,EX,2,30E6
MP,ALPX,2,70E-7
TREF,70                   ! REFERENCE TEMPERATURE
N,1,-10                   ! DEFINE NODES AND ELEMENTS
N,3,10
FILL
N,4,-10,-20
N,6,10,-20
FILL
E,1,4
E,3,6
MAT,2
E,2,5
CP,1,UY,5,4,6
D,1,ALL,,,3               ! BOUNDARY CONDITIONS AND LOADING
F,5,FY,-4000
BFUNIF,TEMP,80            ! UNIFORM TEMPERATURE (TREF+10)
FINISH
/SOLU
OUTPR,BASIC,1
OUTPR,NLOAD,1
NSUBST,1
SOLVE
FINISH
```

```
/POST1
STEEL_N  = NODE (,,,)
COPPER_N = NODE (10,0,0)
STEEL_E = ENEARN (STEEL_N)
COPPER_E = ENEARN (COPPER_N)
ETABLE,STRS_ST,LS,1
ETABLE,STRS_CO,LS,1
*GET,STRSS_ST,ELEM,STEEL_E,ETAB,STRS_ST
*GET,STRSS_CO,ELEM,COPPER_E,ETAB,STRS_CO

*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'STRSS_ST','STRSS_CO'
LABEL(1,2) = ' (psi)  ',' (psi)  '
*VFILL,VALUE(1,1),DATA,19695,10152
*VFILL,VALUE(1,2),DATA,STRSS_ST,STRSS_CO
*VFILL,VALUE(1,3),DATA,ABS(STRSS_ST/19695 ) ,ABS( STRSS_CO/10152 )
/COM
/OUT,vm3,vrt
/COM,------------------- VM3 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vm3,vrt
```

VM4 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM4
/PREP7
/TITLE, VM4, DEFLECTION OF A HINGED SUPPORT
C***     STR. OF MATL., TIMOSHENKO, PART 1, 3RD ED., PAGE 10, PROB. 2
L=15*12                         ! LENGTH OF BAR IN INCHES
*AFUN,DEG                       ! TRIG FUNCTIONS IN DEGREES
THETA=30                        ! ANGLE TO BE USED TO CALCULATE A AND B
A=2*L*COS(THETA)                ! CALCULATED X LOCATION - NODE 3
B=L*SIN(THETA)                  ! CALCULATED Y LOCATION - NODE 2
ET,1,LINK180
SECTYPE,1,LINK
SECDATA,0.5
MP,EX,1,30E6
N,1
N,2,A/2,-B                      ! X LOCATION = A/2; A AND B AS ABOVE
N,3,A
E,1,2
E,2,3
D,1,ALL,,,3,2
F,2,FY,-5000
OUTPR,,1
FINISH
/SOLU
SOLVE
FINISH
/POST1
MID_NODE = NODE (A/2,-B,0 )
*GET,DISP,NODE,MID_NODE,U,Y
LEFT_EL = ENEARN (MID_NODE)
ETABLE,STRS,LS,1
*GET,STRSS,ELEM,LEFT_EL,ETAB,STRS

*DIM,LABEL,CHAR,2
*DIM,VALUE,,2,3
```

```
LABEL(1) = 'STRS_psi','DEF_in'
*VFILL,VALUE(1,1),DATA,10000,-0.120
*VFILL,VALUE(1,2),DATA,STRSS,DISP
*VFILL,VALUE(1,3),DATA,ABS(STRSS /10000 ) ,ABS( DISP /0.120 )
/OUT,vm4,vrt
/COM
/COM,------------------- VM4 RESULTS COMPARISON ---------------------
/COM,
/COM,          |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vm4,vrt
```

VM5 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM5
/PREP7
/TITLE, VM5, LATERALLY LOADED TAPERED SUPPORT STRUCTURE (QUAD. ELEMENTS)
C***     MECHANICS OF SOLIDS, CRANDALL AND DAHL, 1959, PAGE 342, PROB. 7.18
C***          USING PLANE42 ELEMENTS
ANTYPE,STATIC
ET,1,PLANE182,2,,3
R,1,2
MP,EX,1,30E6
MP,NUXY,1,0.0            ! POISSON'S RATIO SET TO 0.0 TO AGREE WITH BEAM THEORY
N,1,25
N,7,75
FILL
N,8,25,-3
N,14,75,-9
FILL
E,2,1,8,9
EGEN,6,1,1
NSEL,S,LOC,X,75
D,ALL,ALL                ! CONSTRAIN NODES AT FIXED END
NSEL,ALL
F,1,FY,-4000
FINISH
/SOLU
OUTPR,,1
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
END_NODE = NODE (75,0,0)
*GET,STS_E_182,NODE,END_NODE,S,X       ! STRESS AT FIXED END (END NODE )
PLDISP,2
MID_NODE = NODE (50,0,0)
*GET,STS_M_182,NODE,MID_NODE,S,EQV
FINISH
/PREP7
/TITLE, VM5, LATERALLY LOADED TAPERED SUPPORT STRUCTURE (QUAD. ELEMENTS)
C***          MECHANICS OF SOLIDS, CRANDALL AND DAHL, 1959, PAGE 342, PROB. 7.18
C***          USING PLANE183 ELEMENTS
C***                      ! CHANGE ELEMENT TYPE TO HIGHER ORDER PLANE82
ET,1,PLANE183,,,3
EMID                      ! ADD MIDSIDE NODES TO PLANE183 ELEMENTS
NSEL,R,LOC,X,75
NSEL,R,LOC,Y,-4.5         ! SELECT MIDSIDE NODE AT FIXED END
D,ALL,ALL                 ! CONSTRAIN  MIDSIDE NODE AT FIXED END
NSEL,ALL
```

```
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
END_NODE = NODE (75,0,0)
*GET,STS_E_183,NODE,END_NODE,S,X       ! STRESS AT FIXED END (END NODE )
MID_NODE = NODE (50,0,0)
*GET,STS_M_183,NODE,MID_NODE,S,EQV

*DIM,LABEL,CHAR,2,2
*DIM,VALUEI,,2,3
*DIM,VALUEII,,2,3
LABEL(1,1) = 'MID_STRS','END-STRS'
LABEL(1,2) = ' (psi)  ',' (psi)  '
*VFILL,VALUEI(1,1),DATA,8333,7407
*VFILL,VALUEI(1,2),DATA,STS_M_182,STS_E_182
*VFILL,VALUEI(1,3),DATA,(STS_M_182/8333),(STS_E_182/7407)
*VFILL,VALUEII(1,1),DATA,8333,7407
*VFILL,VALUEII(1,2),DATA,STS_M_183,STS_E_183
*VFILL,VALUEII(1,3),DATA,(STS_M_183/8333),(STS_E_183/7407)
/COM,STS_M_42 = STRESS AT MID-LENGTH USING ELEMENT 42
/COM,STS_E_42 = STRESS AT FIXED END USING ELEMENT 42
/COM,STS_M_183 = STRESS AT MID-LENGTH USING ELEMENT 183
/COM,STS_E_183 = STRESS AT FIXED END USING ELEMENT 183
/COM,
/OUT,vm5,vrt
/COM,------------------- VM5 RESULTS COMPARISON ---------------------
/COM,
/COM,RESULTS FOR PLANE182:
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
*VWRITE,LABEL(1,1),LABEL(1,2),VALUEI(1,1),VALUEI(1,2),VALUEI(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,
/COM,RESULTS FOR PLANE183:
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
*VWRITE,LABEL(1,1),LABEL(1,2),VALUEII(1,1),VALUEII(1,2),VALUEII(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vm5,vrt
```

VM6 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM6
/PREP7
SMRT,OFF
/TITLE, VM6, PINCHED CYLINDER
/COM,  REF: COOK, CONCEPTS AND APPL. OF FEA 2ND ED., 1981, PP. 284-287.
C***          USING SHELL181 ELEMENTS
/PREP7
SMRT,OFF
ANTYPE,STATIC
ET,1,SHELL181, , ,2
SECTYPE,1,SHELL
SECDATA,0.094,1,0,5
MP,EX,,10.5E6
MP,NUXY,,.3125
CSYS,1
K,1,4.953                  ! DEFINE MODEL GEOMETRY
K,2,4.953,,5.175
```

```
KGEN,2,1,2,1,,90
A,1,2,4,3
ESIZE,,8
AMESH,1
CSYS,0
NSEL,S,LOC,X,0
DSYM,SYMM,X,0
NSEL,S,LOC,Y,0
DSYM,SYMM,Y,0
NSEL,S,LOC,Z,0
DSYM,SYMM,Z,0
NSEL,ALL
FK,3,FY,-25
FINISH
/SOLU
SOLVE
FINISH
/POST1
NSEL,S,LOC,Y,4.953              ! SELECT NODE AT LOAD APPLICATION
NSEL,R,LOC,Z,0
NSEL,R,LOC,X,0
PRNSOL,U,COMP                   ! PRINT DISPLACEMENTS AND VECTOR SUM
TOP_NODE = NODE (4.953,90,0)
*GET,DISP,NODE,TOP_NODE,U,Y
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1) = 'DEF_IN'
*VFILL,VALUE(1,1),DATA,0.1139
*VFILL,VALUE(1,2),DATA,ABS(DISP)
*VFILL,VALUE(1,3),DATA,ABS( DISP /0.1139 )
SAVE,TABLE_1
FINISH
/CLEAR,NOSTART
/TITLE, VM6, PINCHED CYLINDER
C***         USING SHELL281 ELEMENTS
/PREP7
SMRT,OFF
ANTYPE,STATIC
ET,1,SHELL281
SECTYPE,1,SHELL
SECDATA,0.094,1,0,5
MP,EX,,10.5E6
MP,NUXY,,.3125
CSYS,1
K,1,4.953                 ! DEFINE MODEL GEOMETRY
K,2,4.953,,5.175
KGEN,2,1,2,1,,90
A,1,2,4,3
ESIZE,,8
AMESH,1
CSYS,0
NSEL,S,LOC,X,0
DSYM,SYMM,X,0
NSEL,S,LOC,Y,0
DSYM,SYMM,Y,0
NSEL,S,LOC,Z,0
DSYM,SYMM,Z,0
NSEL,ALL
FK,3,FY,-25
FINISH
/SOLU
SOLVE
FINISH
/POST1
NSEL,S,LOC,Y,4.953              ! SELECT NODE AT LOAD APPLICATION
NSEL,R,LOC,Z,0
NSEL,R,LOC,X,0
PRNSOL,U,COMP                   ! PRINT DISPLACEMENTS AND VECTOR SUM
TOP_NODE = NODE (4.953,90,0)
*GET,DISP,NODE,TOP_NODE,U,Y
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
```

```
LABEL(1) = 'DEF_IN'
*VFILL,VALUE(1,1),DATA,0.1139
*VFILL,VALUE(1,2),DATA,ABS(DISP)
*VFILL,VALUE(1,3),DATA,ABS( DISP /0.1139 )
SAVE,TABLE_2
RESUME,TABLE_1
/COM
/OUT,vm6,vrt
/COM,------------------- VM6 RESULTS COMPARISON ---------------------
/COM,
/COM,              |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,
/COM,
/COM,SHELL181
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A10,'   ',F10.4,'  ',F14.4,'   ',1F13.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,SHELL281
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A10,'   ',F10.4,'  ',F14.4,'   ',1F13.3)
/COM,-----------------------------------------------------------------
/OUT
FINISH
/DEL,TABLE_1
/DEL,TABLE_2
FINISH
*LIST,vm6,vrt
```

VM7 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM7
/PREP7
/TITLE, VM7, PLASTIC COMPRESSION OF A PIPE ASSEMBLY
C***          MECHANICS OF SOLIDS, CRANDALL AND DAHL, 1959, PAGE 180, EX. 5.1
C***          USING PIPE288, SOLID185 AND SHELL181 ELEMENTS
THETA=6                              ! SUBTENDED ANGLE
ET,1,PIPE288,,,,2
ET,2,SOLID185
ET,3,SHELL181,,,2                    ! FULL INTEGRATION
SECTYPE,1,SHELL
SECDATA,0.5,1,0,5                    ! THICKNESS (SHELL181)
SECTYPE,2,SHELL
SECDATA,0.5,2,0,5                    ! THICKNESS (SHELL181)
SECTYPE,3,PIPE
SECDATA,4.9563384,0.5                ! OUTSIDE DIA. AND WALL THICKNESS FOR INSIDE TUBE (PIPE288)
SECTYPE,4,PIPE
SECDATA,8.139437,0.5                 ! OUTSIDE DIA. AND WALL THICKNESS FOR OUTSIDE TUBE (PIPE288)
MP,EX  ,1,26.875E6                   ! STEEL
MP,PRXY,1,0.3
MP,EX  ,2,11E6                       ! ALUMINUM
MP,PRXY,2,0.3
TB,BKIN,1,1                          ! DEFINE NON-LINEAR MATERIAL PROPERTY FOR STEEL
TBTEMP,0
TBDATA,1,86000,0
TB,BKIN,2,1                          ! DEFINE NON-LINEAR MATERIAL PROPERTY FOR ALUMINUM
TBTEMP,0
TBDATA,1,55000,0
N,1                                  ! GENERATE NODES AND ELEMENTS FOR PIPE288
N,2,,,10
MAT,1
SECNUM,3                             ! STEEL (INSIDE) TUBE
```

```
E,1,2
MAT,2
SECNUM,4                              ! ALUMINUM (OUTSIDE) TUBE
E,1,2
CSYS,1
N,101,1.9781692                       ! GENERATE NODES AND ELEMENTS FOR SOLID185
N,102,2.4781692
N,103,3.5697185
N,104,4.0697185
N,105,1.9781692,,10
N,106,2.4781692,,10
N,107,3.5697185,,10
N,108,4.0697185,,10
NGEN,2,10,101,108,,,THETA             ! GENERATE 2ND SET OF NODES TO FORM A THETA DEGREE SLICE
NROTAT,101,118,1
TYPE,2
MAT,1                                 ! INSIDE (STEEL) TUBE
E,101,102,112,111,105,106,116,115
MAT,2                                 ! OUTSIDE (ALUMINUM) TUBE
E,103,104,114,113,107,108,118,117
N,201,2.2281692                       ! GENERATE NODES AND ELEMENTS FOR SHELL181
N,203,2.2281692,,10
N,202,3.8197185
N,204,3.8197185,,10
NGEN,2,4,201,204,,,THETA              ! GENERATE NODES TO FORM A THETA DEGREE SLICE
TYPE,3
SECNUM,1                              ! INSIDE (STEEL) TUBE
E,203,201,205,207
SECNUM,2                              ! OUTSIDE (ALUMINUM) TUBE
E,204,202,206,208
C*** APPLY CONSTRAINTS TO PIPE288 MODEL
D,1,ALL                               ! FIX ALL DOFS FOR BOTTOM END OF PIPE288
D,2,UX,,,,,UY,ROTX,ROTY,ROTZ          ! ALLOW ONLY UZ DOF AT TOP END OF PIPE288 MODEL
C*** APPLY CONSTRAINTS TO SOLID185 AND SHELL181 MODELS
CP,1,UX,101,111,105,115               ! COUPLE NODES AT BOUNDARY IN RADIAL DIR FOR SOLID185
CPSGEN,4,,1
CP,5,UX,201,205,203,20                ! COUPLE NODES AT BOUNDARY IN RADIAL DIR FOR SHELL181
CPSGEN,2,,5
CP,7,ROTY,201,205                     ! COUPLE NODES AT BOUNDARY IN ROTY DIR FOR SHELL181
CPSGEN,4,,7
NSEL,S,NODE,,101,212                  ! SELECT ONLY NODES IN SOLID185 AND SHELL181 MODELS
NSEL,R,LOC,Y,0                        ! SELECT NODES AT THETA = 0 FROM THE SELECTED SET
DSYM,SYMM,Y,1                         ! APPLY SYMMETRY BOUNDARY CONDITIONS
NSEL,S,NODE,,101,212                  ! SELECT ONLY NODES IN SOLID185 AND SHELL181 MODELS
NSEL,R,LOC,Y,THETA                    ! SELECT NODES AT THETA FROM THE SELECTED SET
DSYM,SYMM,Y,1                         ! APPLY SYMMETRY BOUNDARY CONDITIONS
NSEL,ALL
NSEL,R,LOC,Z,0                        ! SELECT ONLY NODES AT Z = 0
D,ALL,UZ,0                            ! CONSTRAIN BOTTOM NODES IN Z DIRECTION
NSEL,ALL
FINISH
/SOLU
OUTPR,BASIC,LAST                      ! PRINT BASIC SOLUTION AT END OF LOAD STEP
C*** APPLY DISPLACEMENT LOADS TO ALL MODELS
*CREATE,DISP
NSEL,R,LOC,Z,10                       ! SELECT NODES AT Z = 10 TO APPLY DISPLACEMENT
D,ALL,UZ,ARG1
NSEL,ALL
/OUT,SCRATCH
SOLVE
*END
*USE,DISP,-.032
*USE,DISP,-.05
*USE,DISP,-.1
FINISH
/OUT,
/POST1
C*** CREATE MACRO TO GET RESULTS FOR EACH MODEL
*CREATE,GETLOAD
NSEL,S,NODE,,1,2                     ! SELECT NODES IN PIPE288 MODEL
NSEL,R,LOC,Z,0
/OUT,SCRATCH
```

```
FSUM                                ! FZ IS TOTAL LOAD FOR PIPE288 MODEL
*GET,LOAD_288,FSUM,,ITEM,FZ
NSEL,S,NODE,,101,118                ! SELECT NODES IN SOLID185 MODEL
NSEL,R,LOC,Z,0
FSUM
*GET,ZFRC,FSUM,0,ITEM,FZ
LOAD=ZFRC*360/THETA                 ! MULTIPLY BY 360/THETA FOR FULL 360 DEGREE RESULTS
*STATUS,LOAD
LOAD_185 = LOAD
NSEL,S,NODE,,201,212                ! SELECT NODES IN SHELL181 MODEL
NSEL,R,LOC,Z,0
FSUM
/OUT,
*GET,ZFRC,FSUM,0,ITEM,FZ
LOAD=ZFRC*360/THETA                 ! MULTIPLY BY 360/THETA FOR FULL 360 DEGREE RESULTS
*STATUS,LOAD
LOAD_181 = LOAD
*VFILL,VALUE_288(1,1),DATA,1024400,1262000,1262000
*VFILL,VALUE_288(I,2),DATA,ABS(LOAD_288)
*VFILL,VALUE_288(I,3),DATA,ABS(LOAD_288)/(VALUE_288(I,1))
*VFILL,VALUE_185(1,1),DATA,1024400,1262000,1262000
*VFILL,VALUE_185(J,2),DATA,ABS(LOAD_185)
*VFILL,VALUE_185(J,3),DATA,ABS(LOAD_185)/(VALUE_185(J,1))
*VFILL,VALUE_181(1,1),DATA,1024400,1262000,1262000
*VFILL,VALUE_181(K,2),DATA,ABS(LOAD_181)
*VFILL,VALUE_181(K,3),DATA,ABS(LOAD_181)/(VALUE_181(K,1))
*END
C*** GET TOTAL LOAD FOR DISPLACEMENT = 0.032
C*** --------------------------------------
SET,1,1
I = 1
J = 1
K = 1
*DIM,LABEL,CHAR,3,2
*DIM,VALUE_288,,3,3
*DIM,VALUE_185,,3,3
*DIM,VALUE_181,,3,3
*USE,GETLOAD
C*** GET TOTAL LOAD FOR DISPLACEMENT = 0.05
C*** -------------------------------------
SET,2,1
I = I + 1
J = J + 1
K = K + 1
*USE,GETLOAD
C*** GET TOTAL LOAD FOR DISPLACEMENT = 0.1
C*** ------------------------------------
SET,3,1
I = I +1
J = J + 1
K = K + 1
*USE,GETLOAD
LABEL(1,1) = 'LOAD, lb','LOAD, lb','LOAD, lb'
LABEL(1,2) = ' UX=.032',' UX=0.05',' UX=0.10'
FINISH
/OUT,vm7,vrt
/COM,------------------- VM7 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS FOR PIPE288:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_288(1,1),VALUE_288(1,2),VALUE_288(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,
/COM,RESULTS FOR SOLID185:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_185(1,1),VALUE_185(1,2),VALUE_185(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,
/COM,RESULTS FOR SHELL181:
/COM,
```

```
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_181(1,1),VALUE_181(1,2),VALUE_181(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,
/COM,----------------------------------------------------------------
/OUT
*LIST,vm7,vrt
```

VM8 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM8
*CREATE,MAC
LENGTH              ! LABEL FOR THIS BLOCK IN THE USER FILE
!
!       THIS BLOCK IN THE USER FILE CALCULATES THE STRAIGHT LINE
!       DISTANCE BETWEEN TWO POINTS IN SPACE DEFINED BY EITHER
!       KEYPOINTS OR NODES ( CONTROLLED BY ARG1 ).  OTHER INPUT
!       AND OUTPUT ARGUMENTS ARE DEFINED BELOW.
!
!      INPUT-    ARG1 == IF ZERO, ARG2 AND ARG3 REPRESENT NODES (DEFAULT)
!                     == IF NONZERO, ARG2 AND ARG3 REPRESENT KEYPOINTS
!                ARG2 == NUMBER OF THE FIRST NODE OR KEYPOINT
!                ARG3 == NUMBER OF THE SECOND NODE OR KEYPOINT
!
!      OUTPUT-   PDIS == EXTERNAL PARAMETER ASSIGNED WITH THE DISTANCE VALUE
!
!
!      NOTES:    1. "NORMALLY" THIS BLOCK WOULD ALREADY EXIST IN A LOCALLY
!                   ATTACHED USER FILE, AND WOULDN'T REQUIRE THE "*CREATE"
!                   OPERATION TO MAKE IT.
!                2. THE CHARACTER ":" USED IN THE FIRST COLUMN OF AN ANSYS
!                   INPUT LINE HAS THE EFFECT OF MAKING THE ENTIRE LINE A
!                   NON-ECHOING COMMENT (USUALLY USED FOR A BRANCHING LABEL).
!
/NOPR                 ! SUPPRESS PRINTOUT DURING MACRO EXECUTION
*GET,AR10,CSYS        ! SAVE CURRENT COORDINATE SYSTEM FOR LATER RESTORATION
CSYS,0                ! CHANGE TO GLOBAL CARTESIAN SYSTEM
*IF,ARG1,EQ,0,THEN
  *GET,ARG4,NX,ARG2     ! RETRIEVE COORDINATE LOCATIONS OF BOTH NODES
  *GET,ARG5,NY,ARG2
  *GET,ARG6,NZ,ARG2
  *GET,ARG7,NX,ARG3
  *GET,ARG8,NY,ARG3
  *GET,ARG9,NZ,ARG3
*ELSE
  *GET,ARG4,KX,ARG2     ! RETRIEVE COORDINATE LOCATIONS OF BOTH KEYPOINTS
  *GET,ARG5,KY,ARG2
  *GET,ARG6,KZ,ARG2
  *GET,ARG7,KX,ARG3
  *GET,ARG8,KY,ARG3
  *GET,ARG9,KZ,ARG3
*ENDIF

!      ----- NOW CALCULATE DISTANCE WITH LOCATIONS OBTAINED ABOVE -----
PDIS=((ARG7-ARG4)*(ARG7-ARG4))+((ARG8-ARG5)*(ARG8-ARG5))
PDIS=SQRT(PDIS+((ARG9-ARG6)*(ARG9-ARG6)))
CSYS,AR10             ! RESTORE ORIGINAL COORDINATE SYSTEM
*IF,ARG1,EQ,0,THEN    ! BRANCH TO KEYPOINT LOGIC IF APPROPRIATE
  /COM LENGTH BETWEEN NODES HAS BEEN DEFINED AS PARAMETER PDIS (FROM USERFILE)
*ELSE
  /COM LENGTH BETWEEN KEYPOINTS DEFINED AS PARAMETER PDIS (FROM USERFILE)
*ENDIF
/GOPR                 ! TURN PRINTOUT BACK ON
*END
/PREP7
/TITLE, VM8, MACRO TO CALCULATE DISTANCES BETWEEN POINTS
C***        ANY BASIC GEOMETRY TEXT
*ULIB,MAC                     ! ASSIGN MACRO LIBRARY FILE
```

```
*ABBR,KLEN,*USE,LENGTH,1      ! ASSIGN ABBREVIATIONS FOR "CALLS" TO USERFILE
*ABBR,NLEN,*USE,LENGTH,0
N,1,1.5,2.5,3.5               ! DEFINE TEST NODE AND KEYPOINT LOCATIONS
N,2,-3.7,4.6,-3
K,3,100,0,30
K,4,-200,25,80
KLEN,4,3                      ! USE KEYPOINT DISTANCE PART OF MACRO
LEN1=PDIS
KDIS = LEN1
CSYS,1         ! CYLINDRICAL COORDINATE SYSTEM (SHOULDN'T AFFECT CALCULATION)
NLEN,1,2                      ! USE NODE DISTANCE PART OF MACRO
LEN2=PDIS
NDIS = LEN2
*status,parm

*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'N1-N2 DI','K3-K4 DI'
LABEL(1,2) = 'STANCE','STANCE'
*VFILL,VALUE(1,1),DATA,8.5849,305.16
*VFILL,VALUE(1,2),DATA,LEN2,LEN1
*VFILL,VALUE(1,3),DATA,ABS(LEN2 / 8.5849 ) , ABS( LEN1 / 305.16 )
/COM
/OUT,vm8,vrt
/COM,------------------- VM8 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.2,'   ',1F15.3)
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vm8,vrt
```

VM9 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM9
/PREP7
/TITLE, VM9, LARGE LATERAL DEFLECTION OF UNEQUAL STIFFNESS SPRINGS
/COM, REF: G.N. VANDERPLAATS, "NUMERICAL OPTIMIZATION TECHNIQUES FOR
/COM,      ENGINEERING DESIGN", PP 72-73, MCGRAW-HILL, 1984
ET,1,COMBIN14,,,2          ! UX AND UY DOF ELEMENT
ET,3,COMBIN40,,,,,,2       ! ALL MASS IS AT NODE J, UX DOF ELEMENT
ET,4,COMBIN40,,,2,,,2      ! ALL MASS IS AT NODE J, UY DOF ELEMENT
R,1,1                      ! SPRING STIFFNESS = 1
R,2,8                      ! SPRING STIFFNESS = 8
/COM USE COMBIN40 MASS, K, AND DAMPING C, TO APPROX. CRITICAL DAMPING
R,3,,1.41,1                ! C = 1.41, M = 1
R,4,,2,1                   ! C = 2, M = 1
N,1
N,2,,10
N,3,,20
N,4,-1,10
N,5,,9
E,1,2                      ! ELEMENT 1 IS SPRING ELEMENT WITH STIFFNESS 1
REAL,2
E,2,3                      ! ELEMENT 2 IS SPRING ELEMENT WITH STIFFNESS 8
TYPE,3
REAL,3
E,4,2                      ! ELEMENT 3 IS COMBINATION ELEMENT WITH C = 1.41
TYPE,4
REAL,4
E,5,2                      ! ELEMENT 4 IS COMBINATION ELEMENT WITH C = 2
NSEL,U,NODE,,2
D,ALL,ALL
NSEL,ALL
```

```
FINISH
/SOLU
ANTYPE,TRANS                 ! FULL TRANSIENT DYNAMIC ANALYSIS
NLGEOM,ON                    ! LARGE DEFLECTION
KBC,1                        ! STEP BOUNDARY CONDITION
F,2,FX,5
F,2,FY,5
AUTOTS,ON
NSUBST,30
OUTPR,,LAST
OUTPR,VENG,LAST
TIME,15                      ! ARBITRARY TIME FOR SLOW DYNAMICS
/OUT,SCRATCH
SOLVE
FINISH
/POST1
SET,,,,,15                   ! USE ITERATION WHEN TIME = 15
/OUT,
ETABLE,SENE,SENE             ! STORE STRAIN ENERGY
SSUM                         ! SUM ALL ACTIVE ENTRIES IN ELEMENT STRESS TABLE
*GET,ST_EN,SSUM,,ITEM,SENE
PRNSOL,U,COMP                ! PRINT DISPLACEMENTS IN GLOBAL COORDINATE SYSTEM
*GET,DEF_X,NODE,2,U,X
*GET,DEF_Y,NODE,2,U,Y
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'STRAIN E','DEF_X (C','DEF_Y (C'
LABEL(1,2) = ', N-cm  ','m)      ','m)      '
*VFILL,VALUE(1,1),DATA,24.01,8.631,4.533
*VFILL,VALUE(1,2),DATA,ST_EN ,DEF_X,DEF_Y
*VFILL,VALUE(1,3),DATA,ABS(ST_EN/24.01), ABS(8.631/DEF_X), ABS(DEF_Y/4.533 )
/COM
/OUT,vm9,vrt
/COM,------------------- VM9 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,-----------------------------------------------------------

/OUT
FINISH
*LIST,vm9,vrt
```

VM10 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM10
/PREP7
MP,PRXY,,0.3
/TITLE, VM10, BENDING OF A TEE SHAPED BEAM
C***    MECHANICS OF SOLIDS, CRANDALL AND DAHL, 1959, PAGE 294, EX. 7.2
ANTYPE,STATIC
ET,1,BEAM188,,,3
SECT,1,BEAM,T
SECD,9,20,4,1.5
MP,EX,1,30E6
N,1
N,2,100
N,3,,1
E,1,2,3
D,1,ALL
F,2,MZ,100000
D,ALL,UZ,,,,,ROTX,ROTY
FINISH
/SOLU
NSUBST,1
```

```
OUTPR,ALL,1
SOLVE
FINISH
/POST1
ETABLE,STRS_B,LS,1
ETABLE,STRS_T,LS,31
*GET,STRSS_B,ELEM,1,ETAB,STRS_B
*GET,STRSS_T,ELEM,1,ETAB,STRS_T
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'STRSS,(B','STRSS,(T'
LABEL(1,2) = 'OT) psi ','OP) psi '
*VFILL,VALUE(1,1),DATA,300,-700
*VFILL,VALUE(1,2),DATA,STRSS_B,STRSS_T
*VFILL,VALUE(1,3),DATA,ABS(STRSS_B/300) ,ABS(STRSS_T/700 )
/COM
/OUT,vm10,vrt
/COM,------------------- VM10 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F10.0,'   ',1F5.3)
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vm10,vrt
```

VM11 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM11
/PREP7
/TITLE, VM11, RESIDUAL STRESS PROBLEM
C***          MECHANICS OF SOLIDS, CRANDALL AND DAHL, 1959, PAGE 234, PROB 5.31
ANTYPE,STATIC
ET,1,LINK180
SECTYPE,1,LINK
SECDATA,1
MP,EX,1,30E6
TB,BKIN                           ! TABLE FOR BILINEAR KINEMATIC HARDENING
TBTEMP,100
TBDATA,1,30000                    ! YIELD STRESS
C*** DEFINE MODEL GEOMETRY USING PARAMETRIC EXPRESSIONS
L=100
*AFUN,DEG                         ! SET ANGULAR FUNCTION ARGUMENTS AND
                                  ! RESULTS TO DEGREES
THETA=30
XLOC=L*TAN(THETA)
N,1,-XLOC
N,3,XLOC
FILL
N,4,,-L
E,1,4
E,2,4
E,3,4
OUTPR,,1
D,1,ALL,,,3
F,4,FY,-51961.5                   ! APPLY LOAD F1
FINISH
/SOLU
SOLVE
FINISH
/POST1
BOT_NODE = NODE (0,-100,0)
*GET,DEF,NODE,BOT_NODE,U,Y
FINISH
```

```
/SOLU
AUTOTS,ON                          ! TURN ON AUTOMATIC LOAD STEPPING
NSUBST,10
OUTPR,,10
F,4,FY,-81961.5                    ! APPLY LOAD F2
SOLVE
NSUBST,5
OUTPR,,5
F,4,FY                             ! REMOVE LOAD F2
SOLVE
FINISH
/POST1
ETABLE,STRS,LS,1
*GET,STRSS,ELEM,2,ETAB,STRS

*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'DEF AT F','STRESS  '
LABEL(1,2) = '1 (in)  ','(psi)   '
*VFILL,VALUE(1,1),DATA,-0.07533,-5650
*VFILL,VALUE(1,2),DATA,DEF,STRSS
*VFILL,VALUE(1,3),DATA,ABS(DEF/0.07533 ) ,ABS(STRSS/5650 )
/COM
/OUT,vm11,vrt
/COM,------------------- VM11 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   ANSYS   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.5,'  ',F11.5,'   ',1F5.3)
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vm11,vrt
```

VM12 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM12
/PREP7
/TITLE, VM12, COMBINED BENDING AND TORSION
C***      USING PIPE16     STR. OF MATL., TIMOSHENKO, PART 1, 3RD ED., PAGE 299, PROB. 2

ANTYPE,STATIC
ET,1,PIPE16
R,1,4.67017,2.33508  ! REAL CONSTANTS FOR SOLID CROSS SECTION
MP,EX,1,30E6
MP,NUXY,1,.3
N,1
N,2,,,300
E,1,2
D,1,ALL
F,2,MZ,9000
F,2,FX,-250
FINISH
/SOLU
OUTPR,BASIC,1
SOLVE
FINISH
/POST1
ETABLE,P_STRS,NMISC,86
ETABLE,SHR,NMISC,88
*GET,P_STRESS,ELEM,1,ETAB,P_STRS
*GET,SHEAR,ELEM,1,ETAB,SHR

*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'MAX PRIN','MAX SH S'
```

```
LABEL(1,2) = 'STRS psi','TRS psi '
*VFILL,VALUE(1,1),DATA,7527,3777
*VFILL,VALUE(1,2),DATA,P_STRESS,(SHEAR/2)
*VFILL,VALUE(1,3),DATA,ABS(P_STRESS/7527 ) ,ABS((SHEAR/2)/3777 )
SAVE,TABLE_1
FINI
/CLEAR,NOSTART


!**********************************************************************


/PREP7
C***     USING PIPE288

ANTYPE,STATIC
ET,1,PIPE288
SECTYPE,1,PIPE
SECDATA,4.67017,2.33508
KEYOPT,1,3,3   !CUBIC SHAPE FUNCTION
MP,EX,1,30E6
MP,NUXY,1,.3
N,1
N,2,,,300
E,1,2
D,1,ALL
F,2,MZ,9000
F,2,FX,-250
FINISH
/SOLU
OUTPR,BASIC,1
SOLVE
FINISH
/POST1
SET,LAST
/GRAPHICS,POWER
/ESHAPE,1
/VIEW,1,1,1,1
PLESOL,S,1
*GET,P_STRESS,PLNSOL,0,MAX
PLESOL,S,INT
*GET,SHEAR,PLNSOL,0,MAX

*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'MAX PRIN','MAX SH S'
LABEL(1,2) = 'STRS psi','TRS psi '
*VFILL,VALUE(1,1),DATA,7527,3777
*VFILL,VALUE(1,2),DATA,P_STRESS,(SHEAR/2)
*VFILL,VALUE(1,3),DATA,ABS(P_STRESS/7527 ) ,ABS((SHEAR/2)/3777 )
SAVE,TABLE_2
FINI
/CLEAR,NOSTART


/NOPR
/COM
/OUT,vm12,vrt
/COM,------------------- VM12 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING PIPE16
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F12.0,'   ',1F15.3)
/COM,
RESUME,TABLE_2
/COM,USING PIPE288
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
```

```
(1X,A8,A8,'   ',F10.0,'  ',F12.0,'   ',1F15.3)
/COM,
/COM,-----------------------------------------------------------------

/OUT
FINISH
*LIST,vm12,vrt
```

VM13 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM13
/PREP7
/TITLE, VM13, CYLINDRICAL SHELL UNDER PRESSURE
C***   STR. OF MATL., TIMOSHENKO, PART 1, 3RD ED., PAGE 45, ART. 11
C***   AND UGURAL AND FENSTER, ADV. STRENGTH AND APPL. ELAS., 1981
ANTYPE,STATIC
ET,1,SHELL208
SECTYPE,1,SHELL
SECDATA,1
SECNUM,1
MP,EX,1,30E6
MP,NUXY,1,.3
N,1,60
N,2,60,10
E,1,2
CP,1,UX,1,2            ! COUPLE RADIAL DIRECTION
D,1,UY,,,,,ROTZ
D,2,ROTZ
F,2,FY,5654866.8       ! CAP FORCE
SFE,1,1,PRES,,500      ! INTERNAL PRESSURE
FINISH
/SOLU
OUTPR,ALL,1
SOLVE
FINISH
/POST1
ETABLE,STRS_Y,S,Y
ETABLE,STRS_Z,S,Z
*GET,STRSS_Y,ELEM,1,ETAB,STRS_Y
*GET,STRSS_Z,ELEM,1,ETAB,STRS_Z
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'STRESS,Y ','STRESS,Z'
LABEL(1,2) = ' (psi)  ',' (psi)  '
*VFILL,VALUE(1,1),DATA,15000,29749
*VFILL,VALUE(1,2),DATA,STRSS_Y,STRSS_Z
*VFILL,VALUE(1,3),DATA,ABS(STRSS_Y/15000 ) ,ABS(STRSS_Z/29749 )
/COM
/OUT,vm13,vrt
/COM,------------------- VM13 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F12.0,'   ',1F15.3)
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vm13,vrt
```

VM14 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
```

```
/VERIFY,VM14
/PREP7
/TITLE, VM14, LARGE DEFLECTION ECCENTRIC COMPRESSION OF SLENDER COLUMN
C***      STR. OF MATL., TIMOSHENKO, PART 1, 3RD ED., PG. 263, PROB. 1
ET,1,BEAM188,,,3
SECTYPE,1,BEAM,CHAN
SECDATA,2.26,2.26,8,0.39,0.39,0.22
SECOFFSET,USER,,0.6465
MP,EX,1,30E6
MP,PRXY,1,0.3
N,1
N,5,,60
FILL
E,1,2
EGEN,4,1,1
D,1,ALL
F,5,FY,-4000
DSYM,SYMM,Z
FINISH
/SOLU
NLGEOM,ON               ! ACTIVATE LARGE DEFLECTIONS
CNVTOL,F,,1E-4
CNVTOL,M,,1E-4
OUTPR,,LAST
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
END_NODE = NODE (0,120/2,0)
*GET,DEF,NODE,END_NODE,U,X
*GET,STS_TENS,SECR,1,S,X,MAX
*GET,STS_COMP,SECR,1,S,X,MIN
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'DEFLECTI','STRSS_TE','STRSS_CO'
LABEL(1,2) = 'ON (in) ','NS (psi)','MP (psi)'
*VFILL,VALUE(1,1),DATA,.1086,1803.63,-2394.53
*VFILL,VALUE(1,2),DATA,ABS(DEF),STS_TENS,STS_COMP
*VFILL,VALUE(1,3),DATA, ABS(DEF/.1086 ),ABS(STS_TENS/1803.63),ABS(STS_COMP/2394.53)
/COM
/OUT,vm14,vrt
/COM,------------------- VM14 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL    |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F12.4,'   ',1F15.3)
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vm14,vrt
```

VM15 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM15
/PREP7
/TITLE, VM15, BENDING OF A CIRCULAR PLATE USING AXISYMMETRIC SHELL ELEMENTS
C***  CASE 1 - STR. OF MATLS., TIMOSHENKO, PART 2, 3RD ED., PAGE 96, ART. 19
C***  CASE 2 - STR. OF MATLS., TIMOSHENKO, PART 2, 3RD ED., PAGE 103, ART. 21
C***  CASE 3 - STR. OF MATLS., TIMOSHENKO, PART 2, 3RD ED., PAGE 97, ART. 19
ANTYPE,STATIC
ET,1,SHELL208,,,2
SECTYPE,1,SHELL
SECDATA,1,1
SECNUM,1
MP,EX,1,30E6
```

```
MP,NUXY,1,.3
K,1
K,2,40
K,3,20
L,1,3
L,3,2
LESIZE,1,,,5,20              ! BIAS THE MESH TO ALLOW STRESS RECOVERY NEAR
LESIZE,2,,,5,.05             ! THE CENTERLINE AND EDGE CONSTRAINTS
LMESH,ALL                    ! MESH LINE SEGMENTS
FINISH
C***  CASE 1 - UNIFORM LOADING - CLAMPED EDGE
/SOLU
OUTPR,,1
DK,1,UX,,,,ROTZ
DK,2,ALL
SFE,ALL,1,PRES,,6            ! PRESSURE LOAD = 6 PSI ON ALL LINE SEGMENTS
/OUT,SCRATCH
SOLVE
C***  CASE 2 - CONCENTRATED CENTER LOADING - CLAMPED EDGE
FK,1,FY,-7539.82
SFE,ALL,1,PRES,,0            ! REMOVE PRESSURE
SOLVE
C***  CASE 3 - UNIFORM LOADING - SIMPLY SUPPORTED EDGE
DKDELE,2,ROTZ                ! DELETE CLAMPED BOUNDARY CONDITION CONSTRAINT
FK,1,FY                      ! REMOVE CENTERLINE POINT LOAD
SFE,ALL,1,PRES,,1.5
SOLVE
FINISH
/POST1
/DSCALE,1,35                 ! EXAGGERATE DISPLACEMENT SCALING FOR CLARITY
/WINDOW,1,-1,1,-1,-.333
/OUT,
SET,1,1
PLDISP,1
/WINDOW,1,OFF                ! TURN-OFF WINDOW 1
/WINDOW,2,-1,1,-.333,.333,1
/NOERASE                     ! DON'T ERASE EXISTING DISPLAYS
MID_NODE = NODE ( 0,0,0 )
*GET,DEF_C1,NODE,MID_NODE,U,Y
ETABLE,STRS,S,X
*GET,STRSS_C1,ELEM,10,ETAB,STRS
SET,2,1
PLDISP
/WINDOW,2,OFF                ! TURN OFF WINDOW 2
/WINDOW,3,-1,1,.333,1,1
*GET,DEF_C2,NODE,MID_NODE,U,Y
ETABLE,STRS,S,X
*GET,STRSS_C2,ELEM,10,ETAB,STRS
SET,3,1
PLDISP
*GET,DEF_C3,NODE,MID_NODE,U,Y
ETABLE,STRS,S,X
*GET,STRSS_C3,ELEM,1,ETAB,STRS
*DIM,LABEL,CHAR,2,2
*DIM,VALUE_C1,,2,3
*DIM,VALUE_C2,,2,3
*DIM,VALUE_C3,,2,3
LABEL(1,1) = 'DEFLECTI','MAX STRS'
LABEL(1,2) = 'ON (in) ','S (psi) '
*VFILL,VALUE_C1(1,1),DATA,-.08736,7200
*VFILL,VALUE_C1(1,2),DATA,DEF_C1,ABS(STRSS_C1)
*VFILL,VALUE_C1(1,3),DATA,ABS(DEF_C1/.08736 ),ABS(STRSS_C1/7200 )
*VFILL,VALUE_C2(1,1),DATA,-.08736,3600
*VFILL,VALUE_C2(1,2),DATA,DEF_C2,ABS(STRSS_C2)
*VFILL,VALUE_C2(1,3),DATA,ABS(DEF_C2/.08736 ),ABS(STRSS_C2/3600 )
*VFILL,VALUE_C3(1,1),DATA,-.08904,2970
*VFILL,VALUE_C3(1,2),DATA,DEF_C3,ABS(STRSS_C3)
*VFILL,VALUE_C3(1,3),DATA,ABS(DEF_C3/.08904 ),ABS(STRSS_C3/2970 )
/COM
/OUT,vm15,vrt
/COM,------------------- VM15 RESULTS COMPARISON ---------------------
/COM,
```

```
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS FOR CASE 1:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C1(1,1),VALUE_C1(1,2),VALUE_C1(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F15.5,'   ',1F15.3)
/COM,
/COM,RESULTS FOR CASE 2:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C2(1,1),VALUE_C2(1,2),VALUE_C2(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F15.5,'   ',1F15.3)
/COM,
/COM,RESULTS FOR CASE 3:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C3(1,1),VALUE_C3(1,2),VALUE_C3(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F15.5,'   ',1F15.3)
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vm15,vrt
```

VM16 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM16
/PREP7
/TITLE, VM16, BENDING OF A SOLID BEAM (PLANE ELEMENTS)
C***          FORMULAS FOR STRESS AND STRAIN, ROARK, 4TH ED.,PG. 104,106
C***          USING PLANE42 ELEMENTS
ANTYPE,STATIC
ET,1,PLANE42,,,,,,2     ! PLANE42 WITH SURFACE PRINTOUT FOR FACES 1 AND 3
MP,EX,1,30E6
MP,NUXY,1,0.0
N,1
N,6,10
FILL
NGEN,2,10,1,6,1,,2
E,1,2,12,11
EGEN,5,1,1
/COM, VM16, CASE 1 - END MOMENT, ROARK, PAGE 106, NO. 9
D,1,ALL,,,11,10
F,6,FX,1000
F,16,FX,-1000
OUTPR,NSOL,1
OUTPR,ESOL,1
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
/POST1
SET,LAST
*GET,U1,NODE,16,U,Y
/GRAPHICS,POWER
/ESHAPE,1
/VIEW,1,1,1,1
PLNSOL,S,X   !BENDING STRESS
/OUT,
*GET,BEND_STRESS1,PLNSOL,0,MAX
FINI
/SOLU
/COM, VM16, CASE 2 - END LOAD, ROARK, PAGE 104, NO. 1
F,6,FX,,,16,10
F,6,FY,150,,16,10
/OUT,SCRATCH
SOLVE
FINISH
/POST1
SET,LAST
```

```
/OUT,
*GET,U2,NODE,16,U,Y
/GRAPHICS,POWER
/ESHAPE,1
/VIEW,1,1,1,1
PLNSOL,S,X   !BENDING STRESS
*GET,BEND_STRESS2,PLNSOL,0,MAX

*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
*DIM,VALUE2,,2,3
LABEL(1,1) = 'DEFL','BEND_STRESS'
LABEL(1,2) = ' (in)  ',' (psi)  '
*VFILL,VALUE(1,1),DATA,.00500,3000
*VFILL,VALUE(1,2),DATA,U1,BEND_STRESS1
*VFILL,VALUE(1,3),DATA,ABS(U1/.005),ABS(BEND_STRESS1/3000)
SAVE,TABLE_1
*VFILL,VALUE2(1,1),DATA,.00500,4050
*VFILL,VALUE2(1,2),DATA,U2,BEND_STRESS2
*VFILL,VALUE2(1,3),DATA,ABS(U2/.005),ABS(BEND_STRESS2/4050)
SAVE,TABLE_2
FINI
/CLEAR,NOSTART



!**********************************************************************



/PREP7
C***           USING PLANE182 ELEMENTS
ANTYPE,STATIC
ET,1,PLANE182
KEYOPT,1,1,3   !SIMPLIFIED ENHANCED STRAIN FORMULATION
MP,EX,1,30E6
MP,NUXY,1,0.0
N,1
N,6,10
FILL
NGEN,2,10,1,6,1,,2
E,1,2,12,11
EGEN,5,1,1
/COM, VM16, CASE 1 - END MOMENT, ROARK, PAGE 106, NO. 9
D,1,ALL,,,11,10
F,6,FX,1000
F,16,FX,-1000
OUTPR,NSOL,1
OUTPR,ESOL,1
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
/POST1
SET,LAST
/GRAPHICS,POWER
/ESHAPE,1
/VIEW,1,1,1,1
/OUT,
*GET,U2,NODE,16,U,Y
PLNSOL,S,X   !BENDING STRESS
*GET,BEND_STRESS1,PLNSOL,0,MAX
*GET,U1,NODE,16,U,Y
FINI
/SOLU

/COM, VM16, CASE 2 - END LOAD, ROARK, PAGE 104, NO. 1
F,6,FX,,,16,10
F,6,FY,150,,16,10
/OUT,SCRATCH
SOLVE
FINISH
/POST1
```

```
SET,LAST
/GRAPHICS,POWER
/ESHAPE,1
/VIEW,1,1,1,1
/OUT,
*GET,U2,NODE,16,U,Y
PLNSOL,S,X   !BENDING STRESS
*GET,BEND_STRESS2,PLNSOL,0,MAX

*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
*DIM,VALUE2,,2,3
LABEL(1,1) = 'DEFL','BEND_STRESS'
LABEL(1,2) = ' (in)  ',' (psi)  '
*VFILL,VALUE(1,1),DATA,.00500,3000
*VFILL,VALUE(1,2),DATA,U1,BEND_STRESS1
*VFILL,VALUE(1,3),DATA,ABS(U1/.005),ABS(BEND_STRESS1/3000)
SAVE,TABLE_3
*VFILL,VALUE2(1,1),DATA,.00500,4050
*VFILL,VALUE2(1,2),DATA,U2,BEND_STRESS2
*VFILL,VALUE2(1,3),DATA,ABS(U2/.005),ABS(BEND_STRESS2/4050)
SAVE,TABLE_4
FINI
/CLEAR,NOSTART



/NOPR
/COM
/COM
/OUT,vm16,vrt
/COM,------------------- VM16 RESULTS COMPARISON ---------------------
/COM,
/COM, USING PLANE42
RESUME,TABLE_1
/COM,CASE 1:          |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F13.5,'   ',1F15.3)
RESUME,TABLE_2
/COM,CASE 2:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F13.5,'   ',1F15.3)
/COM, USING PLANE182
RESUME,TABLE_3
/COM,CASE 1:          |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F13.5,'   ',1F15.3)
/NOPR
RESUME,TABLE_4
/COM,CASE 2:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F13.5,'   ',1F15.3)
/COM,----------------------------------------------------------------
/COM,
/OUT
FINISH
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
/DELETE,TABLE_4
FINISH
*LIST,vm16,vrt
```

VM17 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
```

```
/VERIFY,VM17
/PREP7
smrt,off
/TITLE, VM17, SNAP-THROUGH BUCKLING OF A HINGED SHELL
:COM    CHANG, C.C.,"PERIODICALLY RESTARTED QUASI-NEWTON UPDATES IN
:COM    IN CONSTANT ARC-LENGTH METHOD", COMPUTERS AND STRUCTURES,
:COM    VOL. 41, NO. 5, PP. 963-972, 1991.
C***    USING SHELL63 ELEMENTS
ANTYPE,STATIC            ! STATIC ANALYSIS
ET,1,SHELL63,,1
R,1,6.350                ! SHELL THICKNESS
MP,EX,1,3102.75
MP,NUXY,1,0.3
:COM  CREATE FINITE ELEMENT MODEL
R1 = 2540                ! SHELL MID-SURFACE RADIUS
L  = 254                 ! HALF THE LENGTH
PI = 4*ATAN(1)           ! VALUE OF PI COMPUTED
THETA = 0.1*180/PI       ! 0.1 RADIANS CONVERTED TO DEGREES
CSYS,1                   ! CYLINDRICAL CO-ORDINATE SYSTEM
N,1,R1,90                ! NODES 1 AND 2 ARE CREATED AT POINTS
N,2,R1,90,L              ! A AND B RESPECTIVELY.
K,1,R1,90
K,2,R1,(90-THETA)
K,3,R1,90,L
K,4,R1,(90-THETA),L
ESIZE,,2                 ! TWO DIVISION ALONG THE REGION BOUNDARY
A,1,3,4,2
AMESH,1
NUMMRG,NODE
FINISH
*CREATE,SOLVIT,MAC
/PREP7
:COM  APPLY BOUNDARY CONDITIONS
NSEL,S,LOC,Z,0
DSYM,SYMM,Z
NSEL,S,LOC,Y,90
DSYM,SYMM,X
NSEL,S,LOC,Y,(90-THETA)
D,ALL,UX,,,,,UY,UZ
NSEL,ALL
FINISH
:COM   SOLUTION PHASE
:COM SINCE THE SOLUTION OUTPUT IS SUBSTANTIAL IT IS DIVERTED TO A
:COM  SCRATCH FILE
/OUTPUT,SCRATCH
/SOLUTION
NLGEOM,ON                ! LARGE DEFLECTION TURNED ON
OUTRES,,1                ! WRITE SOLUTION ON RESULTS FILE FOR EVERY SUBSTEP
F,1,FY,-250              ! 1/4 TH OF THE TOTAL LOAD APPLIED DUE TO SYMMETRY
NSUBST,30                ! BEGIN WITH 30 SUBSTEPS
ARCLEN,ON,5              ! ARC-LENGTH SOLUTION TECHNIQUE TURNED ON WITH
                         !  MAX. ARC-LENGTH KEPT AT 5 TO COMPUTE AND STORE
    !  SUFFICIENT INTERMEDIATE SOLUTION INFORMATION
SOLVE
FINISH
/OUTPUT
:COM   POSTPROCESSING PHASE
/POST26
NSOL,2,1,U,Y             ! STORE UY DISPLACEMENT OF NODE 1
NSOL,3,2,U,Y             ! STORE UY DISPLACEMENT OF NODE 2
PROD,4,1,,,LOAD,,,4*250  ! TOTAL LOAD IS 4*250 DUE TO QUARTER SYMMETRY
PROD,5,2,,,,,,-1         ! CHANGE SIGNS OF THE DISPLACEMENT VALUES
PROD,6,3,,,,,,-1
*GET,UY1,VARI,2,EXTREM,VMIN
*GET,UY2,VARI,3,EXTREM,VMIN
PRVAR,2,3,4              ! PRINT STORED INFORMATION
/AXLAB,X, DEFLECTION (MM)
/AXLAB,Y, TOTAL LOAD (N)
/GRID,1
/XRANGE,0,35
/YRANGE,-500,1050
XVAR,5
```

```
PLVAR,4                  ! PLOT LOAD WITH RESPECT TO -UY OF NODE 1
/NOERASE
XVAR,6
PLVAR,4                  ! PLOT LOAD WITH RESPECT TO -UY OF NODE 2
/ERASE
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'UY @A ','UY @B '
LABEL(1,2) = 'mm ','mm '
*VFILL,VALUE(1,1),DATA,-30,-26
*VFILL,VALUE(1,2),DATA,UY1,UY2
*VFILL,VALUE(1,3),DATA,ABS(UY1/30) ,ABS(UY2/26 )
FINISH
*END
SOLVIT
SAVE,TABLE_1
/CLEAR, NOSTART          ! CLEAR DATABASE FOR NEXT SOLUTION
/TITLE, VM17, SNAP-THROUGH BUCKLING OF A HINGED SHELL
C***    USING SHELL181 ELEMENTS
/PREP7
SMRT,OFF
ANTYPE,STATIC            ! STATIC ANALYSIS
ET,1,SHELL181
SECT,1,SHELL
SECD,6.350,1             ! SHELL THICKNESS
MP,EX,1,3102.75
MP,NUXY,1,0.3
:COM  CREATE FINITE ELEMENT MODEL
R1 = 2540                ! SHELL MID-SURFACE RADIUS
L  = 254                 ! HALF THE LENGTH
PI = 4*ATAN(1)           ! VALUE OF PI COMPUTED
THETA = 0.1*180/PI       ! 0.1 RADIANS CONVERTED TO DEGREES
CSYS,1                   ! CYLINDRICAL CO-ORDINATE SYSTEM
N,1,R1,90                ! NODES 1 AND 2 ARE CREATED AT POINTS
N,2,R1,90,L              ! A AND B RESPECTIVELY.
K,1,R1,90
K,2,R1,(90-THETA)
K,3,R1,90,L
K,4,R1,(90-THETA),L
ESIZE,,2                 ! TWO DIVISION ALONG THE REGION BOUNDARY
A,1,3,4,2
AMESH,1
NUMMRG,NODE
FINISH
SOLVIT
SAVE,TABLE_2
/CLEAR, NOSTART          ! CLEAR DATABASE FOR NEXT SOLUTION
/TITLE, VM17, SNAP-THROUGH BUCKLING OF A HINGED SHELL
C***    USING SHELL281 ELEMENTS
/PREP7
SMRT,OFF
ANTYPE,STATIC            ! STATIC ANALYSIS
ET,1,SHELL281
SECT,1,SHELL
SECD,6.350,1             ! SHELL THICKNESS
MP,EX,1,3102.75
MP,NUXY,1,0.3
:COM  CREATE FINITE ELEMENT MODEL
R1 = 2540                ! SHELL MID-SURFACE RADIUS
L  = 254                 ! HALF THE LENGTH
PI = 4*ATAN(1)           ! VALUE OF PI COMPUTED
THETA = 0.1*180/PI       ! 0.1 RADIANS CONVERTED TO DEGREES
CSYS,1                   ! CYLINDRICAL CO-ORDINATE SYSTEM
N,1,R1,90                ! NODES 1 AND 2 ARE CREATED AT POINTS
N,2,R1,90,L              ! A AND B RESPECTIVELY.
K,1,R1,90
K,2,R1,(90-THETA)
K,3,R1,90,L
K,4,R1,(90-THETA),L
ESIZE,,2                 ! TWO DIVISION ALONG THE REGION BOUNDARY
A,1,3,4,2
AMESH,1
```

```
NUMMRG,NODE
FINISH
SOLVIT
SAVE,TABLE_3
/NOPR
RESUME,TABLE_1
/COM
/OUT,vm17,vrt
/COM,------------------- VM17 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,SHELL63
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,SHELL181
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM,SHELL281
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm17,vrt
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
/DELETE,SOLVIT,MAC
```

VM18 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM18
/PREP7
/TITLE, VM18, OUT-OF-PLANE BENDING OF A CURVED BAR
!    USING PIPE18    STR. OF MATL., TIMOSHENKO, PART 1, 3RD ED., PAGE 412, EQN. 241
ANTYPE,STATIC
ET,1,PIPE18,,,,,,2   ! KEYOPT(6)=2 PRINTS MEMBER FORCES
MP,EX,1,30E6
MP,NUXY,1,.3
R,1,2,1,100          ! OD = 2, WALL THICKNESS = 1, RADIUS = 100
N,1,100              ! DEFINE NODES
N,2,,100
N,10
E,1,2,10             ! DEFINE ELEMENT
D,1,ALL              ! BOUNDARY CONDITIONS + LOAD
F,2,FZ,-50
FINISH
/SOLU
OUTPR,BASIC,1
/OUT,SCRATCH
SOLVE
FINISH
/POST1
SET,LAST
/OUT,
```

```
*GET,DEF,NODE,2,U,Z
ETABLE,STRS_BEN,NMISC,91
ETABLE,STRS_SHR,LS,4
*GET,STRSS_B,ELEM,1,ETAB,STRS_BEN
*GET,STRSS_T,ELEM,1,ETAB,STRS_SHR

*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'DEFLECTI','STRSS BE','STRSS SH'
LABEL(1,2) = 'ON (in) ','ND   psi','EAR  psi'
*VFILL,VALUE(1,1),DATA,-2.648,6366,-3183
*VFILL,VALUE(1,2),DATA,DEF,ABS(STRSS_B) ,STRSS_T
*VFILL,VALUE(1,3),DATA,ABS(DEF/2.648) ,ABS(STRSS_B /6366 ),ABS(STRSS_T /3183 )
SAVE,TABLE_1
FINI
/CLEAR,NOSTART

!**********************************************

/PREP7
!     USING ELBOW290
ANTYPE,STATIC
ET,1,ELBOW290
MP,EX,1,30E6
MP,NUXY,1,.3
SECTYPE,1,PIPE
SECDATA,2,1,8      ! OD = 2, WALL THICKNESS = 1

K,1,100              ! DEFINE NODES
K,2,,100
K,3,70.710,70.710
LARC,1,2,3
LESIZE,1,,,9
LMESH,ALL

DK,1,ALL              ! BOUNDARY CONDITIONS + LOAD
FK,2,FZ,-50
FINISH
/SOLU
OUTPR,BASIC,1
/OUT,SCRATCH
SOLVE
FINISH
/POST1
SET,LAST
/GRAPHICS,POWER
/ESHAPE,1
/VIEW,1,1,1,1
/OUT,
*GET,DEF,NODE,2,U,Z
ETABLE,STRS_BEN,SMISC,12
*GET,STRSS_B,ELEM,1,ETAB,STRS_BEN
PLESOL,S,YZ
*GET,SHEAR,PLNSOL,0,MAX
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'DEFLECTI','STRSS BE','STRSS SH'
LABEL(1,2) = 'ON (in) ','ND   psi','EAR  psi'
*VFILL,VALUE(1,1),DATA,-2.648,6366,-3183
*VFILL,VALUE(1,2),DATA,DEF,ABS(STRSS_B) ,SHEAR
*VFILL,VALUE(1,3),DATA,ABS(DEF/2.648) ,ABS(STRSS_B /6366 ),ABS(SHEAR /3183 )

SAVE,TABLE_2

/NOPR
/COM,
/OUT,vm18,vrt
/COM,------------------- VM18 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
RESUME,TABLE_1
```

```
/COM,USING PIPE18
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,
RESUME,TABLE_2
/COM,USING ELBOW290
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vm18,vrt
```

VM19 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM19
/PREP7
/TITLE, VM19, RANDOM VIBRATION ANALYSIS OF A DEEP SIMPLY-SUPPORTED BEAM
/COM REFERENCE:  NAFEMS FORCED VIBRATION BENCHMARKS TEST 5R
ET,1,BEAM188                         ! DEFINE ELEMENT TYPE
KEYOPT,1,3,3
MP,EX,1,200E9                      ! DEFINE MATERIAL PROPERTIES
MP,NUXY,1,0.3
MP,ALPX,1,0.1E-5
MP,DENS,1,8000
SECT,1,BEAM,RECT
SECD,2,2
N,1,0
N,11,10
FILL
E,1,2
EGEN,10,1,1
FINISH

/SOLU
ANTYPE,MODAL                       ! DEFINE ANALYSIS TYPE
MXPAND,9,,,YES                     ! EXPAND 9 MODES, CALC. STRESS VALUES
MODOPT,LANB,9
D,1,UX,0,0,1,1,UY,UZ,ROTX          ! APPLY CONSTRAINTS
D,11,UY,0,0,11,1,UZ
/OUT,SCRATCH
SOLVE
*GET,FREQ,MODE,1,FREQ
FINISH
!/COPY,,tri,,mode,tri

/SOLU
ANTYPE,SPECTR                      ! PREFORM SPECTRUM PSD ANALYSIS
SPOPT,PSD,9,ON                     ! CALC. STRESS RESPONSE FOR FIRST 9 MODES
PSDUNIT,1,FORCE
DMPRAT,0.02
F,1,FY,-0.5E6                      ! SCALE LOADS
F,11,FY,-0.5E6
F,2,FY,-1E6,,10,1
PSDFRQ,1,1,0.1,70.
PSDVAL,1,1,1                       ! IN N**2/HZ
PFACT,1,NODE
PSDRES,DISP,REL
PSDCOM
SOLVE
FINISH

/POST26
/OUT,
STORE,PSD,10
```

```
NSOL,2,6,U,Y
RPSD,8,2,2,0,2,,,1.0e-3
PRTIME,42.630,42.631
PRVAR,8
*GET,P1,VARI,8,RTIME,42.63
PM=P1*1000000
FINISH

/POST26
STORE,PSD,10
ESOL,3,5,6,SMISC,37
RPSD,9,3,3,0,2,,,1.0e-3
PRTIME,42.630,42.631
PRVAR,9
*GET,P2,VARI,9,RTIME,42.63
PM2=P2/(1E12)
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'FREQ1','PEAK d','PSD(N/mm'
LABEL(1,2) = ' (Hz)',' mm^2/Hz','^2)^2/Hz'
*VFILL,VALUE(1,1),DATA,42.65,180.9,58515.6
*VFILL,VALUE(1,2),DATA,FREQ,PM,PM2
*VFILL,VALUE(1,3),DATA,ABS(FREQ/42.65) ,ABS(PM/180.9 ),ABS(PM2/58515.6 )
FINISH
/COM
/OUT,vm19,vrt
/COM,------------------- VM19 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.2)
/COM,-----------------------------------------------------------------
/COM,
/COM,-----------------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM19 NOT CONTAINED IN
/COM,THIS TABLE
/COM,-----------------------------------------------------------------
/OUT
*LIST,vm19,vrt
```

VM20 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM20
/PREP7
/TITLE, VM20, CYLINDRICAL MEMBRANE UNDER PRESSURE
C*** STR. OF MATLS., TIMOSHENKO, PART 2, 3RD ED., PAGE 121, ART. 25
C*** USING SHELL141 - MEMBRANE SHELL
ANTYPE,STATIC
ET,1,SHELL41
MP,EX,1,30E6
MP,NUXY,1,0.3
R,1,1                   ! THICKNESS = 1
CSYS,1                  ! CYLINDRICAL C.S.
N,1,60                  ! DEFINE NODES
N,2,60,,10
NGEN,2,2,1,2,1,,10
NROTAT,ALL              ! ROTATE NODAL C.S. TO CYLINDRICAL C.S.
E,1,2,4,3               ! DEFINE ELEMENT
CP,1,UX,1,2,3,4         ! COUPLE RADIAL DISPLACEMENTS
CP,2,UZ,2,4             ! COUPLE UZ DISPLACEMENTS
D,1,UZ,,,3,2
D,ALL,UY
SFE,1,4,PRES,,-15000    ! AXIAL TRACTION
SFE,1,1,PRES,,-500      ! INTERNAL PRESSURE
FINISH
/SOLU
```

```
OUTPR,,1
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
*GET,STRS_HOP,NODE,1,S,2
*GET,STRS_AX,NODE,1,S,1
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'AXIAL ST','HOOP STR'
LABEL(1,2) = 'RSS psi ','SS  psi '
*VFILL,VALUE(1,1),DATA,15000,29749
*VFILL,VALUE(1,2),DATA,STRS_HOP,STRS_AX
*VFILL,VALUE(1,3),DATA,ABS(STRS_HOP/15000),ABS(STRS_AX/29749)
SAVE,TABLE_1
FINISH
/CLEAR,NOSTART
/TITLE, VM20, CYLINDRICAL MEMBRANE UNDER PRESSURE
C*** USING SHELL181 - FINITE STRAIN MEMBRANE
/PREP7
ANTYPE,STATIC
ET,1,SHELL181
KEYOPT,1,1,1            ! MEMBRANE STIFFNESS ONLY
KEYOPT,1,3,2            ! FULL INTEGRATION
MP,EX,1,30E6
MP,NUXY,1,0.3
SECT,1,SHELL
SECD,1,1                ! THICKNESS = 1
CSYS,1                  ! CYLINDRICAL C.S.
N,1,60                  ! DEFINE NODES
N,2,60,,10
NGEN,2,2,1,2,1,,10
NROTAT,ALL              ! ROTATE NODAL C.S. TO CYLINDRICAL C.S.
E,1,2,4,3               ! DEFINE ELEMENT
CP,1,UX,1,2,3,4         ! COUPLE RADIAL DISPLACEMENTS
CP,2,UZ,2,4             ! COUPLE UZ DISPLACEMENTS
D,1,UZ,,,3,2
D,ALL,UY
SFE,1,4,PRES,,-15000    ! AXIAL TRACTION
SFE,1,1,PRES,,-500      ! INTERNAL PRESSURE
FINISH
/SOLU
OUTPR,NSOL,1
OUTPR,RSOL,1
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
*GET,STRS_HOP,NODE,1,S,2
*GET,STRS_AX,NODE,1,S,1
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'AXIAL ST','HOOP STR'
LABEL(1,2) = 'RSS psi ','SS  psi '
*VFILL,VALUE(1,1),DATA,15000,29749
*VFILL,VALUE(1,2),DATA,STRS_HOP,STRS_AX
*VFILL,VALUE(1,3),DATA,ABS(STRS_HOP/15000),ABS(STRS_AX/29749)
SAVE,TABLE_2
RESUME,TABLE_1
/COM
/OUT,vm20,vrt
/COM,------------------- VM20 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM, SHELL41
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/NOPR
```

```
RESUME,TABLE_2
/GOPR
/COM,
/COM, SHELL181
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vm20,vrt
/DELETE,TABLE_1
/DELETE,TABLE_2
```

VM21 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM21
/PREP7
MP,PRXY,,0.3
/TITLE, VM21, TIE ROD WITH LATERAL LOADING, NO STREES STIFFENING
C***   STR. OF MATLS., TIMOSHENKO, PART 2, 3RD ED., PAGE 42, ART. 6
ANTYPE,STATIC
ET,1,BEAM188
KEYOPT,1,3,3
SECT,1,BEAM,RECT
SECD,2.5,2.5
MP,EX,1,30E6
N,1                              ! DEFINE NODES
N,5,100
FILL
E,1,2                            ! DEFINE ELEMENTS
EGEN,4,1,1
D,ALL,UY,,,,,ROTX,ROTZ           ! BOUNDARY CONDITIONS AND LOADINGS
D,1,UZ
NSEL,S,,,5
DSYM,SYMM,X                      ! DEFINE SYMMETRY BOUNDARY
NSEL,ALL
F,1,FX,-21972.6                  ! APPLY LOADS
SFBEAM,ALL,1,PRES,1.79253
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
NSEL,S,,,1,5,4
PRNSOL,U,Z
PRNSOL,ROT,Y
NSEL,ALL
PRRSOL
RGHT_END = NODE (200,0,0)
LFT_END  = NODE (0,0,0)
*GET,UZ_MX_C2,NODE,RGHT_END,U,Z
*GET,SLOPE_C2,NODE,LFT_END,ROT,Y
FINISH
/POST26
RFORCE,2,RGHT_END,M,Y
STORE
*GET,M_MX_C2,VARI,2,EXTREM,VMAX
FINISH
/PREP7
/TITLE, VM21, TIE ROD WITH LATERAL LOADING, STRESS STIFFENING PRESENT
NSUBST,5
AUTOTS,ON                        ! AUTO TIME STEPPING ACTIVATED
FINISH
/SOLU
```

```
NLGEOM,ON
CNVTOL,F,,.0001,,1               ! SMALLER CONVERGENCE TOLERANCE
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
NSEL,S,,,1,5,4
PRNSOL,U,Z
PRNSOL,ROT,Y
PRRSOL
*GET,UZ_MX_C1,NODE,RGHT_END,U,Z
*GET,SLOPE_C1,NODE,LFT_END,ROT,Y
FINISH
/POST26
RFORCE,2,RGHT_END,M,Y
STORE
*GET,M_MX_C1,VARI,2,EXTREM,VMAX
*DIM,LABEL,CHAR,3,2
*DIM,VALUE_C1,,3,3
*DIM,VALUE_C2,,3,3
LABEL(1,1) = 'UZ MAX  ','SLOPE   ','MOMENT M'
LABEL(1,2) = '(in)    ','(rad)   ','AX in-lb'
*VFILL,VALUE_C1(1,1),DATA,-.19945,.0032352,-4580.1
*VFILL,VALUE_C1(1,2),DATA,UZ_MX_C1,SLOPE_C1,M_MX_C1
*VFILL,VALUE_C1(1,3),DATA,ABS(UZ_MX_C1/.19945),ABS(SLOPE_C1/.0032352), ABS(M_MX_C1/4580.1)
*VFILL,VALUE_C2(1,1),DATA,-.38241,.0061185,-8962.7
*VFILL,VALUE_C2(1,2),DATA,UZ_MX_C2,SLOPE_C2,M_MX_C2
*VFILL,VALUE_C2(1,3),DATA,ABS(UZ_MX_C1/.19945),ABS(SLOPE_C1/.0032352), ABS(M_MX_C1/4580.1)
/COM
/OUT,vm21,vrt
/COM,------------------- VM21 RESULTS COMPARISON ---------------------
/COM,
/COM,                        |     TARGET     |    Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS FOR F<>0 (STIFFENED):
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C1(1,1),VALUE_C1(1,2),VALUE_C1(1,3)
(1X,A8,A8,'   ',F17.7,'  ',F19.7,'   ',1F15.3)
/COM,
/COM,RESULTS FOR F=0 (UNSTIFFENED):
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C2(1,1),VALUE_C2(1,2),VALUE_C2(1,3)
(1X,A8,A8,'   ',F17.7,'  ',F19.7,'   ',1F15.3)
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vm21,vrt
```

VM22 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM22
/PREP7
/TITLE, VM22, SMALL DEFLECTION OF A BELLEVILLE SPRING
C*** STR. OF MATL., TIMOSHENKO, PART 2, 3RD ED., PAGE 143, PROB. 2
ANTYPE,STATIC
ET,1,SHELL208,,,2
SECTYPE,1,SHELL
SECDATA,0.2
SECNUM,1
MP,EX,1,3E7
MP,NUXY,1,0
N,1,1,(.5*TAN(.12217))      ! DEFINE NODES
N,2,1.5
E,1,2                       ! DEFINE ELEMENT
D,2,UY                      ! BOUNDARY CONDITIONS AND LOADS
F,1,FY,-628.31853
```

```
FINISH
/SOLU
SOLVE
FINISH
/POST1
SET,1,1
NSEL,S,NODE,,1
PRNSOL,U,COMP                ! DISPLACEMENTS AT NODE 1
*GET,DEF,NODE,1,U,Y
*DIM,LABEL,CHAR,1,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'UY (in)'
*VFILL,VALUE(1,1),DATA,-.0028205
*VFILL,VALUE(1,2),DATA,DEF
*VFILL,VALUE(1,3),DATA,ABS( DEF /.0028205)
/COM
/OUT,vm22,vrt
/COM,------------------- VM22 RESULTS COMPARISON ---------------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.7,'  ',F14.7,'   ',1F15.3)
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vm22,vrt
```

VM23 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM23
/PREP7
/TITLE, VM23, THERMAL-STRUCTURAL CONTACT OF TWO BODIES
/COM
/COM,  SOLVING USING PLANE13 ELEMENTS
/COM,
ET,1,PLANE13,4,,2         ! COUPLE-FIELD ELEMENT TYPE
ET,2,CONTA175,1           ! CONTACT ELEMENT TYPE
ET,3,TARGE169             ! TARGET ELEMENT TYPE
MP,EX,1,10E6              ! YOUNG'S MODULUS
MP,KXX,1,250              ! CONDUCTIVITY
MP,ALPX,1,12E-6           ! THERMAL EXPANSION COEFFICIENT
MP,PRXY,,0.3
R,2,,,-1000,-0.005
RMORE,,,,,,-100
RMORE,,100
RMORE
RMORE,0.01
!      SET UP FINITE ELEMENT MODEL
N,1
N,2,0.4
N,3,(0.4+0.0035)
N,4,(0.9+0.0035)
NGEN,2,4,1,4,1,,0.1
E,1,2,6,5                 ! PLANE13 ELEMENTS
E,3,4,8,7
TYPE,2                    ! CONTACT ELEMENTS
REAL,2
E,2
E,6
TYPE,3                    ! TARGET ELEMENTS
REAL,2
NSEL,S,NODE,,3,7,4
ESLN
ESURF
ALLSEL
!      APPLY INITIAL BOUNDARY CONDITIONS
```

```
D,ALL,AZ
D,1,UY,,,4,1
D,1,UX,,,5,4
D,4,UX,,,8,4
TREF,100
FINISH
/SOLU
NLGEOM,ON                ! LARGE DEFLECTION EFFECTS TURNED ON
D,1,TEMP,500,,5,4
D,3,TEMP,100,,4
D,7,TEMP,100,,8
/OUT,SCRATCH
SOLVE                    ! FIRST LOAD STEP
OUTRES,ALL,ALL           ! STORE ALL DATA
DDELE,3,TEMP,7,4
D,4,TEMP,850,,8,4
NSUBST,3
SOLVE                    ! SECOND LOAD STEP
D,4,TEMP,100,,8,4
SOLVE                    ! THIRD LOAD STEP
FINISH

/POST1
/OUT,
INRES,NSOL,MISC          ! RETRIEVE NODAL AND MISCELLANEOUS DATA
SUBSET,2,2               ! READ LOAD STEP 2, SUBSTEP 2 DATA
ESEL,S,,,3,4
ETABLE,HEAT-FLO,SMISC,14 ! STORE HEAT FLOWS FOR CONTACT ELEMENTS
SSUM
*GET,HEAT_C1,SSUM,,ITEM,HEAT-FLO
NSEL,S,,,2,6,4
PRNSOL,TEMP
*GET,TEMP_C1,NODE,2,TEMP
APPEND,2,3               ! APPEND (OVERWRITE IN THIS CASE) BY
                         !  LOAD STEP 2 AND SUBSTEP 3 DATA
ETABLE,REFL
SSUM
*GET,HEAT_C2,SSUM,,ITEM,HEAT-FLO
PRNSOL,TEMP
*GET,TEMP_C2,NODE,2,TEMP
SUBSET,3,3               ! READ LOAD STEP 3, SUBSTEP 3 DATA
ETABLE,REFL
PRETAB
*GET,TEMP_C3,ELEM,4,ETAB,HEAT-FLO
PRNSOL,TEMP
ALLSEL,ALL
*DIM,LABEL,CHAR,2,2
*DIM,LABEL_C3,CHAR,1,2
*DIM,VALUE_C1,,2,3
*DIM,VALUE_C2,,2,3
*DIM,VALUE_C3,,1,2
LABEL(1,1) = 'TEMP AT ','HEAT FLO'
LABEL(1,2) = 'EA2 (C) ','W (W)   '
LABEL_C3(1,1) = 'HEAT FLO'
LABEL_C3(1,2) = 'W (W)   '
*VFILL,VALUE_C1(1,1),DATA,539,2439
*VFILL,VALUE_C1(1,2),DATA,TEMP_C1,HEAT_C1
*VFILL,VALUE_C1(1,3),DATA,ABS(TEMP_C1/539  ) ,ABS( HEAT_C1/2439 )
*VFILL,VALUE_C2(1,1),DATA,636.6,8536.6
*VFILL,VALUE_C2(1,2),DATA,TEMP_C2,HEAT_C2
*VFILL,VALUE_C2(1,3),DATA,ABS(TEMP_C2/636.6 ) ,ABS( HEAT_C2/8536.6)
*VFILL,VALUE_C3(1,1),DATA,0
*VFILL,VALUE_C3(1,2),DATA,TEMP_C3
SAVE,TABLE_1
FINISH
/CLEAR,NOSTART

/COM,
/COM,  SOLVING USING PLANE233 ELEMENT WITH WEAK COUPLING BETWEEN U AND TEMP DOF
/COM,

/PREP7
```

```
ET,1,PLANE223,11,1       ! COUPLE-FIELD ELEMENT TYPE, WEAK COUPLING
ET,2,CONTA175,1          ! CONTACT ELEMENT TYPE
ET,3,TARGE169            ! TARGET ELEMENT TYPE
MP,EX,1,10E6             ! YOUNG'S MODULUS
MP,KXX,1,250             ! CONDUCTIVITY
MP,ALPX,1,12E-6          ! THERMAL EXPANSION COEFFICIENT
MP,PRXY,,0.3
R,2,,,-1000,-0.005
RMORE,,,,,,-100
RMORE,,100
RMORE
RMORE,0.01
!      SET UP FINITE ELEMENT MODEL
N,1
N,2,0.4
N,3,(0.4+0.0035)
N,4,(0.9+0.0035)
NGEN,2,4,1,4,1,,0.1
E,1,2,6,5                ! PLANE223 ELEMENTS
E,3,4,8,7
TYPE,2                   ! CONTACT ELEMENTS
REAL,2
E,2
E,6
TYPE,3                   ! TARGET ELEMENTS
REAL,2
NSEL,S,NODE,,3,7,4
ESLN
ESURF
ALLSEL
!      APPLY INITIAL BOUNDARY CONDITIONS
D,1,UY,,,4,1
D,1,UX,,,5,4
D,4,UX,,,8,4
TREF,100
FINISH
/SOLU
NLGEOM,ON                ! LARGE DEFLECTION EFFECTS TURNED ON
D,1,TEMP,500,,5,4
D,3,TEMP,100,,4
D,7,TEMP,100,,8
/OUT,SCRATCH
SOLVE                    ! FIRST LOAD STEP
OUTRES,ALL,ALL           ! STORE ALL DATA
DDELE,3,TEMP,7,4
D,4,TEMP,850,,8,4
NSUBST,3
SOLVE                    ! SECOND LOAD STEP
D,4,TEMP,100,,8,4
SOLVE                    ! THIRD LOAD STEP
FINISH

/POST1
/OUT,
INRES,NSOL,MISC          ! RETRIEVE NODAL AND MISCELLANEOUS DATA
SUBSET,2,2               ! READ LOAD STEP 2, SUBSTEP 2 DATA
ESEL,S,,,3,4
ETABLE,HEAT-FLO,SMISC,14 ! STORE HEAT FLOWS FOR CONTACT ELEMENTS
SSUM
*GET,HEAT_C1B,SSUM,,ITEM,HEAT-FLO
NSEL,S,,,2,6,4
PRNSOL,TEMP
*GET,TEMP_C1B,NODE,2,TEMP
APPEND,2,3               ! APPEND (OVERWRITE IN THIS CASE) BY
                         !  LOAD STEP 2 AND SUBSTEP 3 DATA
ETABLE,REFL
SSUM
*GET,HEAT_C2B,SSUM,,ITEM,HEAT-FLO
PRNSOL,TEMP
*GET,TEMP_C2B,NODE,2,TEMP
SUBSET,3,3               ! READ LOAD STEP 3, SUBSTEP 3 DATA
ETABLE,REFL
```

```
PRETAB
*GET,TEMP_C3B,ELEM,4,ETAB,HEAT-FLO
PRNSOL,TEMP
ALLSEL,ALL
*DIM,LABEL,CHAR,2,2
*DIM,LABEL_C3,CHAR,1,2
*DIM,VALUE_C1,,2,3
*DIM,VALUE_C2,,2,3
*DIM,VALUE_C3,,1,2
LABEL(1,1) = 'TEMP AT ','HEAT FLO'
LABEL(1,2) = 'EA2 (C) ','W (W)   '
LABEL_C3(1,1) = 'HEAT FLO'
LABEL_C3(1,2) = 'W (W)   '
*VFILL,VALUE_C1(1,1),DATA,539,2439
*VFILL,VALUE_C1(1,2),DATA,TEMP_C1B,HEAT_C1B
*VFILL,VALUE_C1(1,3),DATA,ABS(TEMP_C1B/539  ) ,ABS( HEAT_C1B/2439 )
*VFILL,VALUE_C2(1,1),DATA,636.6,8536.6
*VFILL,VALUE_C2(1,2),DATA,TEMP_C2B,HEAT_C2B
*VFILL,VALUE_C2(1,3),DATA,ABS(TEMP_C2B/636.6 ) ,ABS( HEAT_C2B/8536.6)
*VFILL,VALUE_C3(1,1),DATA,0
*VFILL,VALUE_C3(1,2),DATA,TEMP_C3B
SAVE,TABLE_2
FINISH
RESUME,TABLE_1
/COM
/OUT,vm23,vrt
/COM,------------------- VM23 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,
/COM,  USING PLANE13 ELEMENTS
/COM,
/COM,TEMP AT EB2 = 600 C:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C1(1,1),VALUE_C1(1,2),VALUE_C1(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,
/COM,TEMP AT EB2 = 850 C:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C2(1,1),VALUE_C2(1,2),VALUE_C2(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,
/COM,TEMP AT EB2 = 100 C:
*VWRITE,LABEL_C3(1,1),LABEL_C3(1,2),VALUE_C3(1,1),VALUE_C3(1,2)
(1X,A8,A8,'   ',F10.1,'  ',F10.1)
/COM,
/COM,
/NOPR
RESUME,TABLE_2
/GOPR,
/COM,
/COM,
/COM,
/COM, USING PLANE233 ELEMENTS
/COM,
/COM,TEMP AT EB2 = 600 C:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C1(1,1),VALUE_C1(1,2),VALUE_C1(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,
/COM,TEMP AT EB2 = 850 C:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C2(1,1),VALUE_C2(1,2),VALUE_C2(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,
/COM,TEMP AT EB2 = 100 C:
*VWRITE,LABEL_C3(1,1),LABEL_C3(1,2),VALUE_C3(1,1),VALUE_C3(1,2)
(1X,A8,A8,'   ',F10.1,'  ',F10.1)
/COM,
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vm23,vrt
/delete,TABLE_1
```

```
/delete,TABLE_2
```

VM24 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM24
/PREP7
/TITLE, VM24, PLASTIC HINGE IN A RECTANGULAR BEAM
C*** STR. OF MATLS., TIMOSHENKO, PART 2, 3RD ED., PG. 349, ART. 64
C*** USING BILINEAR KINEMATIC HARDENING PLASTICITY BEHAVIOR TO DESCRIBE
C*** THE MATERIAL NONLINEARITY
ET,1,BEAM188
SECTYPE,1,BEAM,RECT
SECDATA,2,1,6,1           ! 2 x 1 CROSS-SECTION USING 6 CELLS THRU THE THICKNESS
MP,EX,1,30E6
MP,PRXY,1,0.3
TB,BKIN,1,1               ! BILINEAR KINEMATIC HARDENING
TBTEMP,70
TBDATA,1,36000,0          ! YIELD POINT AND ZERO TANGENT MODULUS
N,1                       ! DEFINE NODES
N,2,10
E,1,2                     ! DEFINE ELEMENT
D,1,ALL                   ! BOUNDARY CONDITIONS
DSYM,SYMM,Z               ! 2-DIMENSIONAL MODEL
FINISH
/SOLU
NSUBS,1
OUTRES,EPPL,1             ! STORE PLASTIC STRAINS FOR EVERY SUBSTEP
CNVTOL,U                  ! CONVERGENCE CRITERION BASED UPON DISPLACEMENTS AND
CNVTOL,ROT                ! ROTATIONS
/OUT,SCRATCH
*DO,I,1,4
  TIME,1.0
  F,2,MZ,(20000+(I*4000)) ! APPLY MOMENT LOAD
  SOLVE
*ENDDO
FINISH
/POST26
/OUT,
NSOL,2,2,U,Y,UY2          ! NODE 2 DISPLACEMENT
NSOL,3,2,ROT,Z,ROTZ       ! NODE 2 ROTATION, USED FOR COMPARISON
ESOL,4,1,,LEPPL,1,EPPLAXL ! AXIAL PLASTIC STRAIN
/OUT,vm24,vrt
PRVAR,2,3,4
/OUT
FINISH
*LIST,vm24,vrt
```

VM25 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM25
/PREP7
SMRT,OFF
/TITLE, VM25, STRESSES IN A LONG CYLINDER
C*** STR. OF MATLS., TIMOSHENKO, PART 2, 3RD ED., PAGE 213, PROB. 1
C***  INTERNAL PRESSURE
ANTYPE,STATIC          ! STATIC ANALYSIS
ET,1,PLANE183,,,1,     ! AXISYMM
MP,EX,1,30E6           ! MATERIAL PROPERTIES
MP,DENS,1,.00073
MP,NUXY,1,0.3          ! DEFINE KEYPOINTS, LINES, AND AREAS
K,1,4
K,2,8
```

```
KGEN,2,1,2,1,,1
L,1,2,7
ESIZE,.5
LESIZE,1,,,14
MSHK,1                    ! MAPPED AREA MESH
MSHA,0,2D                 ! USING QUADS
A,3,1,2,4
AMESH,1
SAVE,MODEL           ! SAVE MODEL FOR SECOND LOAD CASE
NSEL,S,LOC,Y,0       ! SET UP LONG CYLINDER EFFECT
D,ALL,UY
NSEL,S,LOC,Y,1
CP,1,UY,ALL          ! COUPLE AXIAL DISPLACEMENTS AT UNCONSTRAINED Y EDGE
NSEL,ALL
FINISH
/SOLU
NSEL,S,LOC,X,4
SF,,PRES,30000       ! APPLY INTERNAL PRESSURE ON CYLINDER
NSEL,S,LOC,X,8
SF,,PRES,1E-10       ! APPLY DUMMY PRESSURE FOR SURFACE PRINTOUT
NSEL,ALL
OUTPR,,ALL
/OUT,SCRATCH
SOLVE                ! LOAD STEP 1 - INTERNAL PRESSURE
FINISH
/POST1
SET,1,1
LFT_NODE = NODE (4,0,0)
MID_NODE = NODE (6,0,0)
RT_NODE = NODE (8,0,0)
PRNSOL,S,COMP        ! PRINT NODAL STRESS SOLUTION
PATH,STRESS,2,,48    ! DEFINE PATH WITH NAME = "STRESS"
PPATH,1,LFT_NODE     ! DEFINE PATH POINTS BY NODE
PPATH,2,RT_NODE
PLSECT,S,Z,-1        ! DISPLAY SZ STRESSES
PLSECT,S,X,-1        ! DISPLAY SX STRESSES
PRSECT,-1            ! PRINT LINEARIZED STRESSES
/OUT,
*GET,DEF_4,NODE,LFT_NODE,U,X
*GET,RST_4_C1,NODE,LFT_NODE,S,X
*GET,RST_6_C1,NODE,MID_NODE,S,X
*GET,RST_8_C1,NODE,RT_NODE ,S,X
*GET,TST_4_C1,NODE,LFT_NODE,S,Z
*GET,TST_6_C1,NODE,MID_NODE,S,Z
*GET,TST_8_C1,NODE,RT_NODE ,S,Z
*DIM,VALUE_C1,,7,3
*VFILL,VALUE_C1(1,1),DATA,.0078666,-30000,-7778,0,50000,27778,20000
*VFILL,VALUE_C1(1,2),DATA,DEF_4,RST_4_C1,RST_6_C1,RST_8_C1,TST_4_C1,TST_6_C1,TST_8_C1
*VFILL,VALUE_C1(1,3),DATA,ABS(DEF_4/.0078666),ABS(RST_4_C1/30000),ABS(RST_6_C1/7778),0
*VFILL,VALUE_C1(5,3),DATA,ABS(TST_4_C1/50000),ABS(TST_6_C1/27778),ABS(TST_8_C1/20000)
*DIM,LABEL_C1,CHAR,7,2
LABEL_C1(1,1)='DEF (R=4','STRS_R p','STRS_R p','STRS_R p','STRS_T p'
LABEL_C1(6,1)='STRS_T p','STRS_T p'
LABEL_C1(1,2) = ') in    ','si (R=4)','si (R=6)','si (R=8)','si (R=4)'
LABEL_C1(6,2) ='si (R=6)','si (R=8)'
SAVE,TABLE_1
FINISH

/SOLU
RESUME,MODEL
C*** ROTATION ABOUT AXIS
NSEL,S,LOC,Y,0       ! PREVENT RIGID BODY MOTION
NSEL,R,LOC,X,4
D,ALL,UY
NSEL,S,LOC,X,4
SF,,PRES,1E-10       ! LEAVE A SMALL PRESSURE TO ALLOW STRESS PRINTOUT
NSEL,ALL
OMEGA,,1000          ! ROTATE CYLINDER WITH ANGULAR VELOCITY OMEGA
OUTPR,,ALL
/OUT,SCRATCH
SOLVE                ! LOAD STEP 2 - CENTRIFUGAL LOADING
FINISH
```

```
/POST1
/OUT,
LFT_NODE = NODE (4,0,0)
XI_NODE  = NODE (5.43,0,0)

*GET,RST_4_C2,NODE,LFT_NODE,S,X
*GET,TST_4_C2,NODE,LFT_NODE,S,Z
*GET,RST_X_C2,NODE,XI_NODE ,S,X
*GET,TST_X_C2,NODE,XI_NODE ,S,Z
*DIM,VALUE_C2,,4,3
*VFILL,VALUE_C2(1,1),DATA,0,40588,4753,29436
*VFILL,VALUE_C2(1,2),DATA,RST_4_C2,TST_4_C2,RST_X_C2,TST_X_C2
*VFILL,VALUE_C2(1,3),DATA,0,ABS(TST_4_C2/40588 ),ABS(RST_X_C2/4753 ),ABS(TST_X_C2/29436)
*DIM,LABEL_C2,CHAR,4,2
LABEL_C2(1,1) ='STRS_R p','STRS_T p','STRS_R p','STRS_T p'
LABEL_C2(1,2) ='si (R=4)','si (R=4)','si R=5.4','si R=5.4'
SAVE,TABLE_2
RESUME,TABLE_1
/COM
/OUT,vm25,vrt
/COM,------------------- VM25 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS FOR P = 30,000 PSI:
/COM,
*VWRITE,LABEL_C1(1,1),LABEL_C1(1,2),VALUE_C1(1,1),VALUE_C1(1,2),VALUE_C1(1,3)
(1X,A8,A8,'   ',F14.7,'  ',F17.7,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS FOR w = 1000 RAD/SEC
*VWRITE,LABEL_C2(1,1),LABEL_C2(1,2),VALUE_C2(1,1),VALUE_C2(1,2),VALUE_C2(1,3)
(1X,A8,A8,'   ',F14.7,'  ',F17.7,'   ',1F15.3)
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vm25,vrt
```

VM26 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vm26
/FILNAM,vm26
/PREP7
/TITLE, VM26  LARGE DEFLECTION OF A CANTILEVERED PLATE
/COM   REF: BATHE AND DVORKIN, " A FORMULATION OF GENERAL SHELL ELEMENTS... "
/COM                             IJNME, VOL 22, NO. 3 (1986) PAGE 720
/COM   USING SHELL181 ELEMENTS
/OUT,SCRATCH
/NOPR
SMRT,OFF
ANTYPE,STATIC           ! STATIC ANALYSIS
NLGEOM,ON               ! LARGE DEFLECTION OPTION
ET,1,SHELL181,,,2
SECTYPE,1,SHELL
SECDATA,1,1,0,5         ! PLATE THICKNESS = 1
MP,EX,1,1800            ! MATERIAL PROPERTIES
MP,NUXY,1,0
K,1                     ! DEFINE KEYPOINTS
K,2,12
K,3,12,1
K,4,,1
L,1,2                   ! DEFINE LINE SEGMENTS
L,3,4
LESIZE,ALL,,,2          ! 2 DIVISIONS ALONG LENGTH
ESIZE,,1                ! ONE DIVISION ON UNSPECIFIED LINE SEGMENTS
```

```
A,1,2,3,4
AMESH,1                 ! CREATE MESH
NSEL,S,LOC,X
D,ALL,ALL               ! FIXED END B.C.'S
NSEL,S,LOC,X,12
CP,1,ROTY,ALL           ! COUPLE ROTATIONS AT FREE END
TORQ=7.854              ! DEFINE HALF TOTAL LOAD
F,2,MY,TORQ
NSEL,ALL                ! RESELECT ALL NODES
FINISH
/SOLU
AUTOTS,ON               ! USE AUTOMATIC LOAD STEPPING
NSUBST,10,100,10        ! START WITH MAX OF 10 SUBSTEPS FOR EACH LOAD STEP
CNVTOL,F,1,1.0E-2  ! FORCE CONVERGENCE
CNVTOL,U,1,1.0E-2  ! DISPLACEMENT CONVERGENCE
LNSRCH,ON               ! USE LINE SEARCH METHOD
OUTPR,BASIC,LAST        ! BASIC PRINTOUT IN THE LAST SUBSTEP
OUTRES,ALL,ALL          ! WRITE SOLUTION TO THE RESULTS FILE FOR EACH SUBSTEP
SOLVE
FINISH
! THE FOLLOWING 4 COMMANDS ARE NOT NEEDED SINCE THE INITIAL AND THE
! RESTART ANALYSES ARE IN ONE Mechanical APDL RUN. THE USE OF THESE COMMANDS WAS DONE
! IN ORDER TO DEMONSTRATE THE USE OF THE FILES NEEDED FOR A RESTART
/COPY,vm26,rdb,,vm26r,rdb      ! COPY THE FILES NEEDED FOR RESTART TO
/COPY,vm26,ldhi,,vm26r,ldhi    ! FILES NAMED VM26R.***
/COPY,vm26,r001,,vm26r,r001    !
/COPY,vm26,rst,,vm26r,rst      ! NEEDED FOR POSTPROCESSOR ONLY
/CLEAR,NOSTART                 ! CLEAR THE DATA BASE
/FILNAM,vm26r                  ! CONTINUE WITH FILES NAMED VM26R.***
/SOLU
ANTYPE,,REST            ! RESTART ANALYSIS
F,2,MY,TORQ*2           ! APPLY FULL LOAD
SOLVE
FINISH
/POST1
RSYS,SOLU               ! CHOOSE "AS-GENERATED" COORDINATE SYSTEM
SET,2                   ! USE LOAD STEP 2 (FROM RESTART ANALYSIS)
SHELL,TOP               ! CHOOSE TOP SURFACE OF SHELL FOR STRESS PRINTOUT
PRNSOL,S,COMP           ! PRINT NODAL STRESSES AND DISPLACEMENTS
PRNSOL,DOF
*GET,UX_N4,NODE,4,U,X
*GET,UZ_N4,NODE,4,U,Z
*GET,ROTY_N4,NODE,4,ROT,Y
*GET,STRSS_N1,NODE,1,S,X
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'UX,NODE ','UZ,NODE ','ROTY,NOD','STS_X,N_'
LABEL(1,2) = '4 (mm)  ','4 (mm)  ','E 4(rad)','1 N/mm^2'
*VFILL,VALUE(1,1),DATA,-2.9,-6.5,1.26,94.25
*VFILL,VALUE(1,2),DATA,UX_N4,UZ_N4,ROTY_N4,STRSS_N1
*VFILL,VALUE(1,3),DATA,ABS(UX_N4/2.9),ABS(UZ_N4/6.5),ABS(ROTY_N4/1.26),ABS(STRSS_N1/94.25)
SAVE,TABLE_1
FINISH
/DELETE,vm26r,rdb
/DELETE,vm26r,ldhi
/DELETE,vm26r,r001
/DELETE,vm26r,rst
/CLEAR,NOSTART

/TITLE, VM26  LARGE DEFLECTION OF A CANTILEVERED PLATE
/COM          USING SHELL281 ELEMENTS
/PREP7
smrt,off
/NOPR
ANTYPE,STATIC           ! STATIC ANALYSIS
NLGEOM,ON               ! LARGE DEFLECTION OPTION
ET,1,SHELL281
SECTYPE,1,SHELL
SECDATA,1,1,0,5  ! PLATE THICKNESS = 1
MP,EX,1,1800            ! MATERIAL PROPERTIES
MP,NUXY,1,0
K,1                     ! DEFINE KEYPOINTS
```

```
K,2,12
K,3,12,1
K,4,,1
L,1,2                   ! DEFINE LINE SEGMENTS
L,3,4
LESIZE,ALL,,,2          ! 2 DIVISIONS ALONG LENGTH
ESIZE,,1                ! ONE DIVISION ON UNSPECIFIED LINE SEGMENTS
A,1,2,3,4
AMESH,1                 ! CREATE MESH
NSEL,S,LOC,X
D,ALL,ALL               ! FIXED END B.C.'S
NSEL,S,LOC,X,12
CP,1,ROTY,ALL           ! COUPLE ROTATIONS AT FREE END
TORQ=7.854              ! DEFINE HALF TOTAL LOAD
F,2,MY,TORQ
NSEL,ALL                ! RESELECT ALL NODES
FINISH
/SOLU
AUTOTS,ON               ! USE AUTOMATIC LOAD STEPPING
NSUBST,10,100,10        ! START WITH MAX OF 10 SUBSTEPS FOR EACH LOAD STEP
CNVTOL,F,1,1.0E-2  ! FORCE CONVERGENCE
CNVTOL,U,1,1.0E-2  ! DISPLACEMENT CONVERGENCE
LNSRCH,ON               ! USE LINE SEARCH METHOD
OUTPR,BASIC,LAST        ! BASIC PRINTOUT IN THE LAST SUBSTEP
OUTRES,ALL,ALL          ! WRITE SOLUTION TO THE RESULTS FILE FOR EACH SUBSTEP
SOLVE
FINISH
/SOLU
ANTYPE,,REST            ! RESTART ANALYSIS
F,2,MY,TORQ*2           ! APPLY FULL LOAD
SOLVE
FINISH
/POST1
RSYS,SOLU               ! CHOOSE "AS-GENERATED" COORDINATE SYSTEM
SET,2                   ! USE LOAD STEP 2 (FROM RESTART ANALYSIS)
SHELL,TOP               ! CHOOSE TOP SURFACE OF SHELL FOR STRESS PRINTOUT
PRNSOL,S,COMP           ! PRINT NODAL STRESSES AND DISPLACEMENTS
PRNSOL,DOF
*GET,UX_N4,NODE,6,U,X
*GET,UZ_N4,NODE,6,U,Z
*GET,ROTY_N4,NODE,6,ROT,Y
! SHELL281 can produce uneven bending stresses due to curvature effects.
! The following method is adopted to linearize the bending stresses
*GET,STRSS_N1_TOP,NODE,1,S,X
SHELL,BOT
*GET,STRSS_N1_BOT,NODE,1,S,X
STRSS_N1 = 0.5*(STRSS_N1_TOP - STRSS_N1_BOT)
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'UX,NODE ','UZ,NODE ','ROTY,NOD','STS_X,N_'
LABEL(1,2) = '4 (mm)  ','4 (mm)  ','E 4(rad)','1 N/mm^2'
*VFILL,VALUE(1,1),DATA,-2.9,-6.5,1.26,94.25
*VFILL,VALUE(1,2),DATA,UX_N4,UZ_N4,ROTY_N4,STRSS_N1
*VFILL,VALUE(1,3),DATA,ABS(UX_N4/2.9),ABS(UZ_N4/6.5),ABS(ROTY_N4/1.26),ABS(STRSS_N1/94.25)
SAVE,TABLE_2
RESUME,TABLE_1
/COM
/COM
/OUT,vm26,vrt
/COM,------------------- VM26 RESULTS COMPARISON ---------------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,SHELL181:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.2)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,SHELL281:
```

```
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.2)
/COM,----------------------------------------------------------------
/OUT
FINISH
/DELETE,TABLE_1
/DELETE,TABLE_2
FINISH
*LIST,vm26,vrt
```

VM27 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM27
/PREP7
/TITLE, VM27, THERMAL EXPANSION TO CLOSE A GAP
C***   INTROD. TO STRESS ANALYSIS, HARRIS, 1ST PRINTING, PAGE 58, PROB. 8
C***           CONTA178 AND LINK180 ELEMENTS (3-D)
ET,1,LINK180
ET,2,CONTA178
SECTYPE,1,LINK
SECDATA,1   ! AREA = 1 - SPAR ELEMENT
R,2,-10E10              ! STIFFNESS = 10E10
MP,EX,1,10.5E6
MP,ALPX,,12.5E-6
LOCAL,11,0,,,,45,,-45   ! LOCAL COORDINATE SYSTEM
N,1                     ! DEFINE NODES
N,2,,,3
N,3,,,3.002
E,1,2                   ! DEFINE SPAR ELEMENT
TYPE,2
REAL,2
E,2,3                   ! DEFINE GAP ELEMENT
NROTAT,ALL              ! ROTATE NODES INTO LOCAL COORDINATE SYSTEM
BFUNIF,TEMP,170         ! BOUNDARY CONDITIONS AND LOADS
TREF,70
D,1,ALL,,,3,2
D,2,UY
D,2,UX
SAVE                    ! SAVE DATABASE FOR SECOND ANALYSIS
FINISH
/SOLU
NSUBST,5
OUTPR,,LAST
AUTOTS,ON
/OUT,SCRATCH
SOLVE
FINISH
/POST1
ETABLE,STRS,LS,1
/OUT,
*GET,STRSS,ELEM,1,ETAB,STRS
ETABLE,THST,LEPTH,1
*GET,THSTR,ELEM,1,ETAB,THST
*DIM,VALUE_C1,,2,3
*VFILL,VALUE_C1(1,1),DATA,-6125,.00125
*VFILL,VALUE_C1(1,2),DATA,STRSS,THSTR
*VFILL,VALUE_C1(1,3),DATA,ABS(STRSS/6125) ,ABS(THSTR/.00125)
*DIM,LABEL,CHAR,2,2
LABEL(1,1) = 'STRESS  ','THERMAL '
LABEL(1,2) = '(psi)   ','STRAIN  '
SAVE,TABLE_1
FINISH
RESUME,TABLE_1
/COM
/OUT,vm27,vrt
/COM,------------------- VM27 RESULTS COMPARISON ---------------------
```

```
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS FOR 3-D ANALYSIS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C1(1,1),VALUE_C1(1,2),VALUE_C1(1,3)
(1X,A8,A8,'   ',F11.5,'  ',F15.5,'   ',1F15.3)
/NOPR
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vm27,vrt
```

VM28 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM28
/PREP7
/TITLE, VM28,  TRANSIENT HEAT TRANSFER IN AN INFINITE SLAB
/COM,   "HEAT TRANSFER", HOLMAN, 4TH ED., PG. 106
/NOPR
ANTYPE,TRANS
ET,1,PLANE77
MP,KXX,1,54
MP,DENS,1,7833
MP,C,1,465
N,1
N,12,,1
FILL,,,,,,,,.1                     ! BIAS MESH TOWARD SURFACE WITH 1:10 RATIO
NGEN,2,12,1,12,1,.1                ! GENERATE EDGE NODES
E,1,13,14,2
EGEN,11,1,-1                       ! GENERATE ELEMENTS FROM EDGE NODES
EMID                               ! PLACE MIDSIDE NODES ON ELEMENTS
NSEL,S,LOC,X,0
NLIST,ALL                          ! LIST NODES ALONG LENGTH
NSEL,S,LOC,Y,1
SF,ALL,CONV,50,1000                ! APPLY CONVECTION TO TOP SURFACE
NSEL,ALL
TUNIF,0                            ! DEFINE INITIAL TEMPERATURES, T(0)
FINISH
/SOLU
SOLCONTROL,0
KBC,1                              ! STEP BOUNDARY CONDITIONS
DELTIM,10                          ! MINIMUM TIME STEP
TIME,2000.0                        ! TIME AT END OF TRANSIENT
OUTRES,,ALL
AUTOTS,ON
SOLVE
FINISH
/POST26
NSOL,2,11,TEMP,,T11                ! STORE TEMPERATURES AT SELECT NODES
NSOL,3,9,TEMP,,T9
NSOL,4,7,TEMP,,T7
NSOL,5,5,TEMP,,T5
NSOL,6,1,TEMP,,T1
PRVAR,2,3,4,5,6                    ! PRINT TEMPERATURE SOLUTION VS. TIME
*GET,TEMP_11,NODE,11,TEMP
*GET,TEMP_9,NODE,9,TEMP
*GET,TEMP_7,NODE,7,TEMP
*GET,TEMP_5,NODE,5,TEMP

*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'TEMP (C)','TEMP (C)','TEMP (C)','TEMP (C)'
LABEL(1,2) = ' NODE 11',' NODE 9 ',' NODE 7 ',' NODE 5 '
*VFILL,VALUE(1,1),DATA,140,98.9,51.8,14.5
*VFILL,VALUE(1,2),DATA,TEMP_11,TEMP_9,TEMP_7,TEMP_5
*VFILL,VALUE(1,3),DATA,ABS(TEMP_11/140),ABS(TEMP_9/98.9),ABS(TEMP_7/51.8),ABS(TEMP_5/14.5)
```

```
/COM
/OUT,vm28,vrt
/COM,------------------- VM28 RESULTS COMPARISON ---------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,-----------------------------------------------------------

/OUT
FINISH
*LIST,vm28,vrt
```

VM29 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM29
/PREP7
/TITLE, VM29, FRICTION ON A SUPPORT BLOCK
C***VECTOR MECHANICS FOR ENGINEERS, BEER AND JOHNSTON, 1962, PAGE 283, PROB. 8.2
ANTYPE,STATIC
ET,1,CONTAC12
R,1,-20,1E6                ! THETA = -20, STIFFNESS = 1E6
MP,MU,1,.3                 ! COEFFICIENT OF FRICTION
N,1                        ! CREATE NODES
N,2
E,1,2                      ! CREATE ELEMENT
D,1,ALL                    ! BOUNDARY CONDITIONS AND LOADS
F,2,FX,-5.7674             ! STICKING LOAD
F,2,FY,-100
NSUBST,1                   ! LIMIT TO ONE ITERATION TO PREVENT DIVERGENCE
OUTPR,BASIC,ALL            ! PRINT NODAL DOF, REACTION & ELEMENT SOLUTION
OUTPR,NLOAD,ALL            ! PRINT ELEMENT NODAL LOADS
KBC,1                      ! STEP CHANGE IN B.C.'S
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST1
ETAB,NOR_FC1,SMISC,1
ETAB,SLI_FC1,SMISC,2
/OUT,
*GET,NORM_FC1,ELEM,1,ETAB,NOR_FC1
*GET,SLID_FC1,ELEM,1,ETAB,SLI_FC1
*DIM,LABEL,CHAR,2,2
*DIM,VALUE_C1,,2,3
LABEL(1,1) = 'NORMAL ','SLIDING '
LABEL(1,2) = 'FORCE lb','FORCE lb'
*VFILL,VALUE_C1(1,1),DATA,-95.942,28.783
*VFILL,VALUE_C1(1,2),DATA,NORM_FC1,SLID_FC1
*VFILL,VALUE_C1(1,3),DATA,ABS(NORM_FC1/95.942),ABS(SLID_FC1/28.783)
SAVE,TABLE_1
FINISH
/SOLU
F,2,FX,-5.76720            ! SLIDING LOAD
/OUT,SCRATCH
SOLVE
FINISH
/POST1
ETAB,NOR_FC2,SMISC,1
ETAB,SLI_FC2,SMISC,2
/OUT,
*GET,NORM_FC2,ELEM,1,ETAB,NOR_FC2
*GET,SLID_FC2,ELEM,1,ETAB,SLI_FC2
*DIM,VALUE_C2,,2,3
LABEL(1,1) = 'NORMAL ','SLIDING '
```

```
LABEL(1,2) = 'FORCE lb','FORCE lb'
*VFILL,VALUE_C2(1,1),DATA,-95.942,28.783
*VFILL,VALUE_C2(1,2),DATA,NORM_FC2,SLID_FC2
*VFILL,VALUE_C2(1,3),DATA,ABS(NORM_FC2/95.942),ABS(SLID_FC2/28.783)
SAVE,TABLE_2
FINISH
/CLEAR,NOSTART
/COM,
/COM,
/COM, SOLVING THE SAME PROBLEM USING CONTA178 ELEMENTS
/COM,
/COM,
/PREP7
ANTYPE,STATIC
ET,1,CONTA178                    ! USING CONTA178 ELEMENTS
KEYOPT,1,2,1                     ! PURE PENALTY METHOD
KEYOPT,1,5,0                     ! CONTACT NORMAL BASED ON REAL CONSTANTS
KEYOPT,1,10,0                    ! STANDARD CONTACT BEHAVIOR
R,1,-1E6,,,-1E6,,0.3420201       ! DEFINE FKN,START,FKS,NX,NY,NZ
RMORE,0.939692,0
N,1,0,0,0
N,2,0,0,0
MP,MU,1,.3                  ! COEFFICIENT OF FRICTION
MP,EX,1,1.0
TYPE,1
MAT,1
REAL,1
E,1,2                       ! CREATE ELEMENT
D,1,ALL                     ! BOUNDARY CONDITIONS AND LOADS
D,2,UZ                      ! 2D ONLY
F,2,FX,-5.7674              ! STICKING LOAD
F,2,FY,-100
NSUBST,1  ! LIMIT TO ONE ITERATION TO PREVENT DIVERGENCE
AUTOTS,ON
TIME,1.0
OUTPR,BASIC,ALL             ! PRINT NODAL DOF, REACTION & ELEMENT SOLUTION
OUTPR,NLOAD,ALL             ! PRINT ELEMENT NODAL LOADS
KBC,1                       ! STEP CHANGE IN B.C.'S
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST1
RSYS,SOLU
ETAB,NOR_FC3,SMISC,1
ETAB,SLI_FC3,SMISC,2
/OUT,
*GET,NORM_FC3,ELEM,1,ETAB,NOR_FC3
*GET,SLID_FC3,ELEM,1,ETAB,SLI_FC3
*DIM,LABEL,CHAR,2,2
*DIM,VALUE_C3,,2,3
LABEL(1,1) = 'NORMAL ','SLIDING '
LABEL(1,2) = 'FORCE lb','FORCE lb'
*VFILL,VALUE_C3(1,1),DATA,-95.942,28.783
*VFILL,VALUE_C3(1,2),DATA,NORM_FC3,SLID_FC3
*VFILL,VALUE_C3(1,3),DATA,ABS(NORM_FC3/95.942),ABS(SLID_FC3/28.783)
SAVE,TABLE_3
FINISH
/SOLU
F,2,FX,-5.76720             ! SLIDING LOAD
/OUT,SCRATCH
SOLVE
FINISH
/POST1
ETAB,NOR_FC4,SMISC,1
ETAB,SLI_FC4,SMISC,2
/OUT,
*GET,NORM_FC4,ELEM,1,ETAB,NOR_FC4
*GET,SLID_FC4,ELEM,1,ETAB,SLI_FC4
*DIM,VALUE_C4,,2,3
LABEL(1,1) = 'NORMAL ','SLIDING '
```

```
LABEL(1,2) = 'FORCE lb','FORCE lb'
*VFILL,VALUE_C4(1,1),DATA,-95.942,28.783
*VFILL,VALUE_C4(1,2),DATA,NORM_FC4,SLID_FC4
*VFILL,VALUE_C4(1,3),DATA,ABS(NORM_FC4/95.942),ABS(SLID_FC4/28.783)
SAVE,TABLE_4

RESUME,TABLE_1
/COM
/OUT,vm29,vrt
/COM,------------------- VM29 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,FX = 5.7674 LB AND MODEL IS STICKING (USING CONTA12 ELEMENTS):
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C1(1,1),VALUE_C1(1,2),VALUE_C1(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,FX = 5.76720 LB AND MODEL IS SLIDING (USING CONTA12 ELEMENTS):
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C2(1,1),VALUE_C2(1,2),VALUE_C2(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM,FX = 5.7674 LB AND MODEL IS STICKING (USING CONTA178 ELEMENTS):
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C3(1,1),VALUE_C3(1,2),VALUE_C3(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,
/NOPR
RESUME,TABLE_4
/GOPR
/COM,
/COM,FX = 5.76720 LB AND MODEL IS SLIDING (USING CONTA178 ELEMENTS):
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C4(1,1),VALUE_C4(1,2),VALUE_C4(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm29,vrt
```

VM30 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM30
/PREP7
SMRT,OFF
/TITLE, VM30, SOLID MODEL OF SURFACE FILLET
/COM,   REF:  NAFEMS BENCHMARKS FOR FINITE ELEMENT PRE-PROCESSORS
/COM,         D.R. HOSE, I.A. RUTHERFORD, REF R0001, ISSUED 12/2/93, PP. 23.
/COM,
ET,1,SHELL281                       ! 8-NODE SHELL
L=8.0                               ! BASE LENGTH
H=2.0                               ! BASE HEIGHT
RECTNG,,L/2,,H,                     ! CREATE RECTANGULAR AREA
WPROTA,,90                          ! ROTATE POSITIVE Y TOWARDS Z
PTXY,0,0,-2,2,6,2,4,0,              ! DEFINE COORDINATE PAIRS FOR POLYGON
POLY                                ! DEFINE POLYGONAL AREA
AGLUE,1,2                           ! GLUE AREAS 1 AND 2
AFILLT,1,3,1                        ! CREATE AREA FILLET WITH CONSTANT RADIUS=1
```

```
/FACET,WIRE
/VIEW,1,1,2,3
/PNUM,AREA,1                    ! TURN ON AREA NUMBERING
APLOT                           ! PLOT AREAS
ACCAT,ALL                       ! CONCATENATE AREAS
LSEL,S,LINE,,5                  ! SELECT LINES TO CONCATENATE
LSEL,A,LINE,,21,24,3
LCCAT,ALL                       ! CONCATENATE LINES
LSEL,S,LINE,,20,23,3            ! SELECT LINES TO CONCATENATE
LSEL,A,LINE,,7
LCCAT,ALL                       ! CONCATENATE LINES
MSHK,1                          ! MAPPED AREA MESH
MSHA,0,2D                       ! USING QUADS
AMESH,1                         ! MESH USING DEFAULT ELEMENT SIZE
EPLOT                           ! PLOT ELEMENTS
LOCAL,11,,,,,,,-45              ! ROTATE X TOWARDS Z
DSYS,11
NROTAT,ALL
NSEL,S,LOC,X,-.1,.1
*GET,NXMAX,NODE,,MXLOC,X           ! CHECK THE POSITIVE DEVIATION FROM ZERO
*GET,NXMIN,NODE,,MNLOC,X           ! CHECK THE NEGATIVE DEVIATION FROM ZERO
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'MAX LOCA','MIN LOCA'
LABEL(1,2) = 'TION    ','TION    '
*VFILL,VALUE(1,1),DATA,0,0
*VFILL,VALUE(1,2),DATA,NXMAX,NXMIN
*VFILL,VALUE(1,3),DATA,0,0
/COM
/OUT,vm30,vrt
/COM,------------------- VM30 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,DEVIATION:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',E14.3,'   ',1F15.3)
/COM,
/COM,NOTE: THE LARGER OF THE TWO DEVIATIONS LISTED IS THE 'MAXIMUM DEVIATION'
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm30,vrt
```

VM31 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM31
/PREP7
/TITLE, VM31, CABLE SUPPORTING HANGING LOADS
C***VECTOR MECHANICS FOR ENGINEERS, BEER AND JOHNSTON, 1962, PAGE 260, PROB. 7.8
ANTYPE,STATIC
ET,1,LINK180
SECTYPE,1,LINK
SECDATA,0.1         ! AREA = .1
MP,EX,1,20E6
N,1                 ! DEFINE NODES
N,2,20,-5.56
N,3,30,-5
N,4,45,5.83
N,5,60,20
E,1,2               ! DEFINE ELEMENTS
EGEN,4,1,1
INIS,SET,CSYS,-2    ! ARBITRARY SMALL INITIAL STRAIN
INIS,SET,DTYP,EPEL
INIS,DEFINE,,,,,1E-7
NSUBST,3
OUTPR,,3
```

```
OUTPR,NLOAD,3        ! PRINT NODAL FORCES
KBC,1                ! STEP CHANGE B.C.'S
D,1,ALL,,,5,4        ! BOUNDARY CONDITIONS AND LOADS
D,2,UZ,,,4
F,2,FY,-6
F,3,FY,-12
F,4,FY,-4
FINISH
/SOLU
NLGEOM,ON            ! LARGE DEFLECTION TURNED ON
/OUT,SCRATCH
SOLVE
FINISH
/POST26
RFORCE,2,1,F,X
RFORCE,3,1,F,Y
STORE
/OUT,
*GET,AX,VARI,2,EXTREM,VMAX
*GET,AY,VARI,3,EXTREM,VMAX
FINISH
/POST1
ETABLE,MFX,SMISC,1
*GET,MX_FOR_X,ELEM,4,ETAB,MFX

*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'AX, (kip','AY, (kip','MAX TENS'
LABEL(1,2) = 's)      ','s)      ',' (kips) '
*VFILL,VALUE(1,1),DATA,-18.000,5.0000,24.762
*VFILL,VALUE(1,2),DATA,AX,AY,MX_FOR_X
*VFILL,VALUE(1,3),DATA,ABS(AX/18.000) ,ABS(AY/5.000),ABS(MX_FOR_X/24.762)
/COM
/OUT,vm31,vrt
/COM,------------------- VM31 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,----------------------------------------------------------

/OUT
FINISH
*LIST,vm31,vrt
```

VM32 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM32
/PREP7
/TITLE, VM32, THERMAL STRESSES IN A LONG CYLINDER
!           STR. OF MATLS., TIMOSHENKO, PART 2, 3RD ED., PAGE 234, PROB. 1
!           THERMAL SOLUTION ***
ET,1,PLANE55,,,1        ! AXISYMMETRIC KEYOPT(S) OPTION
ET,2,PLANE55,,,1
MP,KXX,1,3
N,1,.1875
N,8,.625
FILL,,,,,,,,2           ! BIAS MESH DENSITY TOWARD CENTERLINE
NGEN,2,10,1,8,1,,.1
E,11,1,2,12
TYPE,2
E,12,2,3,13
EGEN,5,1,2
TYPE,1
E,8,18,17,7
FINISH
```

```
/SOLU
ANTYPE,STATIC
D,1,TEMP,-1,,11,10     ! APPLY TEMPERATURES TO INNER AND OUTER SURFACES
D,8,TEMP,,,18,10
OUTPR,BASIC,ALL
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
LFT_NODE = NODE (0.1875,0,0)
IN_NODE  = NODE (0.2788,0,0)
RT_NODE  = NODE (0.625,0,0)
*GET,LFT_TEMP,NODE,LFT_NODE,TEMP
*GET,IN_TEMP,NODE,IN_NODE,TEMP
*GET,RT_TEMP,NODE,RT_NODE,TEMP
*DIM,VALUE_C1,,3,3
*VFILL,VALUE_C1(1,1),DATA,-1,-.67037,0
*VFILL,VALUE_C1(1,2),DATA,LFT_TEMP,IN_TEMP,RT_TEMP
*VFILL,VALUE_C1(1,3),DATA,ABS(LFT_TEMP/1 ),ABS(IN_TEMP/.67037 ),0
*DIM,LABEL_1,CHAR,3,2
LABEL_1(1,1) = 'T (C) X=','T (C) X=','T (C) X='
LABEL_1(1,2) = '.1875 in','.2788 in','0.625 in'
SAVE,TABLE_1

FINISH
/PREP7
!           STRESS SOLUTION, STATIC ANALYSIS   ***
ETCHG,TTS              ! CHANGE ELEMENT TYPE PLANE55 TO PLANE42
KEYOPT,1,1,2
KEYOPT,1,3,1
KEYOPT,2,1,2
KEYOPT,2,3,1
MP,EX,1,30E6           ! DEFINE STRUCTURAL PROPERTIES
MP,ALPX,,1.435E-5
MP,NUXY,1,.3
CPNGEN,7,UY,11,18      ! COUPLE APPROPRIATE NODAL DISPLACEMENTS
CP,8,UX,1,11
CPSGEN,8,1,8
FINISH
/SOLU
ANTYPE,STATIC
D,1,UY,,,8
LDREAD,TEMP,,,,,,rth   ! READ IN BODY FORCE TEMPERATURES
/OUT,SCRATCH
SOLVE
FINISH
/POST1
LFT_NODE = NODE (0.1875,0,0)
RT_NODE  = NODE (0.625,0,0)
/OUT,
*GET,LFT_AXST,NODE,LFT_NODE,S,Y
*GET,LFT_TST,NODE,LFT_NODE ,S,Z
*GET,RT_AXST,NODE,RT_NODE,S,Y
*GET,RT_TST,NODE,RT_NODE ,S,Z
*DIM,VALUE_C2,,4,3
*VFILL,VALUE_C2(1,1),DATA,420.42,420.42,-194.58,-194.58
*VFILL,VALUE_C2(1,2),DATA,LFT_AXST,LFT_TST,RT_AXST,RT_TST
*VFILL,VALUE_C2(1,3),DATA,ABS(LFT_AXST/420.42),ABS(LFT_TST/420.42),ABS(RT_AXST/194.58)
*VFILL,VALUE_C2(4,3),DATA,ABS(RT_TST/194.58)
*DIM,LABEL_2,CHAR,4,2
LABEL_2(1,1) = 'A_STS ps','T_STS ps','A_STS ps','T_STS ps'
LABEL_2(1,2) = 'i X=.187','i X=.187','i X=.625','i X=.625'
SAVE,TABLE_2
RESUME,TABLE_1
/COM
/OUT,vm32,vrt
/COM,------------------- VM32 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,THERMAL ANALYSIS:
```

```
/COM,
*VWRITE,LABEL_1(1,1),LABEL_1(1,2),VALUE_C1(1,1),VALUE_C1(1,2),VALUE_C1(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/NOPR,
RESUME,TABLE_2
/GOPR
/COM,STATIC ANALYSIS:
/COM,
*VWRITE,LABEL_2(1,1),LABEL_2(1,2),VALUE_C2(1,1),VALUE_C2(1,2),VALUE_C2(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm32,vrt
```

VM33 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM33
/PREP7
SMRT,OFF
/TITLE, VM33, TRANSIENT THERMAL STRESS IN A CYLINDER
/COM,   REF: ROARK AND YOUNG "FORMULAS FOR STRESS AND STRAIN",5TH
/COM,   EDITION, MCGRAW-HILL, PG. 585
/COM,
ET,1,SOLID5                    ! SOLID5 UX,UY,UZ,TEMP,VOLT,MAG DOF SET
MP,KXX,1,625E-6                ! DEFINE THERMAL CONDUCTIVITY
MP,EX,1,30E6                   ! MODULUS OF ELASTICITY
MP,NUXY,1,.3                   ! POISSON'S RATIO
MP,ALPX,1,8.4E-6               ! COEFFICIENT OF THERMAL EXPANSION
MP,DENS,1,.284                 ! DENSITY (LB/IN**3)
MP,C,1,.10                     ! SPECIFIC HEAT
CSYS,1
H=.20                          ! MODEL HEIGHT
TH=2.5                         ! MODEL HALF-ANGLE
A=1                            ! INNER RADIUS
B=3                            ! OUTER RADIUS
K,1,A,TH                       ! DEFINE KEYPOINTS
K,2,B,TH
KGEN,2,1,2,1,,,H
KGEN,2,1,4,1,,-(TH*2)
L,1,2                          ! DEFINE LINE SEGMENTS
*REPEAT,4,2,2
LESIZE,ALL,,,15,5
ESIZE,,1
V,1,2,4,3,5,6,8,7              ! DEFINE VOLUME
MSHK,1                         ! MAPPED VOLUME MESH
MSHA,0,3D                      ! USING HEX
VMESH,1                        ! MESH VOLUME
NSEL,S,LOC,Y,TH
NSEL,A,LOC,Y,-TH
DSYM,SYMM,Y,1                  ! DEFINE STRUCTURAL B.C.
NSEL,S,LOC,Z
DSYM,SYMM,Z,1
NSEL,S,LOC,Z,H                 ! SELECT NODES ON TOP SURFACE
CP,1,UZ,ALL                    ! COUPLE ALL NODES IN UZ
NSEL,S,LOC,X,B                 ! SELECT NODES AT OUTER RADIUS
D,ALL,TEMP,500                 ! DEFINE FINAL SURFACE TEMPERATURE
NSEL,ALL
FINISH
/out,scratch
/SOLU
ANTYPE,TRANS                   ! TRANSIENT ANALYSIS
TIMINT,OFF,STRUC               ! SUPPRESS STRUCTURAL DYNAMICS
CNVTOL,HEAT                    ! CONVERGENCE BASED ON HEAT FLOWS
CNVTOL,F                       !  AND FORCES ONLY
AUTOTS,ON                      ! AUTOMATIC TIME STEPPING
```

```
OUTRES,,ALL                     ! RESULTS FOR ALL TIME POINTS
KBC,0                           ! RAMP LOAD OVER LOAD STEP
TREF,70                         ! SET REFERENCE TEMPERATURE
TUNIF,70                        ! SET INITIAL UNIFORM TEMPERATURE
DELTIM,1,,60                    ! MINIMUM TIME STEP OF 1 SEC
TIME,430                        ! TIME AT END OF LOAD STEP
SOLVE
FINISH
/out
/POST1
*GET,IN_STRS,NODE,1,S,Y
*GET,OUT_STRS,NODE,2,S,Y
FINISH
/POST26
NSOL,2,1,TEMP                   ! STORE TEMP AT INNER RADIUS
NSOL,3,2,TEMP                   ! STORE TEMP AT OUTER RADIUS
ESOL,4,1,1,S,Y,SYB              ! STORE SY AT INNER RADIUS
ESOL,5,15,2,S,Y,SYC             ! STORE SY AT OUTER RADIUS
ADD,6,3,2,,DELT,,,1,-1          ! CALCULATE DELTA TEMP. (OUTER-INNER)
PRVAR,2,3,4,5,6                 ! PRINT VARIABLES VS. TIME
/GRID,1
/AXLAB,Y,DELT
PLVAR,6                         ! DISPLAY DELTA TEMP. VS TIME
/AXLAB,Y,SY
PLVAR,4,5                       ! DISPLAY SY VS. TIME

*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'STRS R=B','STRS R=A'
LABEL(1,2) = '(PSI)   ','(PSI)   '
*VFILL,VALUE(1,1),DATA,-13396,10342
*VFILL,VALUE(1,2),DATA,OUT_STRS,IN_STRS
*VFILL,VALUE(1,3),DATA,ABS(OUT_STRS/13396),ABS(IN_STRS/10342)
/COM
/OUT,vm33,vrt
/COM,------------------- VM33 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,SOLID5
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/OUT
FINISH
!
/CLEAR,NOSTART
/UNITS,BIN
/PREP7
SMRT,OFF
ET,1,SOLID226,11,0              ! SOLID226 UX,UY,UZ,TEMP
MP,KXX,1,625E-6*9.34E3          ! DEFINE THERMAL CONDUCTIVITY, LBF/(S-F)
MP,EX,1,30E6                    ! MODULUS OF ELASTICITY, PSI
MP,NUXY,1,.3                    ! POISSON'S RATIO
MP,ALPX,1,8.4E-6                ! COEFFICIENT OF THERMAL EXPANSION, 1/F
MP,DENS,1,.284                  ! DENSITY (LB/IN**3)
MP,C,1,0.10*9.34E3              ! SPECIFIC HEAT, LBF-IN/(F-LB)
CSYS,1
H=.20                           ! MODEL HEIGHT
TH=2.5                          ! MODEL HALF-ANGLE
A=1                             ! INNER RADIUS
B=3                             ! OUTER RADIUS
K,1,A,TH                        ! DEFINE KEYPOINTS
K,2,B,TH
KGEN,2,1,2,1,,,H
KGEN,2,1,4,1,,-(TH*2)
L,1,2                           ! DEFINE LINE SEGMENTS
*REPEAT,4,2,2
LESIZE,ALL,,,15,5
ESIZE,,1
V,1,2,4,3,5,6,8,7               ! DEFINE VOLUME
MSHK,1                          ! MAPPED VOLUME MESH
MSHA,0,3D                       ! USING HEX
VMESH,1                         ! MESH VOLUME
```

```
NSEL,S,LOC,Y,TH
NSEL,A,LOC,Y,-TH
DSYM,SYMM,Y,1                   ! DEFINE STRUCTURAL B.C.
NSEL,S,LOC,Z
DSYM,SYMM,Z,1
NSEL,S,LOC,Z,H                  ! SELECT NODES ON TOP SURFACE
CP,1,UZ,ALL                     ! COUPLE ALL NODES IN UZ
NSEL,S,LOC,X,B                  ! SELECT NODES AT OUTER RADIUS
D,ALL,TEMP,500                  ! DEFINE FINAL SURFACE TEMPERATURE
NSEL,ALL
FINISH
/out,scratch
/SOLU
ANTYPE,TRANS                    ! TRANSIENT ANALYSIS
CNVTOL,HEAT                     ! CONVERGENCE BASED ON HEAT FLOWS
CNVTOL,F                        !  AND FORCES ONLY
AUTOTS,ON                       ! AUTOMATIC TIME STEPPING
OUTRES,,ALL                     ! RESULTS FOR ALL TIME POINTS
KBC,0                           ! RAMP LOAD OVER LOAD STEP
TREF,70                         ! SET REFERENCE TEMPERATURE
TUNIF,70                        ! SET INITIAL UNIFORM TEMPERATURE
TOFFST,460
DELTIM,1,,60                    ! MINIMUM TIME STEP OF 1 SEC
TIME,430                        ! TIME AT END OF LOAD STEP
SOLVE
FINISH
/out
/POST1
*GET,IN_STRS,NODE,1,S,Y
*GET,OUT_STRS,NODE,2,S,Y
FINISH
/POST26
NSOL,2,1,TEMP                   ! STORE TEMP AT INNER RADIUS
NSOL,3,2,TEMP                   ! STORE TEMP AT OUTER RADIUS
ESOL,4,1,1,S,Y,SYB              ! STORE SY AT INNER RADIUS
ESOL,5,15,2,S,Y,SYC             ! STORE SY AT OUTER RADIUS
ADD,6,3,2,,DELT,,,1,-1          ! CALCULATE DELTA TEMP. (OUTER-INNER)
PRVAR,2,3,4,5,6                 ! PRINT VARIABLES VS. TIME
/GRID,1
/AXLAB,Y,DELT
PLVAR,6                         ! DISPLAY DELTA TEMP. VS TIME
/AXLAB,Y,SY
PLVAR,4,5                       ! DISPLAY SY VS. TIME
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'STRS R=B','STRS R=A'
LABEL(1,2) = '(PSI)   ','(PSI)   '
*VFILL,VALUE(1,1),DATA,-13396,10342
*VFILL,VALUE(1,2),DATA,OUT_STRS,IN_STRS
*VFILL,VALUE(1,3),DATA,ABS(OUT_STRS/13396),ABS(IN_STRS/10342)
/COM
/OUT,vm33,vrt,,append
/COM,SOLID226
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm33,vrt
```

VM34 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM34
/TITLE, VM34, BENDING OF A TAPERED PLATE (BEAM)
C***     INTROD. TO STRESS ANALYSIS, HARRIS, 1ST PRINTING, PAGE 114, PROB. 61
C***     PLATE ELEMENTS (SHELL63)
/PREP7
```

```
ANTYPE,STATIC               ! STATIC ANALYSIS
ET,1,SHELL63,2
R,1,.5                      ! THICKNESS = 0.5
MP,EX,1,30E6
MP,NUXY,1,0                 ! POISSON'S RATIO IS ZERO
N,1
N,8,20,-1.5
FILL
N,11
N,18,20,1.5
FILL
E,1,2,12
E,2,3,12
E,13,12,3
E,3,4,14
E,14,13,3
EGEN,3,2,2,5
CP,1,UZ,2,12                ! COUPLE APPROPRIATE DEGREES OF FREEDOM
CP,2,ROTY,2,12
CPSGEN,6,1,1,2              ! GENERATE 6 SETS OF EQUATIONS
OUTPR,ALL,ALL
D,8,ALL,,,18,10
D, ALL,ROTX,0               ! REMOVE "TORSIONAL" DEGREES OF FREEDOM
F,1,FZ,-10
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
ETABLE,STRS,S,1             ! STORE S1(TOP) FOR SHELL63
ESORT,STRS                  ! SORT ELEMENTS BASED ON S1(TOP)
*GET,SMAX,SORT,,MAX         ! GET MAXIMUM S1 AS SMAX
PRNSOL,DOF                  ! PRINT NODAL DISPLACEMENTS
LFT_NODE = NODE (0,0,0)
*GET,DEFL,NODE,LFT_NODE,U,Z
*DIM,LABEL,CHAR,2,2
*DIM,VALUE_C1,,2,3
LABEL(1,1) = 'DEFLECTI','MX_PRIN_'
LABEL(1,2) = 'ON (in) ','STRS psi'
*VFILL,VALUE_C1(1,1),DATA,-.042667,1600
*VFILL,VALUE_C1(1,2),DATA,DEFL,SMAX
*VFILL,VALUE_C1(1,3),DATA,ABS(DEFL/.042667 ) ,ABS( SMAX/1600 )
FINISH
SAVE,TABLE_1
/CLEAR, NOSTART
/PREP7
/TITLE, VM34, BENDING OF A TAPERED PLATE (BEAM188)
C***          TAPERED BEAM ELEMENTS (BEAM188)
ANTYPE,STATIC               ! STATIC ANALYSIS
ET,1,BEAM188
MP,EX,1,30E6
MP,NUXY,1,0                 ! POISSON'S RATIO IS ZERO
SECTYPE,1,BEAM,RECT         ! RECTANGULAR BEAM CROSS-SECTION
SECDATA,1E-6,0.5           ! CROSS-SECTION AT LEFT END OF TAPERED BEAM
SECTYPE,2,BEAM,RECT         ! RECTANGULAR BEAM CROSS-SECTION
SECDATA,3.0,0.5             ! CROSS-SECTION AT RIGHT END OF TAPERED BEAM
SECTYPE,3,TAPER             ! TAPERED BEAM
SECDATA,1, 0.0,0.0          ! STARTING LOCATION OF TAPERED BEAM
SECDATA,2, 20.0, 0.0        ! ENDING LOCATION OF TAPERED BEAM
N,1
N,8,20
FILL
N,10,,,1
NGEN,8,1,10
SECNUM,3
E,1,2,10
EGEN,7,1,1,,,,,1
D,8,ALL
D,1,UY,,,7,,ROTX,ROTZ
F,1,FZ,-10
```

```
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
*GET,SMAX,SECR,ALL,S,X,MAX  ! HIGHEST COMPONENT TOTAL STRESS OF ALL ELEMENTS
PRNSOL,DOF                  ! PRINT NODAL DISPLACEMENTS
LFT_NODE = NODE (0,0,0)
*GET,DEFL,NODE,LFT_NODE,U,Z
*DIM,LABEL,CHAR,2,2
*DIM,VALUE_C2,,2,3
LABEL(1,1) = 'DEFLECTI','MX_PRIN_'
LABEL(1,2) = 'ON (in) ','STRS psi'
*VFILL,VALUE_C2(1,1),DATA,-.042667,1600
*VFILL,VALUE_C2(1,2),DATA,DEFL,SMAX
*VFILL,VALUE_C2(1,3),DATA,ABS(DEFL/.042667 ) ,ABS( SMAX/1600 )
FINISH
SAVE,TABLE_2
/CLEAR, NOSTART
/TITLE, VM34, BENDING OF A TAPERED PLATE (BEAM)
C***     SHELL ELEMENTS (SHELL181)
/PREP7
ANTYPE,STATIC               ! STATIC ANALYSIS
ET,1,SHELL181
SECTYPE,1,SHELL
SECDATA,0.5,1,0,3           ! THICKNESS = 0.5
MP,EX,1,30E6
MP,NUXY,1,0                 ! POISSON'S RATIO IS ZERO
N,1
N,8,20,-1.5
FILL
N,11
N,18,20,1.5
FILL
E,1,2,12
E,2,3,12
E,13,12,3
E,3,4,14
E,14,13,3
EGEN,3,2,2,5
CP,1,UZ,2,12                ! COUPLE APPROPRIATE DEGREES OF FREEDOM
CP,2,ROTY,2,12
CPSGEN,6,1,1,2              ! GENERATE 6 SETS OF EQUATIONS
OUTPR,ALL,ALL
D,8,ALL,,,18,10
D, ALL,ROTX,0               ! REMOVE "TORSIONAL" DEGREES OF FREEDOM
F,1,FZ,-10
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
ETABLE,STRS,S,1             ! STORE S1(TOP) FOR SHELL181
ESORT,STRS                  ! SORT ELEMENTS BASED ON S1(TOP)
*GET,SMAX,SORT,,MAX         ! GET MAXIMUM S1 AS SMAX
PRNSOL,DOF                  ! PRINT NODAL DISPLACEMENTS
LFT_NODE = NODE (0,0,0)
*GET,DEFL,NODE,LFT_NODE,U,Z
*DIM,LABEL,CHAR,2,2
*DIM,VALUE_C3,,2,3
LABEL(1,1) = 'DEFLECTI','MX_PRIN_'
LABEL(1,2) = 'ON (in) ','STRS psi'
*VFILL,VALUE_C3(1,1),DATA,-.042667,1600
*VFILL,VALUE_C3(1,2),DATA,DEFL,SMAX
*VFILL,VALUE_C3(1,3),DATA,ABS(DEFL/.042667 ) ,ABS( SMAX/1600 )
FINISH
SAVE,TABLE_3
/CLEAR, NOSTART
```

```
/TITLE, VM34, BENDING OF A TAPERED PLATE (BEAM)
C***      SHELL ELEMENTS (SHELL281)
/PREP7
ANTYPE,STATIC                ! STATIC ANALYSIS
ET,1,SHELL281, , ,
SECTYPE,1,SHELL
SECDATA,0.5,1,0,3            ! THICKNESS = 0.5
MP,EX,1,30E6
MP,NUXY,1,0                  ! POISSON'S RATIO IS ZERO
K, ,0
K, ,20,-1.5
K, ,20,1.5
A,1,2,3
LSEL,S,LINE,,1,3,2
LESIZE,ALL, , ,7
LSEL,INVE
LESIZE,ALL, , ,1
LSEL,ALL
AMESH,1
CP,1,UZ,3,30
CP,2,ROTY,3,30
CP,3,UZ,4,31,29
CP,4,ROTY,4,31,29
CP,5,UZ,6,36,27
CP,6,ROTY,6,36,27
CP,7,UZ,8,32,25
CP,8,ROTY,8,32,25
CP,9,UZ,10,33,23
CP,10,ROTY,10,33,23
CP,11,UZ,12,34,21
CP,12,ROTY,12,34,21
CP,13,UZ,14,35,19
CP,14,ROTY,14,35,19
OUTPR,NSOL,ALL
OUTPR,RSOL,ALL
NSEL,S,LOC,X,20
D,ALL,ALL
NSEL,ALL
D,ALL,ROTX,0
F,1,FZ,-10
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
ETABLE,STRS,S,1              ! STORE S1(TOP)
ESORT,STRS                   ! SORT ELEMENTS BASED ON S1(TOP)
*GET,SMAX,SORT,,MAX          ! GET MAXIMUM S1 AS SMAX
PRNSOL,DOF                   ! PRINT NODAL DISPLACEMENTS
LFT_NODE = NODE (0,0,0)
*GET,DEFL,NODE,LFT_NODE,U,Z
*DIM,LABEL,CHAR,2,2
*DIM,VALUE_C4,,2,3
LABEL(1,1) = 'DEFLECTI','MX_PRIN_'
LABEL(1,2) = 'ON (in) ','STRS psi'
*VFILL,VALUE_C4(1,1),DATA,-.042667,1600
*VFILL,VALUE_C4(1,2),DATA,DEFL,SMAX
*VFILL,VALUE_C4(1,3),DATA,ABS(DEFL/.042667 ) ,ABS( SMAX/1600 )
FINISH
SAVE,TABLE_4
/NOPR
RESUME,TABLE_1
/COM
/OUT,vm34,vrt
/COM,------------------- VM34 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS USING SHELL63:
/COM,
```

```
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C1(1,1),VALUE_C1(1,2),VALUE_C1(1,3)
(1X,A8,A8,'   ',F12.6,'  ',F16.6,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING TAPERED BEAM188:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C2(1,1),VALUE_C2(1,2),VALUE_C2(1,3)
(1X,A8,A8,'   ',F12.6,'  ',F16.6,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM,RESULTS USING SHELL181:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C3(1,1),VALUE_C3(1,2),VALUE_C3(1,3)
(1X,A8,A8,'   ',F12.6,'  ',F16.6,'   ',1F15.3)
/NOPR
RESUME,TABLE_4
/GOPR
/COM,
/COM,RESULTS USING SHELL281:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C4(1,1),VALUE_C4(1,2),VALUE_C4(1,3)
(1X,A8,A8,'   ',F12.6,'  ',F16.6,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm34,vrt
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
/DELETE,TABLE_4
```

VM35 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM35
/PREP7
SMRT,OFF
/TITLE,VM35: BIMETALLIC LAYERED CANTILEVER PLATE WITH THERMAL LOADING
C***     ROARK AND YOUNG, FORMULAS FOR STRESS AND STRAIN, PP. 113-114.
C*** USING SHELL281
ANTYPE,STATIC
ET,1,SHELL281
SECTYPE,1,SHELL
SECDATA,0.05,1,0       ! LAYER 1: 0.05 THICK, MAT'L 1, THETA 0
SECDATA,0.05,2,0       ! LAYER 2: 0.05 THICK, MAT'L 2, THETA 0,
MP,EX,1,3E7            ! MATERIAL PROPERTIES
MP,EX,2,3E7
MP,ALPX,1,1E-5
MP,ALPX,2,2E-5
MP,NUXY,1,0
MP,NUXY,2,0
K,1                    ! DEFINE GEOMETRY
K,2,,1
K,3,10,1
K,4,10
A,1,2,3,4
ESIZE,2                ! ELEMENT SIDE LENGTHS = 2
AMESH,1
NSEL,S,LOC,X
NSEL,R,LOC,Y,.5
D,ALL,ALL              ! FIX ONE END OF CANTILEVER
NSEL,S,LOC,Y,0.5
DSYM,SYMM,Y            ! SYMMETRY PLANE DOWN CENTERLINE
NSEL,ALL
```

```
TREF,70
BFUNIF,TEMP,170         ! DEFINE UNIFORM TEMPERATURE
FINISH
/SOLU
OUTPR,NSOL,1
OUTPR,RSOL,1
/OUT,SCRATCH
SOLVE
FINISH
/POST1
SHELL,TOP               ! SELECT TOP SURFACE FOR STRESS PRINT
/OUT,
PRNSOL,S,COMP
NSEL,S,LOC,X,10         ! SELECT CENTERLINE OF FREE END FOR DISPLACEMENT PRINT
NSEL,R,LOC,Y,.5
PRNSOL,U,COMP
RT_NODE = NODE (10,.5,0)
*GET,DEF_Z,NODE,RT_NODE,U,Z
*GET,DEF_X,NODE,RT_NODE,U,X
*GET,OUT_STRS,NODE,1,S,X
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'RT_END U','RT_END U','LFT_END '
LABEL(1,2) = 'Z (in)  ','X (in)  ','STRS psi'
*VFILL,VALUE(1,1),DATA,.750,.015,7500
*VFILL,VALUE(1,2),DATA,DEF_Z,DEF_X,OUT_STRS
*VFILL,VALUE(1,3),DATA,ABS(DEF_Z/.750) ,ABS(DEF_X/.015),ABS(OUT_STRS/7500)
SAVE,TABLE_1
RESUME,TABLE_1
/COM
/OUT,vm35,vrt
/COM,------------------- VM35 RESULTS COMPARISON ---------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM, SHELL281
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm35,vrt
/DELETE,TABLE_1
```

VM36 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM36
/PREP7
/TITLE, VM36, LIMIT MOMENT ANALYSIS
!           MECHANICS OF SOLIDS, CRANDALL AND DAHL, 1959, PAGE 389, EX. 8.9
ANTYPE,STATIC
ET,1,BEAM188,,,3
ET,2,COMBIN40,,,5,             ! ROTY D.O.F. SPRING
SECT,1,BEAM,RECT
SECD,3.93597,3.93597
R,2,1E12,,,,27777.8           ! DEFINE REAL CONSTANTS FOR COMBIN ELEMENTS
R,3,1,,,,1E6
MP,EX,1,30E6                  ! DEFINE MATERIAL PROPERTIES
MP,NUXY,1,.3
N,1                           ! BEGIN NODES DEFINITION
N,2,100
N,3,100
N,4,150
N,5,150
E,1,2                         ! DEFINE BEAM ELEMENTS
E,3,4
```

```
TYPE,2                         ! DEFINE BREAKAWAY HINGE ELEMENTS
REAL,2
E,2,3
E,4,5
REAL,3
E,2,3
E,4,5                          ! EXTRA ELEMENTS FOR SOLUTION STABILITY
OUTPR,ALL,ALL
CNVTOL,M,27778,.001
CP,1,UX,2,3                    ! COUPLE TRANSLATIONS ACROSS PLASTIC HINGE
CPLGEN,1,UZ                    ! GENERATE 2ND SET IN DIRECTION UZ W/ SAME NODES
CPSGEN,2,2,1,2,1               ! GENERATE TWO ADDITIONAL SETS W/ DIFFERENT NODES
DSYM,SYMM,Y                    ! CONSTRAIN MODEL SYMMETRICALLY IN Y DIRECTION
D,1,UZ                         ! CONSTRAIN SIMPLY SUPPORTED END AGAINST DISP.
D,4,UZ,,,,,UX                  ! CONSTRAIN RIGID END AGAINST TWO DIRECTIONAL DISP
D,5,ROTY                       ! CONSTRAIN RIGID END AGAINST ROTATIONAL MOVEMENT
F,2,FZ,-1000                   ! APPLY ELASTIC FORCE AT HINGE B
FINISH
/SOLU
SOLCONTROL,0
/OUT,SCRATCH
SOLVE                          ! WRITE LOAD STEP
FINISH

/POST26
/OUT,
RFORCE,2,1,F,Z
RFORCE,3,5,M,Y
STORE
*GET,RA,VARI,2,EXTREM,VMAX
*GET,MC,VARI,3,EXTREM,VMAX
*GET,UB,NODE,2,U,Z
*DIM,LABEL1,CHAR,3,2
*DIM,VALUE1,,3,3
LABEL1(1,1) = 'DEFLECTI','REACTION','MOMENT_C'
LABEL1(1,2) = 'ON (in) ','_A (lb) ',' (ib-lb)'
*VFILL,VALUE1(1,1),DATA,-.02829,148.15,27778
*VFILL,VALUE1(1,2),DATA,UB,RA,MC
*VFILL,VALUE1(1,3),DATA,ABS(UB/.02829) ,ABS(RA/148.15 ),ABS(MC/27778)
SAVE,TABLE_1
FINISH

/SOLUTION

NSUBST,3                       ! USE CONVERGENCE CRITERIA,3 SUBSTEPS MAX
OUTPR,ALL,LAST                 ! PRINT LAST ITERATION.
F,2,FZ,-1388.8                 ! APPLY VALUE SLIGHTLY SMALLER THAN PL TO HINGE B
/OUT,SCRATCH
SOLVE
FINI

/POST1
/OUT,
ESEL,S,ELEM,,3,4
ETABLE,ELEM_STAT,NMISC,1      !RETRIEVE THE STATUS(COMBIN40)
ESEL,ALL
PRETAB,

/GRAPHICS,POWER
/ESHAPE,1
/VIEW,1,1,1,1
/SHOW

PLETAB,ELEM_STAT                     !PLOT ELEMENT TABLE(COMBIN40 STATUS)
*GET,PLETAB_MAX1,PLNSOL,0,MAX
*GET,PLETAB_MIN1,PLNSOL,0,MIN

*DIM,LABEL2,CHAR,2,2
*DIM,VALUE2,,2,3
LABEL2(1,1) = 'HINGE','HINGE'
LABEL2(1,2) = '@B','@C'
*VFILL,VALUE2(1,1),DATA,1.0,2.0
```

```
*VFILL,VALUE2(1,2),DATA,PLETAB_MIN1,PLETAB_MAX1
*VFILL,VALUE2(1,3),DATA,ABS(PLETAB_MIN1/1.0) ,ABS(PLETAB_MAX1/2)
SAVE,TABLE_2

FINI

/SOLU

F,2,FZ,-1390                  ! APPLY VALUE SLIGHTLY LARGER THAN PL TO HINGE B
!                               LARGE DISPLACEMENT VALUES INDICATE COLLAPSE
!                               AND PLASTIC DEFORMATION
/OUT,SCRATCH
SOLVE

FINISH

/POST1
/OUT,
ESEL,S,ELEM,,3,4
ETABLE,ELEM_STAT,NMISC,1  !RETRIEVE THE STATUS(COMBIN40)
ESEL,ALL
PRETAB,

PLETAB,ELEM_STAT   !PLOT ELEMENT TABLE(COMBIN40 STATUS)

*GET,PLETAB_MAX2,PLNSOL,0,MAX
*GET,PLETAB_MIN2,PLNSOL,0,MIN

*DIM,LABEL3,CHAR,2,2
*DIM,VALUE3,,2,3
LABEL3(1,1) = 'HINGE','HINGE'
LABEL3(1,2) = '@B','@C'
*VFILL,VALUE3(1,1),DATA,-2.0,2.0
*VFILL,VALUE3(1,2),DATA,PLETAB_MIN2,PLETAB_MAX2
*VFILL,VALUE3(1,3),DATA,ABS(ABS(PLETAB_MIN2)/2.0) ,ABS(PLETAB_MAX2/2.0)
SAVE,TABLE_3
FINI

RESUME,TABLE_1
/COM
/OUT,vm36,vrt
/COM,------------------- VM36 RESULTS COMPARISON ---------------
/COM,
/COM,                  |   TARGET   |   ANSYS   |   RATIO
/COM,
/COM,RESULTS FOR P=1000 LBS (ELASTIC):
/COM,
*VWRITE,LABEL1(1,1),LABEL1(1,2),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A8,A8,'   ',F11.5,'  ',F11.5,'   ',1F5.3)
/COM,
/COM,
/NOPR
/COM,RESULTS FOR P=1388.8 LBS:
/COM
RESUME,TABLE_2
*VWRITE,LABEL2(1,1),LABEL2(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F11.5,'  ',F11.5,'   ',1F5.3)
/NOPR
/COM,
/COM,RESULTS FOR P=1390 LBS :
/COM
RESUME,TABLE_3
*VWRITE,LABEL3(1,1),LABEL3(1,2),VALUE3(1,1),VALUE3(1,2),VALUE3(1,3)
(1X,A8,A8,'   ',F11.5,'  ',F11.5,'   ',1F5.3)
/COM,
/COM,-----------------------------------------------------------
/COM,

/OUT
FINISH
*LIST,vm36,vrt
```

VM37 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM37
/PREP7
smrt,off
/TITLE, VM37, ELONGATION OF A SOLID BAR
/COM    INTROD. TO STRESS ANALYSIS, HARRIS, 1ST PRINTING, PAGE 237, PROB. 4
/COM    USING 3-D STRUCTURAL SOLID45 ELEMENTS
ANTYPE,STATIC
ET,1,SOLID45
MP,EX,1,10.4E6
MP,NUXY,1,.3
K,1,1,,1               ! DEFINE KEYPOINTS
K,2,-1,,1
K,3,-1,,-1
K,4,1,,-1
K,5,.5,10,.5
K,6,-.5,10,.5
K,7,-.5,10,-.5
K,8,.5,10,-.5
V,1,2,3,4,5,6,7,8      ! DEFINE VOLUME
LSEL,S,LINE,,5,11,2    ! SELECT LINES
LESIZE,ALL,,,7         ! DEVIDE SELECTED LINES BY 7 DIVISIONS
LSEL,ALL               ! SELECT ALL LINES
ESIZE,,1               ! USE 1 ELEMENT PER LINE DIVISION
/OUT,SCRATCH
VMESH,1                ! MESH THE VOLUME
/OUT
OUTPR,BASIC,ALL
NSEL,S,LOC,Y,0         ! APPLY BOUNDARY CONDITIONS AT THE BASE OF THE MODEL
D,ALL,ALL              ! FIX ALL DEGREES OF FREEDOM AT SELECTED NODE SET
NSEL,ALL
NSEL,S,LOC,Y,10        ! APPLY LOAD ON FREE END OF THE MODEL
SF,,PRES,-10000
NSEL,ALL
SAVE
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
/OUT,
FINISH
*CREATE,RES3D,MAC      ! CREATE MACRO TO RETRIEVE RESULTS
/POST1
ETABLE,SIGY,S,Y        ! RETRIEVE CENTROIDAL SY
/VIEW,1,1              ! CHANGE VIEW TO LOOKING DOWN X-AXIS
/VUP,1,-Y              ! REORIENT MODEL ON SCREEN
!/CLABEL,1,1            ! LABEL CONTOUR LINES
!/CVAL,1,2700,3500,4300,5100,5900,6700,7500,8300  ! USER DEFINED CONTOURS
NSLE,S                 ! SELECT NODES ATTACHED TO ELEMENTS
PLNSOL,S,Y             ! DISPLAY AXIAL STRESS
ESEL,S,ELEM,,4         ! SELECT MID-LENGTH ELEMENT
PRETAB,SIGY            ! PRINT OUT STORED STRESS ITEM
PRNSOL,S,COMP          ! PRINT NODAL STRESSES
ESEL,ALL               ! SELECT ALL ELEMENTS
NSEL,S,LOC,Y,10        ! SELECT ALL NODES AT Y=10 (FREE END OF MODEL)
PRNSOL,DOF             ! PRINT OUT DISPLACEMENTS OF NODES
NSEL,ALL
/NOPR
MID_NODE = NODE(0,5,0)
MID_ELM = ENEARN(MID_NODE)
BOT_NODE = NODE (0,10,0)
*GET,DEF,NODE,BOT_NODE,U,Y
*GET,STRSS,ELEM,MID_ELM,ETAB,SIGY
*DIM,LABEL,CHAR,2,2
*DIM,VALUE_C1,,2,3
LABEL(1,1) = 'MAX DEF ','SIGY MID'
LABEL(1,2) = '(in)    ','_ELM psi'
```

```
*VFILL,VALUE_C1(1,1),DATA,.0048077,4444
*VFILL,VALUE_C1(1,2),DATA,DEF,STRSS
*VFILL,VALUE_C1(1,3),DATA,ABS(DEF/.0048077) ,ABS(STRSS/4444)
/GOPR
FINISH
*END
RES3D                  ! EXECUTE MACRO TO RETRIEVE RESULTS
SAVE,TABLE_1

/CLEAR, NOSTART        ! CLEAR DATABASE FOR SECOND SOLUTION
/TITLE, VM37, ELONGATION OF A SOLID BAR
/COM    USING 3-D STRUCTURAL SOLID185 ELEMENTS
/PREP7
RESUME
ET,1,SOLID185, ,2      ! ANALYZE AGAIN USING 3-D SOLID185
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/OUT,
RES3D                  ! EXECUTE MACRO TO RETRIEVE RESULTS
SAVE,TABLE_2

/CLEAR, NOSTART        ! CLEAR DATABASE FOR THIRD SOLUTION
/TITLE, VM37, ELONGATION OF A SOLID BAR
/COM    USING 3-D STRUCTURAL SOLSH190 ELEMENTS
/PREP7
RESUME
ET,1,SOLSH190          ! ANALYZE AGAIN USING 3-D SOLSH190
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/OUT,
RES3D                  ! EXECUTE MACRO TO RETRIEVE RESULTS
SAVE,TABLE_3

/NOPR
RESUME,TABLE_1
/GOPR
/COM
/OUT,vm37,vrt
/COM,------------------- VM37 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS FOR SOLID45:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C1(1,1),VALUE_C1(1,2),VALUE_C1(1,3)
(1X,A8,A8,'   ',F12.7,'  ',F16.7,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS FOR SOLID185:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C1(1,1),VALUE_C1(1,2),VALUE_C1(1,3)
(1X,A8,A8,'   ',F12.7,'  ',F16.7,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM,RESULTS FOR SOLSH190:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_C1(1,1),VALUE_C1(1,2),VALUE_C1(1,3)
(1X,A8,A8,'   ',F12.7,'  ',F16.7,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm37,vrt
```

```
/DELETE,RES3D,MAC
FINISH
```

VM38 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM38
/PREP7
/TITLE, VM38, PLASTIC LOADING OF A THICK-WALLED CYLINDER UNDER PRESSURE
C***      STR. OF MATLS., TIMOSHENKO, PART 2, 3RD ED., PAGE 388, ART. 70

C***     USING PLANE182
ET,1,PLANE182,3,,1            ! AXISYMMETRIC SOLID,SIMPLIFIED ENHANCED STRAIN FORMULATION
ET,2,SURF153,,,1,1           ! AXISYMMETRIC 2-D SURFACE EFFECT ELEMENT WITHOUT
                             !  MIDSIDE NODES
REAL,2
R,2,,,,,,,
RMORE,1                      ! UNIT THICKNESS
MP,EX,1,30E6
MP,NUXY,1,.3
TB,BKIN,1,1                  ! BILINEAR KINEMATIC HARDENING
TBTEMP,70
TBDATA,1,30000,0             ! YIELD STRESS AND ZERO TANGENT MODULUS
N,1,4                        ! DEFINE NODES
N,6,8
FILL
NGEN,2,10,1,6,1,,1
E,11,1,2,12                  ! DEFINE ELEMENTS
EGEN,5,1,1
CPNGEN,1,UY,11,16            ! COUPLE NODES
TYPE,2                       ! CREATE SURF153 TO APPLY SURFACE PRESSURE LOADING
REAL,2
NSEL,S,LOC,X,4
ESURF
NSEL,ALL
TREF,70                      ! BOUNDARY CONDITIONS AND LOADING
D,1,UY,,,6
FINISH
/SOLU
ESEL,S,TYPE,,2               ! SELECT SURF153 ELEMENTS TO APPLY SURFACE PRESSURE
                             !  LOADING FOR ELASTIC ANALYSIS
SFE,ALL,1,PRES,,12990
ESEL,ALL
OUTPR,BASIC,1
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
ETABLE,STRS_R,S,X
ETABLE,STRS_T,S,Z
*GET,SIGR_I,ELEM,1,ETAB,STRS_R
*GET,SIGT_I,ELEM,1,ETAB,STRS_T
*GET,SIGR_O,ELEM,5,ETAB,STRS_R
*GET,SIGT_O,ELEM,5,ETAB,STRS_T

*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'SIGR LFT','SIGT LFT','SIGR RT_','SIGT RT_'
LABEL(1,2) = '_END psi','_END psi','END psi ','END psi '
*VFILL,VALUE(1,1),DATA,-9984,18645,-468,9128
*VFILL,VALUE(1,2),DATA,SIGR_I,SIGT_I,SIGR_O,SIGT_O
*VFILL,VALUE(1,3),DATA,ABS(SIGR_I/9984),ABS(SIGT_I/18645)
*VFILL,VALUE(3,3),DATA,ABS(SIGR_O/468),ABS(SIGT_O/9128)
SAVE,TABLE_1


/PREP7
```

```
C*** USING SOLID185
EDELE,ALL
NDELE,ALL                    ! REMOVE PREVIOUS MODEL GEOMETRY
ET,1,SOLID185,,3               ! 3-D SOLID ELEMENT, SIMPLIFIED ENHANCED STRAIN FORMULATION
ET,2,SURF154,,,,1            ! 3-D SURFACE EFFECT ELEMENT WITHOUT
                             !  MIDSIDE NODE
REAL,2
R,2,,,,,,,
RMORE,1                      ! UNIT THICKNESS
CSYS,1
N,1,4,-2.5                   ! DEFINE NODES
N,6,8,-2.5
FILL
NGEN,2,6,1,6,1,,5
NGEN,2,12,1,12,1,,,1
NUMCMP,ELEM
NUMSTR,ELEM,1
TYPE,1
MAT,1
E,1,2,8,7,13,14,20,19        ! DEFINE ELEMENTS
EGEN,5,1,-1
TYPE,2                       ! CREATE SURF154 TO APPLY SURFACE PRESSURE LOADING
REAL,2
NSEL,S,NODE,,1,7,6
NSEL,A,NODE,,13,19,6
ESURF
NSEL,ALL
NROTAT,ALL                   ! ROTATE ALL NODES INTO CYLINDRICAL COORDINATES
CPDELE,1,1,1                 ! REMOVE NODAL COUPLING
SFDELE,ALL,PRES              ! REMOVE NODAL PRESSURES
D,ALL,UY,0.0                 ! CONSTRAIN ALL NODES IN TANGENTIAL DIRECTION
NSEL,S,LOC,Z,1               ! SELECT NODES AT Z = 1
CP,1,UZ,ALL                  ! COUPLE SELECTED NODES IN UZ DIRECTION TO
                             !  SIMULATE GENERALIZED 3-D PLANE STRAIN BEHAVIOR
NSEL,S,LOC,Z,0               ! CONSTRAIN NODES AT Z = 0 IN UZ DIRECTION
D,ALL,UZ
NSEL,ALL
FINISH
/SOLU
ESEL,S,TYPE,,2               ! SELECT SURF154 ELEMENTS TO APPLY SURFACE PRESSURE
                             !  LOADING FOR ELASTIC ANALYSIS
SFE,ALL,1,PRES,,12990
ESEL,ALL
OUTPR,BASIC,1
/OUT,SCRATCH
SOLVE
FINISH

/POST1
/OUT,
ETABLE,STRS_R,S,X
ETABLE,STRS_T,S,Y
*GET,SIGR_I,ELEM,1,ETAB,STRS_R
*GET,SIGT_I,ELEM,1,ETAB,STRS_T
*GET,SIGR_O,ELEM,5,ETAB,STRS_R
*GET,SIGT_O,ELEM,5,ETAB,STRS_T

LABEL(1,1) = 'SIGR LFT','SIGT LFT','SIGR RT_','SIGT RT_'
LABEL(1,2) = '_END psi','_END psi','END psi ','END psi '
*VFILL,VALUE(1,1),DATA,-9984,18645,-468,9128
*VFILL,VALUE(1,2),DATA,SIGR_I,SIGT_I,SIGR_O,SIGT_O
*VFILL,VALUE(1,3),DATA,ABS(SIGR_I/9984),ABS(SIGT_I/18645)
*VFILL,VALUE(3,3),DATA,ABS(SIGR_O/468),ABS(SIGT_O/9128)
SAVE,TABLE_2
FINISH


RESUME,TABLE_1
/COM
/OUT,vm38,vrt
/COM,------------------- VM38 RESULTS COMPARISON ---------------
/COM,
```

```
/COM,                  |    TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,FULLY ELASTIC, PLANE182 RESULTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,FULLY ELASTIC, SOLID185 RESULTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,----------------------------------------------------------
/COM,
/COM,----------------------------------------------------------
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm38,vrt
```

VM39 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM39
/PREP7
/TITLE, VM39, BENDING OF A CIRCULAR PLATE WITH A CENTER HOLE
C***          STR. OF MATLS., TIMOSHENKO, PART 2, 3RD ED., PAGE 111, EQNS. (E,F)
C***          USING SHELL63 ELEMENTS
ANTYPE,STATIC
ET,1,SHELL63
R,1,.25                       ! DEFINE PLATE THICKNESS = .25
MP,EX,1,30.E6
MP,NUXY,1,.3
CSYS,1                        ! DEFINE CYLINDRICAL C.S.
N,1,10                        ! BEGIN NODE DEFINITION
N,7,30
FILL,,,,,,,,3                 ! USE 3:1 SPACING RATIO FOR FILLING IN NODES
NGEN,2,10,1,7,1,,10
NROTAT,1,17,1
E,1,2,12,11                   ! DEFINE FIRST ELEMENT
EGEN,6,1,1                    ! GENERATE NEXT 5 ELEMENTS
D,1,ALL,,,11,10               ! CONSTRAIN INNER EDGE IN ALL D.O.F.
D,2,UY,,,7,,ROTX,ROTZ         ! CONSTRAIN LOWER EDGE AGAINST ROTATIONS IN X & Z
D,12,UY,,,17,,ROTX,ROTZ       ! CONSTRAIN UPPER EDGE AGAINST ROTATIONS IN X & Z
F,7,MY,-26.18,,17,10          ! APPLY MOMENT LOAD AT OUTER EDGE
OUTPR,BASIC,1
FINISH
*CREATE,SOLVIT,MAC
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/WINDOW,1,TOP                 ! SET UP WINDOW 1 FOR DISPLACEMENT CONTOUR DISPLAY
/PLOPTS,MINM,OFF       ! TURN OFF MN AND MX DUE TO INSTABILITY
PLNSOL,U,Z                    ! DISPLAY PERPENDICULAR DISPLACEMENTS AS CONTOURS
/WINDOW,1,OFF                 ! TURN OFF WINDOW 1
/NOERASE                      ! TURN OFF AUTOMATIC ERASE BETWEEN DISPLAYS
/WINDOW,2,BOT                 ! SET UP WINDOW 2 FOR EDGE DISPLACEMENT DISPLAY
/VIEW,2,,-1                   ! CHANGE VIEW FOR WINDOW 2
PLDISP,1                      ! DISPLAY UNDISPLACED & DISPLACED SHAPES
/OUT,
SHELL,TOP
ESEL,,,,1                     ! SELECT INNER ELEMENT(ELEM #1)
ETABLE,MOMX,SMISC,4           ! RETRIEVE MOMENT(X) AND SX AT TOP
ETABLE,SIGX,S,X
```

```
PRETAB,GRP1                  ! PRINT STORED VALUES
*GET,M1,ETAB,1,ELEM,1
*GET,P1,ETAB,2,ELEM,1
ESEL,,,,6                    ! SELECT OUTER ELEMENT(ELEM#6)
ETABLE,REFL
PRETAB,GRP1                  ! PRINT STORED VALUES
*GET,M2,ETAB,1,ELEM,6
*GET,P2,ETAB,2,ELEM,6
ESEL,ALL
RSYS,1
PRNSOL,S,COMP                ! PRINT NODAL STRESSES
NSEL,S,LOC,X,30              ! SELECT NODES AT R=A
PRNSOL,DOF                   ! PRINT DISPLACEMENTS
*GET,DEF,NODE,7,U,Z
*GET,ROT,NODE,7,ROT,Y
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'DEFLECTI','MX_SLOPE'
LABEL(1,2) = 'ON (in) ','(rad)   '
*VFILL,VALUE(1,1),DATA,.049064,-.0045089
*VFILL,VALUE(1,2),DATA,DEF,ROT
*VFILL,VALUE(1,3),DATA,ABS(DEF/.049064 ) ,ABS( ROT/.0045089)
*DIM,LABEL2,CHAR,2,2
*DIM,VALUE2,,2,3
LABEL2(1,1) = 'MOMENT ','PRESSURE'
LABEL2(1,2) = 'in-lb/in',' psi  '
*VFILL,VALUE2(1,1),DATA,-13.783,-1323.2
*VFILL,VALUE2(1,2),DATA,M1,P1
*VFILL,VALUE2(1,3),DATA,ABS(M1/13.783),ABS(P1/1323.2)
*DIM,VALUE3,,2,3
*VFILL,VALUE3(1,1),DATA,-10.127,-972.22
*VFILL,VALUE3(1,2),DATA,M2,P2
*VFILL,VALUE3(1,3),DATA,ABS(M2/10.127),ABS(P2/972.22)
FINISH
*END
SOLVIT
SAVE,TABLE_1
/CLEAR, NOSTART                 ! CLEAR DATABASE FOR SECOND SOLUTION
/TITLE, VM39, BENDING OF A CIRCULAR PLATE WITH A CENTER HOLE
C***          USING SHELL181 ELEMENTS
/PREP7
ANTYPE,STATIC
ET,1,SHELL181, , ,2
SECT,1,SHELL
SECD,.25,1                   ! DEFINE PLATE THICKNESS = .25
MP,EX,1,30.E6
MP,NUXY,1,.3
CSYS,1                       ! DEFINE CYLINDRICAL C.S.
N,1,10                       ! BEGIN NODE DEFINITION
N,7,30
FILL,,,,,,,,3                ! USE 3:1 SPACING RATIO FOR FILLING IN NODES
NGEN,2,10,1,7,1,,10
NROTAT,1,17,1
E,1,2,12,11                  ! DEFINE FIRST ELEMENT
EGEN,6,1,1                   ! GENERATE NEXT 5 ELEMENTS
D,1,ALL,,,11,10              ! CONSTRAIN INNER EDGE IN ALL D.O.F.
D,2,UY,,,7,,ROTX,ROTZ        ! CONSTRAIN LOWER EDGE AGAINST ROTATIONS IN X & Z
D,12,UY,,,17,,ROTX,ROTZ      ! CONSTRAIN UPPER EDGE AGAINST ROTATIONS IN X & Z
F,7,MY,-26.18,,17,10         ! APPLY MOMENT LOAD AT OUTER EDGE
OUTPR,NSOL,1
OUTPR,RSOL,1
FINISH
SOLVIT
SAVE,TABLE_2
/NOPR
RESUME,TABLE_1
/COM
/OUT,vm39,vrt
/COM,------------------- VM39 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
```

```
/COM,RESULTS USING SHELL63:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.7,'  ',F14.7,'   ',1F15.3)
/COM,
/COM,X=10.81 in
/COM,
*VWRITE,LABEL2(1,1),LABEL2(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,
/COM,X=27.1 in
/COM,
*VWRITE,LABEL2(1,1),LABEL2(1,2),VALUE3(1,1),VALUE3(1,2),VALUE3(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING SHELL181:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.7,'  ',F14.7,'   ',1F15.3)
/COM,
/COM,X=10.81 in
/COM,
*VWRITE,LABEL2(1,1),LABEL2(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,
/COM,X=27.1 in
/COM,
*VWRITE,LABEL2(1,1),LABEL2(1,2),VALUE3(1,1),VALUE3(1,2),VALUE3(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm39,vrt
```

VM40 Input Listing

```
/COM,ANSYS MEDIA REL. 140 (11/26/2011) REF. VERIF. MANUAL: REL. 140
/VERIFY,VM40
/PREP7
MP,PRXY,,0.3
/TITLE, VM40, LARGE DEFLECTION AND ROTATION OF A BEAM PINNED AT ONE END
C***          REFERENCE - ANY BASIC MATHEMATICS BOOK
PI=(4.0)*ATAN(1.0)     ! ANALYST FORGETS VALUE OF PI - LETS Mechanical APDL CALCULATE IT
ANTYPE,TRANS           ! NONLINEAR TRANSIENT DYNAMIC ANALYSES
NLGEOM,ON              ! LARGE DEFLECTIONS
ET,1,BEAM188
SECT,1,BEAM,ASEC
SECD,1,1,0.1,1,1,1     ! ARBITRARY GEOMETRIC PROPERTIES
MP,EX,1,30E6           ! DEFINE MATERIAL PROPERTIES
MP,DENS,1,1E-10        ! DEFINE DENSITY OF ALMOST ZERO
N,1                    ! BEGIN NODAL DEFINITION
N,2,10
E,1,2                  ! DEFINE ELEMENT
FINISH
/out,scratch
/SOLU
SOLCONTROL,0
D,1,ROTZ,PI*2          ! ONE COMPLETE REVOLUTION
D,1,UX,,,,,UY          ! CONSTRAIN NODE 1 (PINNED END OF BEAM)
D,ALL,UZ
D,ALL,ROTX
D,ALL,ROTY
NSUBST,24
TIME,.15               ! TIME STEP OF 0.00625 SEC. (.15/24)
OUTRES,NSOL,1          ! SAVE NODAL DOF SOLUTION FOR EVERY SUBSTEP
```

```
OUTRES,ESOL,1          ! SAVE ELEMENT SOLUTION FOR EVERY SUBSTEP
CNVTOL,F,1,0.00001     ! CONVERGENCE CRITERION BASED UPON FORCES
CNVTOL,M,1,0.00001     ! CONVERGENCE CRITERION BASED UPON MOMENTS
SOLVE
FINISH
/out
/POST26
NSOL,2,2,U,X,UX         ! DEFINE NODE 2 UX DISP AS VARIABLE 2
NSOL,3,2,U,Y,UY         ! DEFINE NODE 2 UY DISP AS VARIABLE 3
NSOL,4,1,ROT,Z,ROTZ     ! DEFINE NODE 1 ROTZ AS VARIABLE 4
ESOL,6,1,,SMISC,36,SDIR! GET AXIAL STRESS OF ELEMENT AT NODE 2
DERIV,5,4,,,INPUT_W     ! CALCULATE DERIVATIVE OF VAR. 4 WRT VARIABLE 1 (TIME)
PRVAR,2,3,4,5,6         ! PRINT VARIABLES 1 THRU 6
PLVAR,2,3               ! DISPLAY VARIABLES 2 AND 3 AS A FUNCTION OF TIME
STORE
*GET,MX_STRS,VARI,6,EXTREM,VMAX
*GET,DEFX_60,VARI,2,RSET,4
*GET,DEFY_90,VARI,3,RSET,6
*GET,DEFX_180,VARI,2,RSET,12
*GET,DEFY_210,VARI,3,RSET,14
*GET,DEFX_315,VARI,2,RSET,21
*GET,DEFY_360,VARI,3,RSET,24
*DIM,LABEL,CHAR,6,2
*DIM,VALUE,,6,3
*DIM,STRSS,,1,1
*VFILL,STRSS(1,1),DATA,MX_STRS
LABEL(1,1) = '60 DEG, ','90 DEG, ','180 DEG,','210 DEG,','315 DEG,','360 DEG,'
LABEL(1,2) = ' UX (in)',' UY (in)',' UX (in)',' UX (in)',' UX (in)',' UX (in)'
*VFILL,VALUE(1,1),DATA,-5,10,-20,-5,-2.93,0
*VFILL,VALUE(1,2),DATA,DEFX_60,DEFY_90,DEFX_180,DEFY_210,DEFX_315,DEFY_360
*VFILL,VALUE(1,3),DATA,ABS(DEFX_60/5),ABS(DEFY_90/10),ABS(DEFX_180/20),ABS(DEFY_210/5)
*VFILL,VALUE(5,3),DATA,ABS(DEFX_315/2.93),0
/COM
/OUT,vm40,vrt
/COM,------------------- VM40 RESULTS COMPARISON ---------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,
/COM,THE MAXIMUM AXIAL STRESS IS:
*VWRITE,STRSS(1,1)
(1X,F4.2)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm40,vrt
```

VM41 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM41
/PREP7
MP,PRXY,,0.3
/TITLE, VM41, SMALL DEFLECTION OF A RIGID BEAM
!COM           REFERENCE - ANY BASIC STRENGTH OF MATERIAL BOOK
!COM           USING THICK BEAM GEOMETRY
ET,1,MATRIX27,,,4          ! KEYOPT(3)=4, INPUT DATA AS 12 X 12 STIFFNESS MATRIX
ET,2,BEAM188
R,1                        ! TABLE 1 REAL CONSTANTS FOR MATRIX27 STIFFNESS MATRIX
RMODIF,1,51,10000          ! MODIFY POSITIONS 51, 57 AND 78 IN TABLE 1
RMODIF,1,78,10000          ! RMODIF USED, RATHER THAN RMORE, FOR EASIER INPUT
RMODIF,1,57,-10000
SECT,2,BEAM,ASEC           ! RIGID BEAM PROPERTIES
SECD,100,1000,1,1000,,1
MP,EX,1,30E6
N,1
```

```
N,2
N,3,10
E,1,2                       ! STIFFNESS MATRIX ELEMENT
TYPE,2
SECN,2
E,2,3                       ! BEAM ELEMENT
OUTPR,ALL,1                 ! PRINT ALL ITEMS
D,1,ROTZ
D,2,UX,,,,,UY
F,3,FY,-10
D,ALL,UZ
D,ALL,ROTX
D,ALL,ROTY
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST26
/OUT,
ESOL,2,2,,SMISC,32,SBEN
STORE
*GET,STRS_BEN,VARI,2,EXTREM,VMAX
FINISH
/POST1
*GET,DEF_X,NODE,3,U,X
*GET,DEF_Y,NODE,3,U,Y
*GET,ROT_Z,NODE,3,ROT,Z
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'DEFLECTI','DEFLECTI','ROTATION','SIG_BEND'
LABEL(1,2) = 'ON_X(in)','ON_Y(in)','   (rad)','   (psi)'
*VFILL,VALUE(1,1),DATA,0,-.1,-.01,0
*VFILL,VALUE(1,2),DATA,DEF_X,DEF_Y,ROT_Z,STRS_BEN
*VFILL,VALUE(1,3),DATA,0,ABS(DEF_Y/.1 ),ABS(ROT_Z/.01),0
SAVE,TABLE_1
FINISH
/PREP7
!COM         USING CONSTRAINT EQUATIONS
SECN,2                      ! BEAM PROPERTIES
SECD,.0625,.00032552,.00001,.00032552,,1
CE,1,,3,UY,1,2,ROTZ,-10     ! CONSTRAINT EQUATION
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST26
/OUT,
ESOL,2,2,,SMISC,32,SBEN
STORE
*GET,STRS_BEN,VARI,2,EXTREM,VMAX
FINISH
/POST1
*GET,DEF_X,NODE,3,U,X
*GET,DEF_Y,NODE,3,U,Y
*GET,ROT_Z,NODE,3,ROT,Z
LABEL(1,1) = 'DEFLECTI','DEFLECTI','ROTATION','SIG_BEND'
LABEL(1,2) = 'ON_X(in)','ON_Y(in)','   (rad)','   (psi)'
*VFILL,VALUE(1,1),DATA,0,-.1,-.01,0
*VFILL,VALUE(1,2),DATA,DEF_X,DEF_Y,ROT_Z,STRS_BEN
*VFILL,VALUE(1,3),DATA,0,ABS(DEF_Y/.1 ),ABS(ROT_Z/.01),0
SAVE,TABLE_2
RESUME,TABLE_1
/COM
/OUT,vm41,vrt
/COM,------------------- VM41 RESULTS COMPARISON ---------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS FOR THICK BEAM:
/COM,
```

```
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F13.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS WITH CONSTRAINT EQUATION:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F13.2,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm41,vrt
```

VM42 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM42
/PREP7
smrt,off
/TITLE, VM42, BARREL VAULT ROOF UNDER SELF WEIGHT
/COM, REF:  COOK, CONCEPTS AND APPL. OF F.E.A., 2ND ED., 1981, PP. 284-287.
C***          USING SHELL181 ELEMENTS
ANTYPE,STATIC
ET,1,SHELL181, , ,2
SECTYPE,1,SHELL
SECDATA,0.25,1,0,5
MP,EX,1,4.32E8         ! MATERIAL PROPERTIES
MP,NUXY,1,0.0
MP,DENS,1,36.7347
CSYS,1
K,1,25,50
K,2,25,50,25           ! DEFINE KEYPOINTS AND AREA
KGEN,2,1,2,1,,40
A,1,3,4,2
ESIZE,,4
AMESH,1
CSYS,0                 ! SWITCH BACK TO GLOBAL CARTESIAN C.S.
NSEL,S,LOC,X
DSYM,SYMM,X            ! CONSTRAIN SYMMETRY PLANES
NSEL,S,LOC,Z
DSYM,SYMM,Z
NSEL,S,LOC,Z,25
D,ALL,UX,0,,,,UY,ROTZ  ! CONSTRAIN END OF ROOF
NSEL,ALL
ACEL,,9.8
FINISH
*CREATE,SOLVIT,MAC
/out,scratch
/SOLU
SOLVE
FINISH
/out
/POST1
NSEL,S,NODE,,1,2,1     ! SELECT NODES AT POINTS A AND B
ESLN,S                 ! SELECT ELEMENTS CONTAINING NODES
PRNSOL,U,COMP
*GET,UYA,NODE,1,U,Y
*GET,UXA,NODE,1,U,X
RSYS,1                 ! DISPLAY RESULTS IN CYLINDRICAL SYSTEM
SHELL,TOP
PRNSOL,S,COMP
*GET,SIGZ_TOP,NODE,1,S,Z
*GET,SIGY_TOP,NODE,2,S,Y
SHELL,BOT
PRNSOL,S,COMP
*GET,SIGZ_BOT,NODE,1,S,Z
```

```
*GET,SIGY_BOT,NODE,2,S,Y
*DIM,LABEL,CHAR,6,2
*DIM,VALUE,,6,3
LABEL(1,1) = 'UYA     ','UXA     ','SIGZ, TO','SIGZ, BO','SIGTH,TO','SIGTH,BO'
LABEL(1,2) = '     (m)','     (m)','P_A (PA)','T_A (PA)','P_B (PA)','T_B (PA)'
*VFILL,VALUE(1,1),DATA,-.3019,-.1593,215570,340700,191230,-218740
*VFILL,VALUE(1,2),DATA,UYA,UXA,SIGZ_TOP,SIGZ_BOT,SIGY_TOP,SIGY_BOT
*VFILL,VALUE(1,3),DATA,ABS(UYA/.3019 ),ABS(UXA/.1593 ),ABS(SIGZ_TOP/215570 )
*VFILL,VALUE(4,3),DATA,ABS(SIGZ_BOT/340700),ABS(SIGY_TOP/191230),ABS(SIGY_BOT/218740)
FINISH
*END
SOLVIT                 ! USE MACRO SOLVIT
SAVE,TABLE_1
/CLEAR, NOSTART                ! CLEAR DATABASE FOR SECOND SOLUTION
C***          USING SHELL281 ELEMENTS
/PREP7
SMRT,OFF
ANTYPE,STATIC
ET,1,SHELL281
SECTYPE,1,SHELL
SECDATA,0.25,1,0,5
MP,EX,1,4.32E8         ! MATERIAL PROPERTIES
MP,NUXY,1,0.0
MP,DENS,1,36.7347
CSYS,1
K,1,25,50
K,2,25,50,25           ! DEFINE KEYPOINTS AND AREA
KGEN,2,1,2,1,,40
A,1,3,4,2
ESIZE,,4
AMESH,1
CSYS,0                 ! SWITCH BACK TO GLOBAL CARTESIAN C.S.
NSEL,S,LOC,X
DSYM,SYMM,X            ! CONSTRAIN SYMMETRY PLANES
NSEL,S,LOC,Z
DSYM,SYMM,Z
NSEL,S,LOC,Z,25
D,ALL,UX,0,,,,UY,ROTZ  ! CONSTRAIN END OF ROOF
NSEL,ALL
ACEL,,9.8
FINISH
SOLVIT                 ! USE MACRO SOLVIT
SAVE,TABLE_2
/NOPR
RESUME,TABLE_1
/COM
/OUT,vm42,vrt
/COM,------------------- VM42 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,SHELL181
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F12.4,'  ',F15.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/COM,
/COM,SHELL281
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F12.4,'  ',F15.4,'   ',1F15.3)
/NOPR
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm42,vrt
```

VM43 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM43
/PREP7
SMRT,OFF
/TITLE, VM43, BENDING OF AN AXISYMMETRIC THICK PIPE UNDER GRAVITY LOADING
C***          FORMULAS FOR STRESS AND STRAIN, ROARK, 4TH ED., PAGE 112, NO. 33
ANTYPE,STATIC         ! STATIC ANALYSIS
ET,1,PLANE25,,,,,,2 ! PLANE25
MP,EX,1,30.E6         ! DEFINE MATERIAL PROPERTIES
MP,DENS,1,.00073
MP,NUXY,1,0           ! DEFINE NUXY AS 0.0
K,1,.5                ! DEFINE KEYPOINTS
K,2,.5,100
KGEN,2,1,2,1,.5       ! GENERATE 2 ADDITIONAL KEYPOINTS IN X DIRECTION
L,1,2                 ! DEFINE LINES AND NUMBER OF DIVISIONS
LESIZE,1,,,12
L,2,4
LESIZE,2,,,1
L,3,4
LESIZE,3,,,12
L,1,3
LESIZE,4,,,1
A,3,1,2,4             ! DEFINE AREA
AMESH,1               ! MESH AREA 1
ACEL,386,,-386        ! GRAVITY AS THE SUM OF TWO HARMONICALLY VARYING LOADS
MODE,1,1              ! SYMMETRIC HARMONIC LOAD
NSEL,S,LOC,Y,0        ! SELECT NODES AT Y=0
D,ALL,ALL             ! CONSTRAIN IN ALL DOF
NSEL,S,LOC,Y,100      ! SELECT NODES AT Y=100
D,ALL,UY              ! CONSTRAIN IN Y DISPLACEMENT DOF (SYMMETRY PLANE)
NSEL,ALL
FINISH
/SOLU
OUTPR,BASIC,LAST      ! PRINT BASIC SOLUTION
/OUT,SCRATCH
SOLVE
FINISH
/POST1
SET,1,1,,,,0.0        ! READ IN RESULTS AT ANGLE=0.0
/VUP,1,X              ! DEFINE X AXIS AS VERTICAL AXIS FOR DISPLAYS
/WINDOW,1,-1,1,0,1  ! DEFINE AND TURN ON WINDOW 1
PLDISP,1              ! DISPLAY UNDISPLACED AND DISPLACED SHAPE OF PIPE
/OUT,
PRNSOL,U,COMP         ! PRINT DISPLACEMENTS
*GET,DEF_X,NODE,3,U,X
SET,1,1,,,,90.0       ! READ IN RESULTS AT ANGLE=90.0
/WINDOW,1,OFF         ! TURN OFF WINDOW 1
/NOERASE              ! DON'T ERASE EXISTING DISPLAY
/WINDOW,2,-1,1,-1,0 ! DEFINE AND TURN ON WINDOW 2
/VUP,2,X              ! DEFINE X AXIS AS VERTICAL AXIS FOR DISPLAYS
PLDISP,1              ! DISPLAY UNDIS. AND DISP. SHAPE AT NEW ANGLE
PRNSOL,U,COMP         ! PRINT DISPLACEMENTS
*GET,DEF_Z,NODE,3,U,Z
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'UX, IN  ','UZ, IN ('
LABEL(1,2) = '(ANG=0) ','ANG=90) '
*VFILL,VALUE(1,1),DATA,-.12524,.12524
*VFILL,VALUE(1,2),DATA,DEF_X,DEF_Z
*VFILL,VALUE(1,3),DATA,ABS(DEF_X/.12524 ) ,ABS( DEF_Z/.12524)
/COM
/OUT,vm43,vrt
/COM,------------------- VM43 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
```

```
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,----------------------------------------------------------
/COM,
/COM,----------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM43 NOT CONTAINED IN
/COM,THIS TABLE
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm43,vrt
```

VM44 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM44
/PREP7
/TITLE, VM44, BENDING OF AN AXISYMMETRIC THIN PIPE UNDER GRAVITY LOADING
C***          FORMULAS FOR STRESS AND STRAIN, ROARK, 4TH ED., PAGE 112, NO. 33
ANTYPE,STATIC
ET,1,SHELL61,,,,,,1      ! PRINT DISP. AT ELEMENT ENDS AS WELL AS MIDPOINT
R,1,.1                   ! DEFINE WALL THICKNESS
MP,EX,1,30.E6            ! DEFINE MATERIAL PROPERTIES
MP,DENS,1,.00073         ! DEFINE DENSITY
MP,NUXY,1,0              ! DEFINE NUXY AS 0.0
N,1,1                    ! BEGIN NODE DEFINITION
N,8,1,125
FILL                     ! PLACE NODES 2 THRU 7 BETWEEN NODES 1 & 8
E,1,2                    ! BEGIN ELEMENT DEFINITION
EGEN,7,1,1               ! GENERATE NEXT 6 ELEMENTS
CE,1,,2,UY,1,2,ROTZ,-1   ! DEFINE FIRST CONSTRAINT EQN. (UY(2) = ROTZ(2))
*REPEAT,6,1,,1,,,1       ! REPEAT FOR NODES 3 TO 7
CE,7,,2,UX,1,2,UZ,1      ! UX(2) = -UZ(2) AND FOR 6 INTERIOR NODES
*REPEAT,6,1,,1,,,1
OUTPR,ALL,ALL
ACEL,386,,-386           ! GRAVITY AS THE SUM OF TWO HARMONICALLY VARYING LOADS
MODE,1,1                 ! MODE NUMBER 1, SYMMETRIC LOADING
D,1,ALL                  ! FIXED END
NSEL,S,LOC,Y,125
DSYM,SYMM,Y              ! CENTER PLANE END
NSEL,ALL
FINISH
/SOLU
SOLVE
FINISH
/POST1
SET,1,1,,,,0.0           ! GET RESULTS AT 0 DEGREES
/VUP,1,X                 ! DEFINE X AXIS AS VERTICAL FOR VIEWING
/WINDOW,1,TOP            ! DEFINE WINDOW 1 AS TOP HALF OF SCREEN
PLDISP,1                 ! DISPLAY BOTH DISTORTED AND UNDISTORTED GEOMETRY
PRNSOL,DOF               ! PRINT DEGREE OF FREEDOM VALUES
LCOPER,LPRIN             ! CALCULATE PRINCIPAL STRESSES
PRESOL,ELEM              ! PRINT ELEMENT SOLUTION RESULTS
ETABLE,STRS,NMISC,11
*GET,STRSS,ELEM,1,ETAB,STRS
*GET,DEF_X,NODE,8,U,X
SET,1,1,,,,90.0          ! STUDY RESULTS AT 90.0 DEGREES
/WINDOW,1,OFF            ! TURN-OFF WINDOW 1
/WINDOW,2,BOT            ! DEFINE WINDOW 2 AS BOTTOM HALF OF SCREEN
/NOERASE                 ! OVERLAY NEXT DISPLAY (DON'T ERASE WINDOW 1)
/VUP,2,X
PLDISP                   ! DISPLAY ONLY DISTORTED GEOMETRY
PRNSOL,U,COMP            ! PRINT DISPLACEMENTS
*GET,DEF_Z,NODE,8,U,Z
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'UX, in  ','UZ, in  ','SIGMX,ps'
LABEL(1,2) = ' (ANG=0)','(ANG=90)','i(ANG=90'
*VFILL,VALUE(1,1),DATA,-.19062,.19062,3074.3
```

```
*VFILL,VALUE(1,2),DATA,DEF_X,DEF_Z,STRSS
*VFILL,VALUE(1,3),DATA,ABS(DEF_X/.19062),ABS(DEF_Z/.19062),ABS(STRSS/3074.3)
/COM
/OUT,vm44,vrt
/COM,------------------- VM44 RESULTS COMPARISON ---------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,-----------------------------------------------------------

/OUT
FINISH
*LIST,vm44,vrt
```

VM45 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM45
/PREP7
/TITLE, VM45, NATURAL FREQUENCY OF A SPRING-MASS SYSTEM
C*** VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 6, EX. 1.2-2
ANTYPE,MODAL
MODOPT,LANB,1
ET,1,COMBIN14,,,2      ! TWO-DIMENSIONAL LONGITUDINAL SPRING
ET,2,MASS21,,,4        ! TWO-DIMENSIONAL MASS
R,1,48
R,2,.006477
N,1
N,2,,1
E,1,2
TYPE,2
REAL,2
E,2
OUTPR,ALL,1
OUTRES,ALL,0
D,1,ALL
D,2,UX
FINISH
/SOLU
SOLVE
*GET,FREQ,MODE,1,FREQ
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '      F,'
LABEL(1,2) = ' (Hz)    '
*VFILL,VALUE(1,1),DATA,13.701
*VFILL,VALUE(1,2),DATA,FREQ
*VFILL,VALUE(1,3),DATA,ABS(FREQ/13.701)
/COM
/OUT,vm45,vrt
/COM,------------------- VM45 RESULTS COMPARISON ---------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,-----------------------------------------------------------

/OUT
FINISH
*LIST,vm45,vrt
```

VM46 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM46
/TITLE, VM46, TWO DIMENSIONAL END NOTCHED FLEXURE PROBLEM
/COM, REFERENCE:" J.F.MANDELL, ET AL., PREDICTION OF DELAMINATION IN
/COM,             WIND TURBINE BLADE STRUCTURAL DETAILS
/COM,             JOURNAL OF SOLAR ENERGY ENGINEERING, VOL. 25, 2003, PG: 522-530
/COM,
/OUT,SCRATCH
/PREP7
ET,1,PLANE182                ! ELEMENT TYPE 182
KEYOPT,1,3,2                 ! PLANE STRAIN

!MATERIAL PROPERTIES
YOUNG = 210000               ! YOUNG'S MODULUS
NU = 0.3                     ! POISSION'S RATIO
MP,EX,1,YOUNG                !MPa
MP,PRXY,1,NU
L=30                         ! DISTANCE FROM THE SUPPORT POINT TO LOADING POINT
H=0.6                        ! THICKNESS OF BEAM
AA=10.0                      ! CRACK LENGTH
D=3                          ! THE LEFT END TO SUPPORT POINT
BB=0.2                       ! FINE MESH AREA
PP=-10                       ! LOADING
B=1                          ! SPECIMEN WIDTH
NN=1                         ! CHANGE OF MESH SIZE

K,1,0,0
K,2,2*(D+L)
K,3,2*(D+L),2*H
K,4,,2*H
K,5,,H
K,6,D+AA,H
K,7,,H
K,8,D+AA-BB,H
K,9,D+AA-BB,H+BB
K,10,D+AA+BB,H+BB
K,11,D+AA+BB,H-BB
K,12,D+AA-BB,H-BB
K,13,D+AA-BB,H
K,21,D,0
K,22,2*(D+L)-D,0
K,23,D+L,2*H
K,26,D+AA+BB,H

A,6,26,10,9,8
A,13,12,11,26,6
A,2,3,10,26,11
A,1,21,12,13,7
A,21,22,2,11,12
A,3,23,4,9,10
A,4,5,8,9

AESIZE,1,BB/10*NN
AESIZE,2,BB/10*NN
ALLSEL
AMESH,1,2
ASEL,U,AREA,,1,2
AESIZE,ALL,BB/2*NN
AMESH,ALL
ALLSEL

R,3
REAL,3
ET,2,TARGE169
ET,3,CONTA172
R,3,,,1.0,0.1,0,
RMORE,,,1.0E20,0.0,1.0,
```

```
RMORE,0.0,0,1.0,,1.0,0.5
RMORE,0,1.0,1.0,0.0,,1.0
KEYOPT,3,3,0
KEYOPT,3,4,0
KEYOPT,3,5,0
KEYOPT,3,7,0
KEYOPT,3,8,0
KEYOPT,3,9,0
KEYOPT,3,10,2
KEYOPT,3,11,0
KEYOPT,3,12,0
KEYOPT,3,2,0

LSEL,S,,,5,23,18                    ! Generate the target surface
CM,_TARGET,LINE
TYPE,2
NSLL,S,0
ESLN,S,0
ESURF
ALLSEL

LSEL,S,,,9,15,6                     ! Generate the contact surface
CM,_CONTACT,LINE
TYPE,3
NSLL,S,0
ESLN,S,0
ESURF
ALLSEL

FINISH

/SOLU
TIME,1
KSEL,S,KP,,21
NSLK,S
D,ALL,UX
D,ALL,UY
ALLSEL
KSEL,S,KP,,22
NSLK,S
D,ALL,UY
ALLSEL
KSEL,S,KP,,23
NSLK,S
F,ALL,FY,PP
ALLSEL
KSEL,S,KP,,6
NSLK,S
CM,TIPP,NODE
ALLSEL,ALL

CINT,NEW,1                     ! DEFINE CRACK ID
CINT,TYPE,VCCT
CINT,CTNC,TIPP                 ! DEFINE CRACK TIP NODE COMPONENT
CINT,SYMM,OFF                  ! SYMMETRY OFF
CINT,NORMAL                    ! DEFINE CRACK PLANE NORMAL
CINT,LIST
ALLSEL,ALL

SOLVE
FINISH

/OUT,SCRATCH
/POST1
/SHOW
/ESHAPE,1
/GRAPHICS,POWER
PRCINT,1
CRACK=NODE(13.00,0.60,0.00)
*GET,G1_ANSYS,CINT,1,,CRACK,,1,,G1
*GET,G2_ANSYS,CINT,1,,CRACK,,1,,G2
PLNSOL, U,Y, 0,1.0
```

```
*GET,UY_MIN,PLNSOL,0,MIN
CC=UY_MIN/PP                  ! specimen compliance (=center point deflection / PP)

/OUT
G_ANSYS=ABS(G1_ANSYS)+ABS(G2_ANSYS)
G_REF=(9*PP*PP*AA*AA*CC)/((2*B)*(2*L*L+3*AA*AA*AA))    ! equation (2) in the reference
/COM
/OUT,vm46,vrt
/COM, -------------- VM 46 RESULTS COMPARISON -------------
/COM,
/COM,             |  TARGET    |      Mechanical APDL     |  RATIO
/COM,
/COM,     G COMPUTATION FOR VCCT
/COM,
*VWRITE, 'G',  G_REF, G_ANSYS, G_ANSYS/G_REF
(1X,A8,'     ', F10.5, '       ', F14.5, '     ', F15.3)
/OUT
FINISH
*LIST, vm46,vrt
```

VM47 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM47
/PREP7
/TITLE, VM47, TORSIONAL FREQUENCY OF A SUSPENDED DISK
C*** VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 10, EX 1.3-2
ANTYPE,MODAL
MODOPT,LANB,1,,,
ET,1,COMBIN14,,,1     ! THREE-DIMENSIONAL TORSIONAL SPRING
ET,2,MASS21,,,3       ! TWO-DIMENSIONAL MASS WITH ROTARY INERTIA
R,1,4.8               ! REAL CONSTANT SET #1 SPRING CONSTANT
R,2,1,.30312          ! REAL CONSTANT SET #2 MASS & IZZ(J)
N,1                   ! BEGIN NODE DEFINITION
N,2,,,-1
E,1,2                 ! DEFINE BEAM ELEMENT
TYPE,2                ! DEFINE ACTIVE ELEMENT TYPE AS SET 2
REAL,2                ! DEFINE ACTIVE REAL CONSTANT TYPE AS SET 2
E,2                   ! DEFINE MASS AT END OF WIRE
OUTPR,BASIC,1
D,1,ALL               ! CONSTRAIN END OF WIRE IN ALL DOF
D,2,UX,,,  ,,UY,UX    ! PREVENT TRANSLATION OF THE MASS
FINISH
/SOLU
SOLVE
*GET,FREQ,MODE,1,FREQ
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '      F,'
LABEL(1,2) = ' (Hz)    '
*VFILL,VALUE(1,1),DATA,.63333
*VFILL,VALUE(1,2),DATA,FREQ
*VFILL,VALUE(1,3),DATA,ABS(FREQ/.63333 )
/COM
/OUT,vm47,vrt
/COM,------------------- VM47 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT

FINISH
*LIST,vm47,vrt
```

VM48 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM48
/TITLE, VM48, NATURAL FREQUENCY OF A MOTOR-GENERATOR
C*** VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 10, EX 1.3-3
/PREP7
ET,1,BEAM188           ! 3D 2 NODE BEAM
SECTYPE,1,BEAM,CSOLID
SECDATA,0.375/2,20     ! RADIUS AND NUMBER OF DIVISION AROUND CIRCUMFERENCE

ET,2,MASS21            ! GENERALIZED MASS
R,2,,,,31E-3           ! REAL CONSTANT SET 2 IXX
MP,EX,1,31.2E6         ! DEFINE MODULUS OF ELASTICITY
MP,PRXY,,0.3
N,1                    ! BEGIN NODE DEFINITION
N,2,8
E,1,2                  ! DEFINE PIPE ELEMENT
TYPE,2                 ! DEFINE ACTIVE ELEMENT TYPE AS SET #2
REAL,2                 ! DEFINE ACTIVE REAL CONSTANT TYPE AS SET #2
E,2                    ! DEFINE MASS AT END OF PIPE
OUTPR,BASIC,1
D,ALL,ALL              ! CONSTRAIN ALL DOF'S
DDELE,2,ROTX           ! RELEASE TORSIONAL DOF AT NODE 2
FINISH
/SOLU
ANTYPE,MODAL
MODOPT,LANB,1,,,
SOLVE
*GET,FREQ,MODE,1,FREQ
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '       F,'
LABEL(1,2) = ' (Hz)   '
*VFILL,VALUE(1,1),DATA,48.781
*VFILL,VALUE(1,2),DATA,FREQ
*VFILL,VALUE(1,3),DATA,ABS(FREQ/48.781)
/COM
/OUT,vm48,vrt
/COM,------------------- VM48 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,----------------------------------------------------------

/OUT
FINISH
*LIST,vm48,vrt
```

VM49 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM49
/PREP7
SMRT,OFF
/TITLE, VM49, ELECTROSTATIC FIELD ANALYSIS OF QUADPOLE WIRES IN OPEN AIR
C*** ANY BASIC STATIC AND DYNAMIC ELECTRICITY BOOK
ANTYPE,STATIC
ET,1,PLANE121                ! 2-D 8-NODE ELECTROSTATIC ELEMENT
ET,2,INFIN110,1              ! 2-D 4-NODE INFINITE ELEMENT WITH VOLT DOF
EMUNIT,MKS                   ! MKS UNIT
MP,PERX,1,1                  ! ELECTRICAL PERMITTIVITY
CSYS,1                       ! CYLINDRICAL COORDINATE SYSTEM
```

```
PCIRC,25.4/1000,0,90          ! QUARTER CIRCULAR AREA
PCIRC,50.8/1000,0,90
PCIRC,470/1000,0,90
AOVLAP,1,2,3                  ! OVERLAP AREAS
KPSCALE,7,8,1,2               ! SCALE KEYPOINTS 7 & 8 TO DOUBLE
L,7,6
L,6,9
L,8,9
AL,7,5,6,8
LSEL,S,LINE,,1,4,1            ! SELECT LINES
LSEL,A,LINE,,6,7
LSEL,A,LINE,,10,11
LESIZE,ALL,,,10               ! DIVIDE THE SELECTED LINES INTO TEN
!                               DIVISION
LSEL,ALL
LSEL,S,LINE,,12,13
LESIZE,ALL,,,30,10
LSEL,ALL
LSEL,S,LINE,,5,8,3
LESIZE,ALL,,,1
LSEL,ALL
TYPE,2                        ! USE ELEMENT TYPE 2
MSHK,1                     ! MAPPED AREA MESH
MSHA,0,2D                  ! USING QUADS
ESIZE,,1                      ! CREATE 1 ELEMENT PER LINE DIVISION
ASEL,S,AREA,,2
AMESH,ALL                     ! MESH THE AREA 2
ASEL,ALL
ESIZE,,10                     ! CREATE 10 ELEMENTS PER LINE DIVISION
TYPE,1                        ! USE ELEMENT TYPE 1
ASEL,S,AREA,,1,4,3            ! SELECT AREAS
ASEL,A,AREA,,5
AMESH,ALL
NSEL,S,LOC,X,25.4/1000        ! SELECT NODES
NSEL,R,LOC,Y,0
F,ALL,CHRG,.5E-6              ! APPLY CHARGE  AS POINT LOAD
NSEL,S,LOC,X,25.4/1000
NSEL,R,LOC,Y,90
F,ALL,CHRG,-.5E-6
NSEL,ALL
NSEL,S,LOC,X,940/1000
SF,ALL,INF                    ! FLAG THE EXTERIOR FACE OF INFIN110 AT
!                               INFINITE DISTANCE
NSEL,ALL
FINISH
/SOLU
OUTRES,ALL,ALL
OUTPR,,NONE
SOLVE
FINISH
/POST1
/COM    SELECT THE NODES AT ANGLES FROM 0 TO 90 DEGREE WITH 10
/COM     DIVISION ON SURFACE OF RADIUS 470 MM AND RETRIEVE THE
/COM      ELECTRIC POTENTIAL, V
DSYS,1
*DIM,ANG,,11,2
*VFILL,ANG(1,1),RAMP,0,9
*DO,J,1,11
   NSEL,S,LOC,X,470/1000
   NSEL,R,LOC,Y,ANG(J,1)
   *GET,NOD,NODE,,NUM,MAX
   *GET,ANG(J,2),NODE,NOD,VOLT
   NSEL,ALL
*ENDDO
*DIM,VLT,,11
*VFUN,VLT(1),COPY,ANG(1,2)
*DIM,VALUE,,11,2
*VFILL,VALUE(1,1),DATA,105.05,99.9,84.98,61.74,32.46,0,-32.46,-61.74,-84.98
*VFILL,VALUE(10,1),DATA,-99.98,-105.05
*VFILL,VALUE(1,2),DATA,ABS(VLT(1,1)/105.05 ),ABS(VLT(2,1)/99.9),ABS(VLT(3,1)/84.98)
*VFILL,VALUE(4,2),DATA,ABS(VLT(4,1)/61.74),ABS(VLT(5,1)/32.46),0
*VFILL,VALUE(7,2),DATA,ABS(VLT(7,1)/32.46),ABS(VLT(8,1)/61.74),ABS(VLT(9,1)/84.98)
```

```
*VFILL,VALUE(10,2),DATA,ABS(VLT(10,1)/99.98),ABS(VLT(11,1)/105.05 )
*DIM,LABEL,CHAR,11,2
*DO,I,1,11,1
LABEL(I,1) = 'V(VOLT) '
LABEL(I,2) = 'AT ANGLE'
*ENDDO
! WRITE DESIRED ANGLE AND POTENTIAL VALUES
/COM
/OUT,vm49,vrt
/COM,------------------- VM49 RESULTS COMPARISON ---------------
/COM,
/COM,                        |TARGET | Mechanical APDL  | RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),ANG(1,1),VALUE(1,1),VLT(1),VALUE(1,2)
(1X,A8,A8,': ',F4.1,'  ',F7.2,'  ',F12.2,'  ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm49,vrt
```

VM50 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM50
/PREP7
/TITLE, VM50, FUNDAMENTAL FREQUENCY OF A SIMPLY SUPPORTED BEAM
C*** VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 18, EX 1.5-1
ET,1,BEAM189          ! THREE DIMENSIONAL ELASTIC BEAM
MP,EX,1,30E6          ! DEFINE MATERIAL PROPERTIES
MP,DENS,1,728E-6
MP,GXY,1,30E6/2.6
SECT,1,BEAM,ASEC
SECD,4,(4/3),1e-6,(4/3),,1e-6
K,1                   ! BEGIN DEFINING KEYPOINTS
K,2,80
L,1,2                 ! DEFINE LINE WITH
LESIZE,ALL,,,4        !  4 DIVISIONS
LMESH,1               ! MESH LINE
ALLSEL,ALL
D,ALL,UZ
D,ALL,ROTY
D,ALL,ROTX
FINISH
/out,scratch
/SOLU
ANTYPE,MODAL
MODOPT,LANB,3,,,
MXPAND,3              ! EXPAND FIRST MODE
OUTPR,ALL,1
DK,ALL,UX             ! CONSTRAIN ENDS OF BEAM IN DISP. X DOF
DK,ALL,UY             ! CONSTRAIN ENDS OF BEAM IN DISP. Y DOF
SOLVE
FINISH
/out
/POST26
*GET,FREQ,MODE,1,FREQ
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '       f'
LABEL(1,2) = ', (Hz)  '
*VFILL,VALUE(1,1),DATA,28.766
*VFILL,VALUE(1,2),DATA,FREQ
*VFILL,VALUE(1,3),DATA,ABS(FREQ/28.766)
/COM
/OUT,vm50,vrt
/COM,------------------- VM50 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
```

```
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm50,vrt
```

VM51 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM51
/TITLE,VM51, FORCE BETWEEN CHARGED SPHERES
C*** USING SOLID122
!            THE ELECTROMAGNETIC FIELD,  SHADOWITZ, PAGE 61
/PREP7
smrt,off $ shpp,warn
mopt,amesh,alte
mopt,qmesh,alte
R1 = 1                          ! SPHERE RADIUS
R2 = 3                          ! DISTANCE BETWEEN SPHERES
R3 = 6                          ! RADIUS OF FINITE ELEMENT DOMAIN
R4 = 1.25                       ! MAXWELL SURFACE RADIUS
PER=8.854E-12                   ! FREE SPACE PERMITIVITY
PI=3.14159265359
Q = 4*PI*PER                    ! TOTAL CHARGE
ALPHA = 30                      ! SLICE ANGLE
AREA = 4*PI*(R1**2)             ! TOTAL SPHERE AREA
CHRGS = Q/AREA                  ! SURFACE CHARGE
/NOPR
PCIRC,,R2,0,90                  ! CIRCLE RADIUS R2, 0 TO 90 DEGREES
WPOFFS,,R2/2                    ! WORKING PLANE OFFSET Y = R2/2
PCIRC,,R1,0,90                  ! CIRCLE RADIUS R1, 0 TO 90 DEGREES
PCIRC,,R1,-90,0                 ! CIRCLE RADIUS R1, 0 TO -90 DEGREES
PCIRC,,R4,-90,90                ! CIRCLE RADIUS R4, -90 TO 90 DEGREES
AOVLAP,ALL
NUMCMP,AREA
ET,1,PLANE121                   ! 2-D 8-NODE ELECTROSTATIC SOLID
ET,2,SOLID122                   ! 3-D 20-NODE ELECTROSTATIC SOLID
ET,3,MESH200,7                  ! NEW MESH200 2-D 8-NODE ELEMENT TYPE
ET,4,INFIN111,2,1               ! 3-D INFINITE SOLID ELEMENT
MP,PERX,1,1
MP,PERX,2,1
CSYS,2                          ! SPHERICAL COORDINATE SYSTEM
LSEL,S,LOC,X,R2
LESIZE,ALL,,,30                 ! SET ELEMENT DIVISIONS = 20
ESIZE,,25                       ! SET ELEMENT DIVISIONS FOR EXTRUDE REGION
TYPE,1
LOCAL,11,2,,R2/2                ! DEFINE COORDINATE SYSTEM AT SPHERE CENTER
LSEL,S,LOC,X,R1                 ! SELECT LINES ON SPHERE SURFACE
LESIZE,ALL,,,25                 ! SET ELEMENT DIVISIONS
LSEL,A,LOC,X,R4                 ! SELECT LINES FOR MAXWELL SURFACE
LESIZE,ALL,,,50                 ! SET ELEMENT DIVISIONS
CSYS,0                          ! CARTESIAN COORDINATE SYSTEM
LSEL,S,LOC,Y,                   ! SELECT LINES AT Y = 0
LESIZE,ALL,,,40                 ! SET ELEMENT DIVISIONS
MSHK,2                          ! MAPPED AREA MESH IF POSSIBLE
MSHA,0,2D                       ! USING QUADS
LSEL,ALL
ESIZE,,5                        ! SET ELEMENT DIVISIONS = 5
ALLSEL
AMAP,4,10,7,5,11                ! MAP MESH SPHERE TO MAXWELL SURFACE
AMESH,ALL
K,200                           ! CREATE KEYPOINTS FOR ROTATION
K,201,,R3
MSHK,0                          !  FREE MESH
MSHA,1,                         !  USING TRIS OR TETS
TYPE,2
```

```
ASEL,ALL
ESIZE,,3                          ! 3 DIVISIONS IN ROTATE DIRECTION
MAT,1
VROTAT,ALL,,,,,,200,201,ALPHA     ! ROTATE ALL AREAS THROUGH 30 DEGREES
CSYS,11                           ! CUSTOM SPHERICAL COORDINATE SYSTEM
NSEL,S,LOC,X,0,R1*1.03            ! NODE SELECT RADIUS 0 TO R1
ESLN,S,1                          ! ELEMENT SELECT FROM NODES
EMODIF,ALL,MAT,2                  ! CHANGE MATERIAL PROPERTY TO 2
CSYS,2                            ! SPHERICAL COORDINATE SYSTEM
KSEL,S,LOC,X,R2                   ! KEYPOINT SELECT AT RADIUS R2
LSLK,S,1                          ! LINE SELECT FROM KEYPOINTS
ASLL,S,1                          ! AREA SELECT FROM LINES
TYPE,3                            ! NEW MESH200 ELEMENT TYPE
AMESH,ALL                         ! MESH AREA AT RADIUS R2
ESIZE,,8                          ! EIGHT ELEMENTS IN EXTRUDE DIRECTION
TYPE,2                            ! SOLID122 USED FOR EXTRUDE
VEXT,ALL,,,R3-R2                  ! EXTRUDE AREAS IN RADIAL DIRECTION
KSEL,S,LOC,X,R3                   ! KEYPOINT SELECT AT RADIUS R3
LSLK,S,1                          ! LINE SELECT FROM KEYPOINTS
ASLL,S,1                          ! AREA SELECT FROM LINES
TYPE,3                            ! NEW MESH200 ELEMENT TYPE
AMESH,ALL                         ! MESH AREA AT RADIUS R3
ESIZE,,1                          ! ONE DIVISION IN EXTRUDE DIRECTION
TYPE,4                            ! INFIN122 USED FOR EXTRUDE
VEXT,ALL,,,R3                     ! EXTRUDE AREA IN RADIAL DIRECTION
ALLSEL                            ! SELECT ALL ENTITIES

/OUTPUT,SCRATCH
NUMMRG,NODE
NUMMRG,ELEM
NUMMRG,KP
/OUTPUT

CSYS,0
NSEL,S,LOC,Y,0                    ! SELECT SYMMETRY BOUNDARY
D,ALL,VOLT,0                      ! CONSTRAIN BOUNDARY VOLT DOF
CSYS,2                            ! SPHERICAL COORDINATE SYSTEM
NSEL,S,LOC,X,10,12                ! SELECT OUTER NODES OF INFINITE DOMAIN
ESLN,S
SF,ALL,INF                        ! SET INFINITE FLAG
NSEL,ALL
OUTRES,ALL,ALL
FINISH
/SOLU
ALLSEL
ESEL,U,TYPE,,1,                   ! UNSELECT DUMMY MESHING ELEMENT 122
ESEL,S,MAT,,2                     ! SELECT SPHERE ELEMENTS
NSLE
CSYS,11                           ! CUSTOM SPHERICAL COORDINATE SYSTEM
NSEL,S,LOC,X,0.98*R1,1.02*R1      ! SELECT NODES ON SPHERE SURFACE
ESLN
ESEL,U,MAT,,1
SF,ALL,CHRG,CHRGS                 ! APPLY SURFACE CHARGE
ALLSEL
ESEL,U,TYPE,,1                    ! UNSELECT DUMMY MESHING ELEMENT 122
/TYPE,,6
/DEVICE,VECTOR,ON
/DIST,,3.661
/FOCUS,,3.08,2.884,-.148327
/COM                         *** THE FOLLOWING ANNOTATION COMMANDS ARE ***
/COM                         *** TYPICALLY GENERATED INTERACTIVELY ***
/AUTO, 1
/ANUM ,0,     1,-0.12607    , 0.38512  ! ANNOTATION NUMBER, TYPE AND HOT SPOT
/TLAB,-0.546, 0.385,Infinite Element Domain
/ANUM ,0,     1, 0.16752    ,-0.72533E-01
/TLAB,-0.217,-0.073,Finite Element Domain
/ANUM ,0,    12, 0.77714E-01,-0.24523
/LINE, 0.259,-0.124,-0.104,-0.366
/LSYM,-0.104,-0.366, 213,   1, 1.000
/ANUM ,0,     1,-0.32640    ,-0.34885
/TLAB,-0.571,-0.349,Sphere Surface
/ANUM ,0,    12,-0.44556    ,-0.45247
```

```
/LINE,-0.373,-0.366,-0.518,-0.539
/LSYM,-0.518,-0.539, 229,   1, 1.000
/ANUM ,0,     1,-0.41447E-01,-0.78577
/TSPEC, 15, 1.000,   1,   1,   0
/TLAB,-0.321,-0.791,Maxwell Surface
/ANUM ,0,    12,-0.31258    ,-0.72015
/LINE,-0.235,-0.746,-0.390,-0.694
/LSYM,-0.390,-0.694, 161,   1, 1.000
/ANUM ,0,     1,-0.39893    ,-0.93257
/TSPEC, 15, 1.000,   1,   0,   0
/TLAB,-0.434,-0.933,R3
/ANUM ,0,    12,-0.25214    ,-0.92566
/LINE,-0.373,-0.926,-0.131,-0.926
/LSYM,-0.131,-0.926,   0,   1, 1.000
/ANUM ,0,    12,-0.51118    ,-0.92566
/LINE,-0.442,-0.926,-0.580,-0.926
/LSYM,-0.580,-0.926, 180,   1, 1.000
APLOT
/ANNOT,ON
/USER                                 ! RESET GRAPHICS DISPLAY SETTINGS
/VIEW,1,.5274,.2492,.8123
/ANGLE,1,3.621
/DIST,,7.735
/FOCUS,,6,6,-3
/DEVICE,VECTOR,OFF
/ANNOT,OFF
/PNUM,TYPE,1
/NUMBER,1
VPLOT
EPLOT
SOLVE
FINISH
/POST1                          ! ENTER GENERAL POSTPROCESSOR
RSYS,11                         ! USE CUSTOM SPHERICAL RESULTS COORDINATE SYSTEM
ESEL,S,TYPE,,2                  ! SELECT SOLID122 ELEMENTS
ESEL,U,MAT,,2                   ! UNSELECT SPHERE
NSLE
/AUTO
PLNSOL,EF,X                     ! PLOT NODAL RESULTS, RADIAL ELECTRIC FIELD
PLNSOL,VOLT                     ! PLOT NODAL RESULTS, VOLTAGE DOF
RSYS,0
CSYS,11
NSEL,S,LOC,X,R1
EMFN
YFORCE=_FYSUM*12                ! MULTIPLY TO ACCOUNT FOR 30 DEGREE SLICE
*STATUS,YFORCE
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '   YFORC'
LABEL(1,2) = 'E  (N)  '
*VFILL,VALUE(1,1),DATA,-1.236E-11
*VFILL,VALUE(1,2),DATA,YFORCE
*VFILL,VALUE(1,3),DATA,ABS(YFORCE/1.236E-11)
SAVE,INF1
FINISH
/CLEAR,NOSTART
```

```
/TITLE,VM51, FORCE BETWEEN CHARGED SPHERES
C*** USING SOLID123
/PREP7
R1 = 1                          ! SPHERE RADIUS
R2 = 3                          ! DISTANCE BETWEEN SPHERES
R3 = 6                          ! RADIUS OF FINITE ELEMENT DOMAIN
R4 = 1.25                       ! MAXWELL SURFACE RADIUS
PER=8.854E-12                   ! FREE SPACE PERMITIVITY
PI=3.14159265359
Q = 4*PI*PER                    ! TOTAL CHARGE
ALPHA = 30                      ! SLICE ANGLE
AREA = 4*PI*(R1**2)             ! TOTAL SPHERE AREA
```

```
CHRGS = Q/AREA                    ! SURFACE CHARGE
/NOPR
PCIRC,,R2,0,90                    ! CIRCLE RADIUS R2, 0 TO 90 DEGREES
PCIRC,,R3,0,90   ! CIRCLE RADIUS R3, 0 TO 90 DEGREES
WPOFFS,,R2/2                      ! WORKING PLANE OFFSET Y = R2/2
PCIRC,,R1,0,90                    ! CIRCLE RADIUS R1, 0 TO 90 DEGREES
PCIRC,,R1,-90,0                   ! CIRCLE RADIUS R1, 0 TO -90 DEGREES
PCIRC,,R4,-90,90                  ! CIRCLE RADIUS R4, -90 TO 90 DEGREES
AOVLAP,ALL
NUMCMP,AREA
ET,1,SOLID123                     ! 3-D 10-NODE TETERAHEDRAL ELECTROSTATIC SOLID
ET,2,MESH200,5                    ! NEW MESH200 2-D 6-NODE ELEMENT TYPE
ET,3,INFIN111,2,1                 ! 3-D INFINITE SOLID ELEMENT
MP,PERX,1,1
MP,PERX,2,1
K,200                             ! CREATE KEYPOINTS FOR ROTATION
K,201,,R3                         ! 3 DIVISIONS IN ROTATE DIRECTION
VROTAT,ALL,,,,,,200,201,ALPHA     ! ROTATE ALL AREAS THROUGH 30 DEGREES
TYPE,1
LSEL,S,LINE,,1,12,11
LESIZE,ALL,,,20
LSEL,S,LINE,,3,26,23
LESIZE,ALL,,,20
LSEL,S,LINE,,14,14
LSEL,A,LINE,,18,19
LESIZE,ALL,,,8
LSEL,S,LINE,,4,11,7
LESIZE,ALL,,,30
ESIZE,.1
MAT,1
VMESH,ALL
VSEL,S,VOLU,,1,2  ! CHANGE SPHERE TO MATERIAL 2
ESLV,S,1
EMODIF,ALL,MAT,2
ALLSEL,ALL

LOCAL,11,2,,R2/2
CSYS,2                            ! SPHERICAL COORDINATE SYSTEM
KSEL,S,LOC,X,R3                   ! KEYPOINT SELECT AT RADIUS R3
LSLK,S,1                          ! LINE SELECT FROM KEYPOINTS
ASLL,S,1                          ! AREA SELECT FROM LINES
TYPE,2                            ! NEW MESH200 ELEMENT TYPE
AMESH,ALL                         ! MESH AREA AT RADIUS R3
ESIZE,,1                          ! ONE DIVISION IN EXTRUDE DIRECTION
TYPE,3                            ! INFIN122 USED FOR EXTRUDE
VEXT,ALL,,,R3                     ! EXTRUDE AREA IN RADIAL DIRECTION
ALLSEL                            ! SELECT ALL ENTITIES

/OUTPUT,SCRATCH
NUMMRG,NODE
NUMMRG,ELEM
NUMMRG,KP
/OUTPUT

CSYS,0
NSEL,S,LOC,Y,0                    ! SELECT SYMMETRY BOUNDARY
D,ALL,VOLT,0                      ! CONSTRAIN BOUNDARY VOLT DOF
CSYS,2                            ! SPHERICAL COORDINATE SYSTEM
NSEL,S,LOC,X,10,12                ! SELECT OUTER NODES OF INFINITE DOMAIN
ESLN,S
SF,ALL,INF                        ! SET INFINITE FLAG
NSEL,ALL
OUTRES,ALL,ALL
FINISH
/SOLU
ALLSEL
VSEL,S,VOLU,,1,2
ESLV,S,1                      ! SELECT SPHERE ELEMENTS
NSLE
CSYS,11                           ! CUSTOM SPHERICAL COORDINATE SYSTEM
NSEL,S,LOC,X,0.98*R1,1.02*R1      ! SELECT NODES ON SPHERE SURFACE
ESLN
```

```
ESEL,U,MAT,,1
SF,ALL,CHRG,CHRGS               ! APPLY SURFACE CHARGE
ALLSEL
/TYPE,,6
/DEVICE,VECTOR,ON
/DIST,,3.661
/FOCUS,,3.08,2.884,-.148327
/COM                       *** THE FOLLOWING ANNOTATION COMMANDS ARE ***
/COM                       *** TYPICALLY GENERATED INTERACTIVELY ***
/AUTO, 1
/ANUM ,0,     1,-0.12607    , 0.38512  ! ANNOTATION NUMBER, TYPE AND HOT SPOT
/TLAB,-0.546, 0.385,Infinite Element Domain
/ANUM ,0,     1, 0.16752    ,-0.72533E-01
/TLAB,-0.217,-0.073,Finite Element Domain
/ANUM ,0,    12, 0.77714E-01,-0.24523
/LINE, 0.259,-0.124,-0.104,-0.366
/LSYM,-0.104,-0.366, 213,   1, 1.000
/ANUM ,0,     1,-0.32640    ,-0.34885
/TLAB,-0.571,-0.349,Sphere Surface
/ANUM ,0,    12,-0.44556    ,-0.45247
/LINE,-0.373,-0.366,-0.518,-0.539
/LSYM,-0.518,-0.539, 229,   1, 1.000
/ANUM ,0,     1,-0.41447E-01,-0.78577
/TSPEC, 15, 1.000,   1,   1,   0
/TLAB,-0.321,-0.791,Maxwell Surface
/ANUM ,0,    12,-0.31258    ,-0.72015
/LINE,-0.235,-0.746,-0.390,-0.694
/LSYM,-0.390,-0.694, 161,   1, 1.000
/ANUM ,0,     1,-0.39893    ,-0.93257
/TSPEC, 15, 1.000,   1,   0,   0
/TLAB,-0.434,-0.933,R3
/ANUM ,0,    12,-0.25214    ,-0.92566
/LINE,-0.373,-0.926,-0.131,-0.926
/LSYM,-0.131,-0.926,   0,   1, 1.000
/ANUM ,0,    12,-0.51118    ,-0.92566
/LINE,-0.442,-0.926,-0.580,-0.926
/LSYM,-0.580,-0.926, 180,   1, 1.000
APLOT
/ANNOT,ON
/USER                                 ! RESET GRAPHICS DISPLAY SETTINGS
/VIEW,1,.5274,.2492,.8123
/ANGLE,1,3.621
/DIST,,7.735
/FOCUS,,6,6,-3
/DEVICE,VECTOR,OFF
/ANNOT,OFF
/PNUM,TYPE,1
/NUMBER,1
VPLOT
EPLOT
SOLVE
FINISH
/POST1                          ! ENTER GENERAL POSTPROCESSOR
RSYS,11                         ! USE CUSTOM SPHERICAL RESULTS COORDINATE SYSTEM
ESEL,S,TYPE,,1                  ! SELECT SOLID123 ELEMENTS
ESEL,U,MAT,,2                   ! UNSELECT SPHERE
NSLE
/AUTO
PLNSOL,EF,X                     ! PLOT NODAL RESULTS, RADIAL ELECTRIC FIELD
PLNSOL,VOLT                     ! PLOT NODAL RESULTS, VOLTAGE DOF
RSYS,0
CSYS,11
NSEL,S,LOC,X,R1
EMFN
YFORCE=_FYSUM*12                 ! MULTIPLY TO ACCOUNT FOR 30 DEGREE SLICE
*STATUS,YFORCE
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '   YFORC'
LABEL(1,2) = 'E  (N)  '
*VFILL,VALUE(1,1),DATA,-1.236E-11
*VFILL,VALUE(1,2),DATA,YFORCE
```

```
*VFILL,VALUE(1,3),DATA,ABS(YFORCE/1.236E-11)
SAVE,INF2

RESUME,INF1
/COM
/OUT,vm51,vrt
/COM,------------------- VM51 RESULTS COMPARISON ---------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,--SOLID122--
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',E11.4,'  ',E15.4,'   ',1F15.3)
/COM,
/NOPR
RESUME,INF2
/COM,--SOLID123--
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',E11.4,'  ',E15.4,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm51,vrt
/DELETE,INF1
/DELETE,INF2
```

VM52 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM52
/PREP7
MP,PRXY,,0.3
/TITLE, VM52, AUTOMOBILE SUSPENSION SYSTEM VIBRATIONS
C***VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 181, EX 6.7-1
ANTYPE,MODAL               ! MODE-FREQUENCY ANALYSIS
MXPAND,2                   ! EXPAND MODES
MODOPT,LANB,2
ET,1,BEAM188               ! BEAM ELEMENT
KEYOPT,1,3,3
ET,2,COMBIN14,,,2          ! SPRING ELEMENT
ET,3,MASS21,,,3            ! MASS ELEMENT
R,1,2400                   ! SPRING STIFFNESS (K1) = 2400
R,2,100,1600               ! MASS = 100 (FROM 3220/32.2), I = 1600
R,3,2600                   ! SPRING STIFFNESS (K2) = 2600
SECT,2,BEAM,RECT           ! BEAM PROPERTIES
SECD,1,1
MP,EX,1,4E9
N,1
N,2,,1
N,3,4.5,1
N,4,10,1
N,5,10
TYPE,2
E,1,2                       ! SPRING ELEMENT
TYPE,1
SECN,2
E,2,3                       ! BEAM ELEMENT
TYPE,3
REAL,2
E,3                         ! MASS ELEMENT
TYPE,1
SECN,2
E,3,4                       ! BEAM ELEMENT
TYPE,2
REAL,3
E,4,5                       ! SPRING ELEMENT
D,1,UX,,,5,4,UY             ! BOUNDARY CONDITIONS
D,3,UX
```

```
NSEL,S,NODE,2,4
D,ALL,UZ,,,,,ROTY,ROTX
NSEL,ALL
OUTPR,NSOL,1
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
/OUT,
*GET,FREQ1,MODE,1,FREQ
*GET,FREQ2,MODE,2,FREQ
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = '    f1, ','    f2, '
LABEL(1,2) = 'Hz      ','Hz      '
*VFILL,VALUE(1,1),DATA,1.0981,1.4406
*VFILL,VALUE(1,2),DATA,FREQ1,FREQ2
*VFILL,VALUE(1,3),DATA,ABS(FREQ1/1.0981 ) ,ABS( FREQ2/1.4406)
/COM
/OUT,vm52,vrt
/COM,------------------- VM52 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm52,vrt
```

VM53 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM53
/PREP7
/TITLE, VM53, VIBRATION OF A STRING UNDER TENSION
C***           VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND. PRINTING,
C***           PAGE 264, ART. 8.2,
ANTYPE,STATIC              ! STATIC ANALYSIS
ET,1,LINK180
KEYOPT,1,3,1         ! TENSION ONLY OPTION
SECTYPE,1,LINK
SECDATA,306796E-8          ! DEFINE AREA
MP,EX,1,30E6
MP,DENS,1,73E-5
N,1                        ! DEFINE NODES
N,14,100
FILL
E,1,2                      ! DEFINE ELEMENTS
EGEN,13,1,1
INIS,SET,CSYS,-2           ! ARBITRARY INITIAL STRAIN
INIS,SET,DTYP,EPEL
INIS,DEFINE,,,,,543248E-8
OUTPR,BASIC,1
D,ALL,ALL                  ! FIX ALL MOTIONS FOR STATIC STRESSES
FINISH
/out,scratch
/SOLU
RESCONTROL,LINEAR,ALL,1     ! NEEDED FOR PERTURBED ANALYSIS
SOLVE
FINISH
/out
/POST1
ETABLE,STRS,LS,1
*GET,STRSS,ELEM,13,ETAB,STRS
FINISH
/POST26
```

```
RFORCE,2,1,F,X
STORE
*GET,FORCE,VARI,2,EXTREM,VMAX
PARSAV,ALL
/out,scratch
/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB   ! RESTART FROM LAST LOAD STEP AND LAST SUB STEP
PERTURB,MODAL,,,PARKEEP           ! PERFORM PERTURBED MODAL SOLVE
SOLVE,ELFORM                      ! REFORM ELEMENT MATRICES

PARRES,CHANGE
MODOPT,LANB,3              ! EXTRACT 3 MODES USING LANB EXTRACTION METHOD
MXPAND,3                   ! EXPAND FIRST THREE MODES
DDELE,2,UX,13              ! RELEASE INTERIOR DOFS
DDELE,2,UY,13
SOLVE
/out
*GET,FREQ1,MODE,1,FREQ
*GET,FREQ2,MODE,2,FREQ
*GET,FREQ3,MODE,3,FREQ
*DIM,LABEL,CHAR,5,2
*DIM,VALUE,,5,3
LABEL(1,1) = '      F,','      SI','      f1','      f2','      f3'
LABEL(1,2) = ' lb     ','GMA,psi ',', Hz    ',', Hz    ',', Hz    '
*VFILL,VALUE(1,1),DATA,500,162974,74.708,149.42,224.12
*VFILL,VALUE(1,2),DATA,ABS(FORCE),STRSS,FREQ1,FREQ2,FREQ3
*VFILL,VALUE(1,3),DATA,ABS(FORCE/500),ABS(STRSS/162974),ABS(FREQ1/74.708)
*VFILL,VALUE(4,3),DATA,ABS(FREQ2/149.42),ABS(FREQ3/224.12)
/COM
/OUT,vm53,vrt
/COM,------------------- VM53 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm53,vrt
```

VM54 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM54
/PREP7
/TITLE, VM54, VIBRATION OF A ROTATING CANTILEVER BLADE
C*** CARNEGIE,W., VIBRATIONS OF ROTATING CANTILEVER BLADING,
C*** JOURNAL OF MECHANICAL ENGINEERING SCIENCE,PG. 239,VOL.1,NO.3,1959.
ET,1,SHELL63,,,,,,,1      ! FOUR NODE SHELL, SUPPRESS STRESS PRINTOUT
R,1,3E-3                  ! THICKNESS OF SHELL
MP,EX,1,217E9             ! MATERIAL, STEEL
MP,NUXY,1,0.3
MP,DENS,1,7850
N,1,-.014,,.150           ! DEFINE NODES
N,9,-.014,,.478
FILL
NGEN,2,9,1,9,1,.028
E,1,2,11,10               ! DEFINE ELEMENTS
EGEN,8,1,-1
FINISH
/SOLU
ANTYPE,STATIC             ! STATIC ANALYSIS, PRESTRESS
PSTRES,ON                 ! PRESTRESS ANALYSIS
D,1,ALL,,,10,9            ! BOUNDARY CONDITIONS AND LOADING
OMEGA,314.159265          ! SPINNING LOAD
OUTPR,,1
/OUT,SCRATCH
```

```
SOLVE
FINISH
/SOLU
ANTYPE,MODAL              ! MODAL ANALYSIS
MODOPT,LANB,5             ! LANB EXTRACTION METHOD, EXTRACT 5 MODES
PSTRES,ON                 ! PRESTRESS ANALYSIS
SOLVE
/OUT,
*GET,FREQ,MODE,1,FREQ
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '     f, '
LABEL(1,2) = 'Hz       '
*VFILL,VALUE(1,1),DATA,52.75
*VFILL,VALUE(1,2),DATA,FREQ
*VFILL,VALUE(1,3),DATA,ABS(FREQ /52.75)
FINISH
SAVE,TABLE_1
/CLEAR, NOSTART

/TITLE, VM54, VIBRATION OF A ROTATING CANTILEVER BLADE
C***          USING SOLSH190 ELEMENTS
/PREP7
SMRT,OFF
ET,1,SOLSH190,,,,,,1    ! ANALYZE AGAIN USING 3-D SOLSH190, SUPPRESS STRESS PRINTOUT
THICK = 3E-3   ! THCIKNESS = 3E-3
R,1,THICK
MP,EX,1,217E9             ! MATERIAL, STEEL
MP,NUXY,1,0.3
MP,DENS,1,7850
N,1,-.014,,.150           ! DEFINE NODES
N,9,-.014,,.478
FILL
NGEN,2,9,1,9,1,.028
NGEN,2,18,1,18,1,,THICK
E,1,2,11,10,19,20,29,28  ! DEFINE ELEMENTS
EGEN,8,1,-1
FINISH
/SOLU
ANTYPE,STATIC             ! STATIC ANALYSIS, PRESTRESS
RESCONTROL,LINEAR,ALL,1  ! NEEDED FOR PERTURBATION ANALYSIS
D,1,ALL,,,10,9            ! BOUNDARY CONDITIONS AND LOADING
D,19,ALL,,,28,9   !
OMEGA,314.159265          ! SPINNING LOAD
OUTPR,,1
/OUT,SCRATCH
SOLVE
FINISH

/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB      ! RESTART FROM LAST LOAD STEP AND SUB STEP
PERTURB,MODAL,,,PARKEEP              ! PERFORM PERTURBED MODAL SOLVE
SOLVE,ELFORM                         ! REGENERATE ELEMENT MATRICES

OUTPR,ALL,NONE
MODOPT,LANB,5
MXPAND,5
SOLVE
/OUT,
*GET,FREQ,MODE,1,FREQ
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '     f, '
LABEL(1,2) = 'Hz       '
*VFILL,VALUE(1,1),DATA,52.75
*VFILL,VALUE(1,2),DATA,FREQ
*VFILL,VALUE(1,3),DATA,ABS(FREQ /52.75)
FINISH
SAVE,TABLE_2
/CLEAR, NOSTART

/TITLE, VM54, VIBRATION OF A ROTATING CANTILEVER BLADE
```

```
C***          USING SHELL181 ELEMENTS
/PREP7
ET,1,SHELL181, , ,2,,,,1 ! SUPPRESS STRESS PRINTOUT
SECT,1,SHELL
SECD,3E-3,1              ! THICKNESS OF SHELL
MP,EX,1,217E9            ! MATERIAL, STEEL
MP,NUXY,1,0.3
MP,DENS,1,7850
CSYS,4
WPRO, ,-90
RECTNG,-0.014,0.014,-0.150,-0.478
LSEL,S,LINE,,1,3,2
LESIZE,ALL, , ,1
LSEL,INVE
LESIZE,ALL, , ,9
LSEL,ALL
AMESH,1
FINISH
/OUT,SCRATCH
/SOLU
ANTYPE,STATIC            ! STATIC ANALYSIS, PRESTRESS
RESCONTROL,LINEAR,ALL,1  ! NEEDED FOR PERTURBATION ANALYSIS
NSEL,S,LOC,Y,-0.150
D,ALL,ALL
NSEL,ALL
OMEGA,314.159265         ! SPINNING LOAD
OUTPR,NSOL,1
OUTPR,RSOL,1
SOLVE
FINISH
/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB     ! RESTART FROM LAST LOAD STEP AND SUB STEP
PERTURB,MODAL,,,PARKEEP             ! PERFORM PERTURBED MODAL SOLVE
SOLVE,ELFORM                        ! REGENERATE ELEMENT MATRICES

OUTPR,ALL,NONE
MODOPT,LANB,5
MXPAND,5
SOLVE
/OUT,
*GET,FREQ,MODE,1,FREQ
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '     f, '
LABEL(1,2) = 'Hz       '
*VFILL,VALUE(1,1),DATA,52.75
*VFILL,VALUE(1,2),DATA,FREQ
*VFILL,VALUE(1,3),DATA,ABS(FREQ /52.75)
FINISH
SAVE,TABLE_3

/CLEAR, NOSTART
/TITLE, VM54, VIBRATION OF A ROTATING CANTILEVER BLADE
C***          USING SHELL281 ELEMENTS
/PREP7
ET,1,SHELL281, , ,,,,,1 ! SUPPRESS STRESS PRINTOUT
SECT,1,SHELL
SECD,3E-3,1              ! THICKNESS OF SHELL
MP,EX,1,217E9            ! MATERIAL, STEEL
MP,NUXY,1,0.3
MP,DENS,1,7850
CSYS,4
WPRO, ,-90
RECTNG,-0.014,0.014,-0.150,-0.478
LSEL,S,LINE,,1,3,2
LESIZE,ALL, , ,1
LSEL,INVE
LESIZE,ALL, , ,9
LSEL,ALL
AMESH,1
FINISH
/SOLU
```

```
ANTYPE,STATIC            ! STATIC ANALYSIS, PRESTRESS
RESCONTROL,LINEAR,ALL,1  ! NEEDED FOR PERTURBATION ANALYSIS
NSEL,S,LOC,Y,-0.150
D,ALL,ALL
NSEL,ALL
OMEGA,314.159265         ! SPINNING LOAD
OUTPR,NSOL,1
OUTPR,RSOL,1
/OUT,SCRATCH
SOLVE
FINISH
/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB     ! RESTART FROM LAST LOAD STEP AND SUB STEP
PERTURB,MODAL,,,PARKEEP             ! PERFORM PERTURBED MODAL SOLVE
SOLVE,ELFORM                        ! REGENERATE ELEMENT MATRICES

OUTPR,ALL,NONE
MODOPT,LANB,5
MXPAND,5
SOLVE
/OUT,
*GET,FREQ,MODE,1,FREQ
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '     f, '
LABEL(1,2) = 'Hz      '
*VFILL,VALUE(1,1),DATA,52.75
*VFILL,VALUE(1,2),DATA,FREQ
*VFILL,VALUE(1,3),DATA,ABS(FREQ /52.75)
FINISH
SAVE,TABLE_4
FINISH
/CLEAR,NOSTART

RESUME,TABLE_1
/COM
/OUT,vm54,vrt
/COM,------------------- VM54 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM, SHELL63
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/COM,
/COM, SOLSH190 USING LINEAR PERTURBATION ANALYSIS
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/COM,
/COM, SHELL181 USING LINEAR PERTURBATION ANALYSIS
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_4
/COM,
/COM, SHELL281 USING LINEAR PERTURBATION ANALYSIS
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm54,vrt
/DELETE,TABLE_1
/DELETE,TABLE_2
```

```
/DELETE,TABLE_3
/DELETE,TABLE_4
```

VM55 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM55
/PREP7
MP,PRXY,,0.3
/TITLE, VM55, VIBRATION OF A STRETCHED CIRCULAR MEMBRANE
C***        VIBRATION PROBS. IN ENGR., TIMOSHENKO, 3RD. ED., PAGE  439, EQN. 182
ANTYPE,STATIC        ! STATIC ANALYSIS
ET,1,SHELL208,,,2
MP,EX,1,30E6
MP,DENS,1,73E-5
SECTYPE,1,SHELL
SECDATA,0.01
SECNUM,1
N,1
N,10,15
FILL
E,1,2
EGEN,9,1,1
D,1,UX,,,,,ROTZ
D,10,UY
F,10,FX,9424.778
FINISH
/SOLU
RESCONTROL,LINEAR,ALL,1     ! NEEDED FOR PERTURBATION ANALYSIS
OUTPR,BASIC,1
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
ETABLE,STRS,S,X
*GET,STRSS,ELEM,9,ETAB,STRS
PARSAV,ALL
FINI
/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB  ! RESTART STATIC SOLVE FROM LAST LOAD STEP AND SUB STEP
PERTURB,MODAL,,,PARKEEP    ! PERFORM PERTURBED MODAL SOLVE
SOLVE,ELFORM     ! REFORM ELEMENT MATRICES

PARRES,CHANGE
MXPAND,3             ! EXPAND FIRST 3 MODES
MODOPT,LANB,9        ! EXTRACT FIRST 9 MODES
/OUT,SCRATCH
SOLVE
/OUT,
*GET,FREQ1,MODE,1,FREQ
*GET,FREQ2,MODE,2,FREQ
*GET,FREQ3,MODE,3,FREQ
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'SIG,R  p','f1,     ','f2,     ','f3,     '
LABEL(1,2) = 'si      ','Hz      ','Hz      ','Hz      '
*VFILL,VALUE(1,1),DATA,10000,94.406,216.77,339.85
*VFILL,VALUE(1,2),DATA,STRSS,FREQ1,FREQ2,FREQ3
*VFILL,VALUE(1,3),DATA,(STRSS/10000),(FREQ1/94.406),(FREQ2/216.77),(FREQ3/339.85)
/COM
/OUT,vm55,vrt
/COM,------------------- VM55 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
```

```
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm55,vrt
```

VM56 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM56
/PREP7
SMRT,OFF
/TITLE, VM56, HYPERELASTIC THICK CYLINDER UNDER INTERNAL PRESSURE
/COM           REF: ODEN, J.T., "FINITE ELEMENTS OF NONLINEAR CONTINUA"
/COM                MCGRAW-HILL, 1972, PP 325-331
ANTYPE,STATIC
NLGEOM,ON                 ! LARGE DEFLECTION
ET,1,PLANE183, , ,1       ! 2-D AXISYM 8-NODE STRUCTURAL SOLID
ET,2,PLANE183, , ,1       ! 2-D AXISYM 8-NODE STRUCTURAL SOLID
NU1  = 0.495
DD1  = 2*(1-2*NU1)/(40+10)
DD2  = 2*(1-2*NU1)/(120+30)
TB,HYPER,1,2,2,MOONEY
TBTEMP,20                 ! MOONEY COEFFICIENTS AT TEMP = 20
TBDATA,1,40,10,DD1
TBTEMP,40
TBDATA,1,120,30,DD2
K,1,7                     ! DEFINE KEYPOINTS
K,3,7,2.5
K,2,18.625
K,4,18.625,2.5
A,1,2,4,3                 ! DEFINE AREA
ESIZE,2.5
AMESH,1                   ! CREATE NODES AND ELEMENTS
TYPE,2
EMODIF,1                  ! PRINT ONLY INNERMOST ELEMENT RESULTS
BFUNIF,TEMP,30            ! UNIFORM TEMPERATURES
D,ALL,UY,0                ! FIX ALL NODES AXIALLY
FINISH
/SOLU
SOLCONTROL,0
/TITLE, PRESSURE = 90 PSI
NEQIT,20                  ! MAXIMUM 20 EQUILIBRIUM ITERATIONS
NSEL,S,LOC,X,7.0,7.0
SF,ALL,PRES,90            ! APPLY INTERNAL PRESSURE OF 90 PSI
NSEL,ALL
SOLVE
/TITLE, PRESSURE = 150 PSI
NSEL,S,LOC,X,7.0
SF,ALL,PRES,150           ! APPLY INTERNAL PRESSURE OF 150 PSI
NSEL,ALL
SOLVE
FINISH
/POST1                    ! POSTPROCESS
SET,2
ETABLE,SX1,S,X
AVPRIN,0,0,
ELM=0
NSEL,S,LOC,X,6.5,8.5
ESLN
ELM=ELNEXT(ELM)
*GET,SIGX,ELEM,ELM,ETABLE,SX1
ELM=0
ESEL,ALL
NSEL,ALL
*GET,DEF,NODE,1,U,X
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'UR(INNER'
```

```
LABEL(1,2) = ' RAD),in'
LABEL(2,1) = 'SIGX: EL'
LABEL(2,2) = ' 1 CENT  '
VALUE(1,1) = 7.180
VALUE(1,2) = DEF
VALUE(1,3) = ABS(DEF/7.180)
VALUE(2,1) = -122.0
VALUE(2,2) = SIGX
VALUE(2,3) = ABS(SIGX/(-122.0))
SAVE,TABLE_1
FINISH
/CLEAR,NOSTART ! CLEAR THE PREVIOUS DATABASE
/PREP7
SMRT,OFF
/TITLE, VM56: HYPERELASTIC THICK CYLINDER UNDER INTERNAL PRESSURE
ANTYPE,STATIC
NLGEOM,ON
ET,1,SOLID185               ! 3-D 8-NODE STRUCTURAL SOLID
KEYOPT,1,2,1     ! REDUCED INTEGRATION
ET,2,SOLID185               ! 3-D 8-NODE STRUCTURAL SOLID
KEYOPT,2,2,1     ! REDUCED INTEGRATION
NU1 = 0.495
DD  = 2*(1-2*NU1)/(80+20)
TB,HYPER,1,1,2,MOONEY
TBDATA,1,80,20,DD
CSYS,1
K,1,7,3.16                 ! DEFINE KEYPOINTS
K,2,7,3.16,.775
K,3,7,-3.16,.775
K,4,7,-3.16
KGEN,2,ALL,,,11.625
V,1,2,3,4,5,6,7,8          ! DEFINE VOLUME
LSEL,S,LINE,,5
LSEL,A,LINE,,7
LSEL,A,LINE,,11
LSEL,A,LINE,,9
LESIZE,ALL,,,5
LSEL,ALL
ESIZE,,1
VMESH,ALL                  ! CREATE NODES AND ELEMENTS
TYPE,2
EMODIF,1
NROTAT,ALL                 ! ROTATE ALL NODES INTO CYLINDRICAL COORDINATES
D,ALL,UZ,0.0               ! CONSTRAIN ALL NODES AXIALLY
D,ALL,UY,0.0               ! CONSTRAIN ALL NODES TANGENTIALLY
FINISH
/SOLU
SOLCONTROL,0
/TITLE, PRESSURE = 90 PSI
NEQIT,30                   ! MAXIMUM 30 EQUILIBRIUM ITERATIONS
NSEL,S,LOC,X,7
SF,ALL,PRES,90             ! INTERNAL PRESSURE OF 90 PSI
NSEL,ALL
SOLVE
/TITLE, PRESSURE = 150 PSI
NSEL,S,LOC,X,7
SF,ALL,PRES,150            ! INTERNAL PRESSURE OF 150 PSI
NSEL,ALL
SOLVE
FINISH
/POST1                     ! POSTPROCESS
SET,2
ETABLE,SX1,S,X
AVPRIN,0,0,
ELM=0
NSEL,S,LOC,X,6.5,8.5
ESLN
ELM=ELNEXT(ELM)
*GET,SIGX,ELEM,ELM,ETABLE,SX1
ELM=0
ESEL,ALL
NSEL,ALL
```

```
*GET,DEF,NODE,1,U,X
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'UR(INNER'
LABEL(1,2) = ' RAD),in'
LABEL(2,1) = 'SIGX: EL'
LABEL(2,2) = ' 1 CENT  '
VALUE(1,1) = 7.180
VALUE(1,2) = DEF
VALUE(1,3) = ABS(DEF/7.180)
VALUE(2,1) = -122.0
VALUE(2,2) = SIGX
VALUE(2,3) = ABS(SIGX/(-122.0))
SAVE,TABLE_2
FINISH
/CLEAR,NOSTART ! CLEAR THE PREVIOUS DATABASE
/PREP7
SMRT,OFF
/TITLE, VM56: HYPERELASTIC THICK CYLINDER UNDER INTERNAL PRESSURE
ANTYPE,STATIC
NLGEOM,ON
ET,1,SOLID186             ! 3-D 20-NODE STRUCTURAL SOLID
KEYOPT,1,2,1    ! REDUCED INTEGRATION
ET,2,SOLID186             ! 3-D 20-NODE STRUCTURAL SOLID
KEYOPT,2,2,1    ! REDUCED INTEGRATION
NU1 = 0.495
DD  = 2*(1-2*NU1)/(80+20)
TB,HYPER,1,1,2,MOONEY
TBDATA,1,80,20,DD
CSYS,1
K,1,7,3.16                ! DEFINE KEYPOINTS
K,2,7,3.16,.775
K,3,7,-3.16,.775
K,4,7,-3.16
KGEN,2,ALL,,,11.625
V,1,2,3,4,5,6,7,8         ! DEFINE VOLUME
LSEL,S,LINE,,5
LSEL,A,LINE,,7
LSEL,A,LINE,,11
LSEL,A,LINE,,9
LESIZE,ALL,,,5
LSEL,ALL
ESIZE,,1
VMESH,ALL                 ! CREATE NODES AND ELEMENTS
TYPE,2
EMODIF,1
NROTAT,ALL                ! ROTATE ALL NODES INTO CYLINDRICAL COORDINATES
D,ALL,UZ,0.0              ! CONSTRAIN ALL NODES AXIALLY
D,ALL,UY,0.0              ! CONSTRAIN ALL NODES TANGENTIALLY
FINISH
/SOLU
SOLCONTROL,0
/TITLE, PRESSURE = 90 PSI
NEQIT,30                  ! MAXIMUM 30 EQUILIBRIUM ITERATIONS
NSEL,S,LOC,X,7
SF,ALL,PRES,90            ! INTERNAL PRESSURE OF 90 PSI
NSEL,ALL
SOLVE
/TITLE, PRESSURE = 150 PSI
NSEL,S,LOC,X,7
SF,ALL,PRES,150           ! INTERNAL PRESSURE OF 150 PSI
NSEL,ALL
SOLVE
FINISH
/POST1                    ! POSTPROCESS
SET,2
*GET,DEF,NODE,1,U,X
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'UR(INNER'
LABEL(1,2) = ' RAD),in'
VALUE(1,1) = 7.180
```

```
VALUE(1,2) = DEF
VALUE(1,3) = ABS(DEF/7.180)
SAVE,TABLE_3
RESUME,TABLE_1
/COM
/OUT,vm56,vrt
/COM,------------------- VM56 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL    |   RATIO
/COM,
/COM,RESULTS USING PLANE183:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING SOLID185:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM,RESULTS USING SOLID186:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,-----------------------------------------------------------
/COM,
/OUT
FINISH
*LIST,vm56,vrt

/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
FINISH
```

VM57 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM57
/PREP7
/TITLE, VM57, TORSIONAL FREQUENCIES OF A DRILL PIPE
C*** VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND. PRINTING, PAGE 272, EX. 8.4-5
C*** USING PIPE16 ELEMENTS
/PREP7
ET,1,PIPE16
ET,2,MASS21
R,1,(4.5/12),(.335/12)     ! GEOMETRIC PROPERTIES FOR PIPE ELEMENTS
R,2,,,,,,29.3      ! GEOMETRIC PROPERTY FOR MASS ELEMENT
MP,EX,1,4.4928E9
MP,DENS,1,15.2174
MP,NUXY,1,.3
N,1
N,13,,,-5000
FILL
E,1,2
EGEN,12,1,1       ! PIPE ELEMENTS
TYPE,2
REAL,2
E,13        ! MASS ELEMENT
FINISH
/SOLU
ANTYPE,MODAL      ! MODE-FREQUENCY ANALYSIS
MODOPT,LANB,2      ! EXTRACT FIRST TWO MODES
D,1,UX,,,13,,UY,UZ,ROTX,ROTY
D,1,ROTZ
```

```
OUTPR,,1
MXPAND,2,
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
*GET,FREQ1,MODE,1,FREQ
*GET,FREQ2,MODE,2,FREQ
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = '      f1','      f2'
LABEL(1,2) = ', Hz    ',', Hz    '
*VFILL,VALUE(1,1),DATA,.3833,1.260
*VFILL,VALUE(1,2),DATA,FREQ1,FREQ2
*VFILL,VALUE(1,3),DATA,ABS(FREQ1/.3833),ABS(FREQ2/1.260)
SAVE,TABLE_1
FINISH
/CLEAR,NOSTART
C*** USING PIPE288 ELEMENTS
/PREP7
ET,1,PIPE288,,,2,2
ET,2,MASS21
R,2,,,,,,29.3      ! GEOMETRIC PROPERTY FOR MASS ELEMENT
MP,EX,1,4.4928E9
MP,DENS,1,15.2174
MP,NUXY,1,.3
SECTYPE,1,PIPE
SECDATA,(4.5/12),(0.335/12)    ! DIAMETER = 4.5/12, WALL THICKNESS = 0.335/12
N,1
N,13,,,-5000
FILL
E,1,2
EGEN,12,1,1       ! PIPE ELEMENTS
TYPE,2
REAL,2
E,13        ! MASS ELEMENT
FINISH
/SOLU
ANTYPE,MODAL      ! MODE-FREQUENCY ANALYSIS
MODOPT,LANB,2      ! EXTRACT FIRST TWO MODES
D,1,UX,,,13,,UY,UZ,ROTX,ROTY
D,1,ROTZ
OUTPR,,1
MXPAND,2
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
*GET,FREQ1,MODE,1,FREQ
*GET,FREQ2,MODE,2,FREQ
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = '      f1','      f2'
LABEL(1,2) = ', Hz    ',', Hz    '
*VFILL,VALUE(1,1),DATA,.3833,1.260
*VFILL,VALUE(1,2),DATA,FREQ1,FREQ2
*VFILL,VALUE(1,3),DATA,ABS(FREQ1/.3833),ABS(FREQ2/1.260)
SAVE,TABLE_2
FINISH
/CLEAR,NOSTART
C*** USING PIPE289 ELEMENTS
/PREP7
ET,1,PIPE289,,,,2
ET,2,MASS21
R,2,,,,,,29.3      ! GEOMETRIC PROPERTY FOR MASS ELEMENT
MP,EX,1,4.4928E9
MP,DENS,1,15.2174
MP,NUXY,1,.3
SECTYPE,1,PIPE
SECDATA,(4.5/12),(0.335/12)    ! DIAMETER = 4.5/12, WALL THICKNESS = 0.335/12
```

```
K,1,
K,2,,,-5000
L,1,2
LESIZE,1,,,11
TYPE,1
LMESH,1       ! PIPE ELEMENTS
ALLSEL,ALL
TYPE,2
REAL,2
E,2        ! MASS ELEMENT
FINISH
/SOLU
ANTYPE,MODAL      ! MODE-FREQUENCY ANALYSIS
MODOPT,LANB,2      ! EXTRACT FIRST TWO MODES
D,ALL,ALL,0
DDELE,ALL,ROTZ
D,1,ROTZ
OUTPR,,1
MXPAND,2
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
*GET,FREQ1,MODE,1,FREQ
*GET,FREQ2,MODE,2,FREQ
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = '      f1','      f2'
LABEL(1,2) = ', Hz    ',', Hz    '
*VFILL,VALUE(1,1),DATA,.3833,1.260
*VFILL,VALUE(1,2),DATA,FREQ1,FREQ2
*VFILL,VALUE(1,3),DATA,ABS(FREQ1/.3833),ABS(FREQ2/1.260)
SAVE,TABLE_3
FINISH
/CLEAR,NOSTART
C**** USING BEAM188 ELEMENTS
/PREP7
ET,1,BEAM188,,,2
ET,2,MASS21
R,2,,,,,,29.3      ! GEOMETRIC PROPERTY FOR MASS ELEMENT
SECTYPE,1,BEAM,CTUBE     ! HOLLOW CYLINDER BEAM
SECDATA,3.83/24,4.5/24     ! OD = (4.5/2)/12, ID = (3.83/2)/12
MP,EX,1,4.4928E9
MP,DENS,1,15.2174
MP,NUXY,1,.3
N,1
N,13,,,-5000
FILL
E,1,2
EGEN,12,1,1       ! BEAM ELEMENTS
TYPE,2
REAL,2
E,13        ! MASS ELEMENT
FINISH
/SOLU
ANTYPE,MODAL      ! MODE-FREQUENCY ANALYSIS
MODOPT,LANB,2      ! EXTRACT FIRST TWO MODES
D,1,UX,,,13,,UY,UZ,ROTX,ROTY
D,1,ROTZ
OUTPR,,1
MXPAND,2
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
*GET,FREQ1,MODE,1,FREQ
*GET,FREQ2,MODE,2,FREQ
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = '      f1','      f2'
```

```
LABEL(1,2) = ', Hz    ',', Hz    '
*VFILL,VALUE(1,1),DATA,.3833,1.26
*VFILL,VALUE(1,2),DATA,FREQ1,FREQ2
*VFILL,VALUE(1,3),DATA,ABS(FREQ1/.3833),ABS(FREQ2/1.26)
SAVE,TABLE_4
FINISH
/CLEAR,NOSTART
C**** USING BEAM189 ELEMENTS
/PREP7
ET,1,BEAM189
ET,2,MASS21
R,2,,,,,,29.3               ! GEOMETRIC PROPERTY FOR MASS ELEMENT
SECTYPE,1,BEAM,CTUBE     ! HOLLOW CYLINDER BEAM
SECDATA,3.83/24,4.5/24     ! OD = (4.5/2)/12, ID = (3.83/2)/12
MP,EX,1,4.4928E9
MP,DENS,1,15.2174
MP,NUXY,1,.3
K,1,0,0,0
K,2,0,0,-5000
L,1,2
LESIZE,1,,,11
TYPE,1
LMESH,1       ! BEAM ELEMENTS
ALLSEL,ALL
TYPE,2
REAL,2
E,2        ! MASS ELEMENT
FINI
/SOLU
ANTYPE,MODAL
MODOPT,LANB,2
MXPAND,2
D,ALL,ALL,0
DDELE,ALL,ROTZ
D,1,ROTZ,0
OUTPR,,1
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
*GET,FREQ1,MODE,1,FREQ
*GET,FREQ2,MODE,2,FREQ
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = '      f1','      f2'
LABEL(1,2) = ', Hz    ',', Hz    '
*VFILL,VALUE(1,1),DATA,.3833,1.26
*VFILL,VALUE(1,2),DATA,FREQ1,FREQ2
*VFILL,VALUE(1,3),DATA,ABS(FREQ1/.3833),ABS(FREQ2/1.26)
SAVE,TABLE_5
FINISH
/CLEAR,NOSTART
RESUME,TABLE_1
/COM
/OUT,vm57,vrt
/COM,------------------- VM57 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS USING PIPE16 ELEMENTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING PIPE288 ELEMENTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
```

```
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM,RESULTS USING PIPE289 ELEMENTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_4
/GOPR
/COM,
/COM,RESULTS USING BEAM188 ELEMENTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_5
/GOPR
/COM,
/COM,RESULTS USING BEAM189 ELEMENTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm57,vrt
```

VM58 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM58
/PREP7
SMRT,OFF
/TITLE, VM58, CENTERLINE TEMP. OF A HEAT GENERATING WIRE
C*** HEAT, MASS AND MOMENTUM TRANS., ROHSENOW AND CHOI, 2ND. PR., P. 106,EX 6.5
ANTYPE,STATIC
ET,1,PLANE35              ! 2-D 6 NODE TRIANGULAR THERMAL SOLID
ET,2,SURF151              ! 2-D THERMAL SURFACE EFFECT ELEMENT
KEYOPT,2,8,2
MP,KXX,1,13
CSYS,1
K,1                       ! DEFINE MODEL
K,2,.03125,-15
K,3,.03125,15
L,2,3
CSYS
A,1,2,3
ESIZE,,4
AMESH,1
CSYS,1
NSEL,S,LOC,X,.03125
CP,1,TEMP,ALL             ! COUPLE NODAL TEMPERATURES ON EXTERIOR
TYPE,2                    ! SELECT SURF151 TYPE
ESURF                     ! GENERATE SURF151 ELEMENTS ON OUTER RADIUS
NSEL,ALL
ESEL,S,TYPE,,2
SFE,ALL,,CONV,,5
SFE,ALL,,CONV,2,70
ESEL,ALL
BFA,1,HGEN,111311.7    ! HEAT GENERATION
FINISH
/SOLU
SOLVE
FINISH
/POST1
NSEL,S,LOC,X
```

```
PRNSOL,TEMP
NSEL,S,LOC,X,.03125
PRNSOL,TEMP
ESLN,S,1                  ! SELECT SURFACE ELEMENTS ON OUTER RADIUS
ETABLE,Q1,SMISC,2         ! HEAT RATE OVER EACH SURFACE ELEMENT
SSUM
*GET,HFLW,SSUM,,ITEM,Q1
HFLW=HFLW*12              ! CALCULATE TOTAL HEAT DISSIPATION RATE
*status,parm
ALLSEL
*GET,T_AT_CL,NODE,1,TEMP
*GET,T_AT_S,NODE,2,TEMP
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'T CL,    ','T S,     ','Q, (BTU/'
LABEL(1,2) = '(F)      ','(F)      ','HR)     '
*VFILL,VALUE(1,1),DATA,419.9,417.9,341.5
*VFILL,VALUE(1,2),DATA,T_AT_CL,T_AT_S,HFLW
*VFILL,VALUE(1,3),DATA,ABS(T_AT_CL/419.9),ABS(T_AT_S/417.9),ABS(HFLW/341.5)
/COM
/OUT,vm58,vrt
/COM,------------------- VM58 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm58,vrt
```

VM59 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM59
/PREP7
MP,PRXY,,0.3
/TITLE, VM59, LATERAL VIBRATION OF AN AXIALLY LOADED BAR
C***          VIBRATION PROBS. IN ENGR., TIMOSHENKO, 3RD. ED., PAGE 374, ART. 59
ANTYPE,STATIC                ! STATIC ANALYSIS
RESCONTROL,LINEAR,ALL,1      ! NEEDED FOR PERTURBATION ANALYSIS
ET,1,BEAM188,,,3
SECT,1,BEAM,RECT
SECD,2,2
MP,EX,1,30E6
MP,DENS,1,727973E-9
N,1
N,14,80
FILL
E,1,2
EGEN,13,1,1
D,1,UY,,,14,,ROTX,ROTZ       ! B.C.'S AND LOADING
D,1,UX,,,,,UZ
D,14,UZ
F,14,FX,-40E3
FINISH
/out,scratch
/SOLU
OUTPR,BASIC,1
SOLVE
FINISH
/out
/POST1
ETABLE,STRS,LS,1
*GET,STRSS,ELEM,13,ETAB,STRS
*GET,DEF,NODE,14,U,X
PARSAV,ALL
```

```
FINISH
/out,scratch
/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB ! RESTART STATIC SOLVE FROM LAST LOAD STEP AND SUB STEP
PERTURB,MODAL,,,PARKEEP    ! PERFORM PERTURBED MODAL SOLVE
SOLVE,ELFORM     ! REFORM ELEMENT MATRICES

PARRES,CHANGE
MXPAND,3                     ! EXPAND FIRST 3 MODES
MODOPT,LANB,3                ! SELECT THE BLOCK LANCZOS EIGENSOLVER
SOLVE
/out
*GET,FREQ1,MODE,1,FREQ
*GET,FREQ2,MODE,2,FREQ
*GET,FREQ3,MODE,3,FREQ

*DIM,LABEL,CHAR,5,2
*DIM,VALUE,,5,3
LABEL(1,1) = 'DEFLECTI','SIGMA,  ','f1,      ','f2,      ','f3,      '
LABEL(1,2) = 'ON, (in)','   (psi)','    (Hz)','    (Hz)','    (Hz)'
*VFILL,VALUE(1,1),DATA,-.026667,-10000,17.055,105.32,249.39
*VFILL,VALUE(1,2),DATA,DEF,STRSS,FREQ1,FREQ2,FREQ3
*VFILL,VALUE(1,3),DATA,ABS(DEF/.026667),ABS(STRSS/10000),ABS(FREQ1/17.055)
*VFILL,VALUE(4,3),DATA,ABS(FREQ2/105.32),ABS(FREQ3/249.39)
/COM
/OUT,vm59,vrt
/COM,------------------- VM59 RESULTS COMPARISON ---------------
/COM,
/COM,                      |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F14.6,'  ',F18.6,'   ',1F15.3)
/COM,----------------------------------------------------------
/COM,
/COM,----------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM59  NOT CONTAINED IN
/COM,THIS TABLE
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm59,vrt
```

VM60 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM60
/PREP7
SMRT,OFF
/TITLE,VM60: NATURAL FREQUENCY OF A CROSS-PLY LAMINATED SPHERICAL SHELL
C*** THEORETICAL SOLUTION IS FROM J.N. REDDY
C*** ASCE JOURNAL OF ENGINEERING MECHANICS VOL 110 #5  MAY,1984 PP794-809
C*** USING SHELL281
/PREP7
SMRT,OFF
ET,1,SHELL281
KEYOPT,1,8,1              ! WRITE LAYER RESULTS
SECTYPE,1,SHELL
SECDATA,0.5,1,0           ! LAYER 1: 0.5 THK, THETA 0
SECDATA,0.5,1,90          ! LAYER 2: 0.5 THK, THETA 90
MP,EX,1,25E6
MP,EY,1,1E6
MP,EZ,1,25E6
MP,NUXY,1,.01
MP,NUYZ,1,.01
MP,NUXZ,1,.01
MP,GXY,1,.5E6
MP,GYZ,1,.2E6
MP,GXZ,1,.5E6
```

```
MP,DENS,1,1
CSYS,2                     ! SPHERICAL COORDINATES
K,1,300
K,2,300,19.0986
K,3,300,19.0986,19.0986
K,4,300,,19.0986
ESIZE,,4
A,1,2,3,4
AMESH,ALL
NROTAT,ALL
FINISH
/out,scratch
/SOLU
ANTYPE,MODAL
MODOPT,LANB,5              ! EXTRACT 1ST 5 MODES
NSEL,R,LOC,Y,0
NSEL,A,LOC,Y,19,20
D,ALL,UX,,,,,ROTX,UZ,ROTY
NSEL,S,LOC,Z,0
NSEL,A,LOC,Z,19,20
D,ALL,UX,,,,,ROTX,UY,ROTZ
NSEL,ALL
SOLVE
/out
*GET,FREQ,MODE,1,FREQ
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '      f,'
LABEL(1,2) = ' (Hz)    '
*VFILL,VALUE(1,1),DATA,.73215
*VFILL,VALUE(1,2),DATA,FREQ
*VFILL,VALUE(1,3),DATA,ABS(FREQ/.73215)
SAVE,TABLE_1
FINISH
RESUME,TABLE_1
/COM
/OUT,vm60,vrt
/COM,------------------- VM60 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,SHELL281
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm60,vrt
/DELETE,TABLE_1
```

VM61 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM61
/PREP7
MP,PRXY,,0.3
/TITLE, VM61, LONGITUDINAL VIBRATION OF A FREE-FREE ROD
C***VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 269, EX 8.3-1
ANTYPE,MODAL                     ! MODE-FREQUENCY ANALYSIS
ET,1,BEAM188
SECT,1,BEAM,ASEC
SECD,1,1,,1,,1
MODOPT,LANB,3                    ! SELECT THE BLOCK LANCZOS EIGENSOLVER
MP,EX,1,3E7
MP,DENS,1,73E-5
K,1
K,2,800
```

```
L,1,2
ESIZE,,11
LMESH,1
OUTPR,BASIC,1
D,ALL,UY,,,,,ROTZ,UZ,ROTY,ROTX   ! ALLOW UX DOF'S ONLY
FINISH
/out,scratch
/SOLU
SOLVE
FINISH
/out
/SOLU
*GET,FREQ1,MODE,1,FREQ
*GET,FREQ2,MODE,2,FREQ
*GET,FREQ3,MODE,3,FREQ
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = '      f1','      f2','      f3'
LABEL(1,2) = ',  (Hz) ',',  (Hz) ',',  (Hz) '
*VFILL,VALUE(1,1),DATA,0,126.70,253.40
*VFILL,VALUE(1,2),DATA,FREQ1,FREQ2,FREQ3
*VFILL,VALUE(1,3),DATA,0,ABS(FREQ2/126.70 ),ABS(FREQ3/253.40 )
/COM
/OUT,vm61,vrt
/COM,------------------- VM61 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL    |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,-----------------------------------------------------------

/OUT
FINISH
*LIST,vm61,vrt
```

VM62 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM62
/PREP7
SMRT,OFF
/TITLE, VM62, VIBRATION OF A WEDGE
C***          VIBRATION PROBS. IN ENGR., TIMOSHENKO, 3RD. ED., PAGE 392, ART. 62
C***          USING SHELL63 ELEMENTS WITH BENDING STIFFNESS OPTION
ANTYPE,MODAL                      ! MODE-FREQUENCY ANALYSIS
MXPAND,2                          ! EXPAND MODES
MODOPT,LANB,2,,,
ET,1,SHELL63,2                    ! SHELL63 WITH BENDING STIFFNESS OPTION
R,1,1                             ! UNIT THICKNESS
MP,EX,1,30E6
MP,DENS,1,.000728
MP,NUXY,1,0                       ! POISSON'S RATIO IS ZERO
K,1                               ! DEFINE MODEL GEOMETRY
K,2,16
K,3,16,2
L,2,3
LESIZE,1,,,1
A,1,2,3,3
ARSYM,Y,1                         ! SYMMETRY REFLECTION OF AREAS
NUMMRG,KPOI                       ! MERGE COINCIDENT KEYPOINTS
ESIZE,,4
AMESH,1,2
NSEL,S,LOC,X,16
D,ALL,UZ,,,,,ROTX,ROTY,UX,UY     ! CONSTRAIN DISPLACEMENTS AT BASE
NSEL,ALL
OUTPR,ALL,1
OUTRES,ALL,0
```

```
FINISH
/out,scratch
/SOLU
SOLVE
/out
*GET,FREQ1,MODE,1,FREQ
FINISH
/PREP7
SMRT,OFF
C***      USING SHELL63 ELEMENTS WITH SHELL OPTION
ET,1,SHELL63                         ! USE BENDING AND MEMBRANE STIFFNESS
FINISH
/out,scratch
/SOLU
SOLVE
/out
*GET,FREQ2,MODE,1,FREQ
FINISH
PARSAV
/CLEAR,NOSTART
PARRES,CHANGE
/PREP7
SMRT,OFF
C***      USING SHELL181 ELEMENTS WITH SHELL OPTION
ANTYPE,MODAL                    ! MODE-FREQUENCY ANALYSIS
MXPAND,2                        ! EXPAND MODES
MODOPT,LANB,2,,,
ET,1,SHELL181                   ! SHELL181
KEYOPT,1,3,2
SECTYPE,1,SHELL
SECDATA,1,1,0,3
MP,EX,1,30E6
MP,DENS,1,.000728
MP,NUXY,1,0                     ! POISSON'S RATIO IS ZERO
K,1                             ! DEFINE MODEL GEOMETRY
K,2,16
K,3,16,2
L,2,3
LESIZE,1,,,1
A,1,2,3,3
ARSYM,Y,1                       ! SYMMETRY REFLECTION OF AREAS
NUMMRG,KPOI                     ! MERGE COINCIDENT KEYPOINTS
ESIZE,,4
AMESH,1,2
NSEL,S,LOC,X,16
D,ALL,UZ,,,,,ROTX,ROTY,UX,UY    ! CONSTRAIN DISPLACEMENTS AT BASE
NSEL,ALL
OUTPR,ALL,1
OUTRES,ALL,0
FINISH
/out,scratch
/SOLU
SOLVE
/out
*GET,FREQ3,MODE,1,FREQ
FINISH
PARSAV
/CLEAR, NOSTART                ! CLEAR DATABASE FOR SECOND SOLUTION
PARRES,CHANGE
/TITLE, VM62, VIBRATION OF A FLAT PLATE
C***      USING SHELL281 ELEMENTS WITH SHELL OPTION
/PREP7
SMRT,OFF
ANTYPE,MODAL                    ! MODE-FREQUENCY ANALYSIS
MXPAND,2                        ! EXPAND MODES
MODOPT,LANB,2,,,
ET,1,SHELL281                   ! SHELL281 WITH SHELL OPTION
SECT,1,SHELL
SECD,1,1                        ! UNIT THICKNESS
MP,EX,1,30E6
MP,DENS,1,.000728
MP,NUXY,1,0                     ! POISSON'S RATIO IS ZERO
```

```
K,1                             ! DEFINE MODEL GEOMETRY
K,2,16
K,3,16,2
L,2,3
LESIZE,1,,,1
A,1,2,3,3
ARSYM,Y,1                       ! SYMMETRY REFLECTION OF AREAS
NUMMRG,KPOI                     ! MERGE COINCIDENT KEYPOINTS
ESIZE,,4
AMESH,1,2
NSEL,S,LOC,X,16
D,ALL,UZ,,,,,ROTX,ROTY,UX,UY    ! CONSTRAIN DISPLACEMENTS AT BASE
NSEL,ALL
OUTPR,ALL,1
OUTRES,ALL,0
FINISH
/out,scratch
/SOLU
SOLVE
/out
*GET,FREQ4,MODE,1,FREQ
FINISH
*DIM,LABEL,CHAR,1,2
*DIM,VALUE_1,,1,3
*DIM,VALUE_2,,1,3
*DIM,VALUE_3,,1,3
*DIM,VALUE_4,,1,3
LABEL(1,1) = '      f,'
LABEL(1,2) = ' Hz      '
*VFILL,VALUE_1(1,1),DATA,259.16
*VFILL,VALUE_1(1,2),DATA,FREQ1
*VFILL,VALUE_1(1,3),DATA,ABS(FREQ1/259.16 )
*VFILL,VALUE_2(1,1),DATA,259.16
*VFILL,VALUE_2(1,2),DATA,FREQ2
*VFILL,VALUE_2(1,3),DATA,ABS(FREQ2/259.16 )
*VFILL,VALUE_3(1,1),DATA,259.16
*VFILL,VALUE_3(1,2),DATA,FREQ3
*VFILL,VALUE_3(1,3),DATA,ABS(FREQ3/259.16 )
*VFILL,VALUE_4(1,1),DATA,259.16
*VFILL,VALUE_4(1,2),DATA,FREQ4
*VFILL,VALUE_4(1,3),DATA,ABS(FREQ4/259.16 )
/COM
/OUT,vm62,vrt
/COM,------------------- VM62 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS USING PLATE ELEMENTS:SHELL63
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_1(1,1),VALUE_1(1,2),VALUE_1(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,
/COM,RESULTS USING SHELL ELEMENTS:SHELL63
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_2(1,1),VALUE_2(1,2),VALUE_2(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,
/COM,RESULTS USING SHELL ELEMENTS:SHELL181
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_3(1,1),VALUE_3(1,2),VALUE_3(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,
/COM,RESULTS USING SHELL ELEMENTS:SHELL281
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE_4(1,1),VALUE_4(1,2),VALUE_4(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm62,vrt
```

VM63 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM63
/PREP7
SMRT,OFF
/TITLE, VM63, STATIC HERTZ CONTACT PROBLEM SOLVED USING CONTAC178 ELEMENTS
/COM  REF:  TIMOSHENKO AND GOODIER, THEORY OF ELASTICITY, 3RD ED., ART. 140.
ET,1,PLANE82,,,1        ! AXISYMMETRIC ELEMENTS
ET,2,PLANE183,,,1
ET,3,CONTA178,,4        ! NODAL CONTACT
R,1
RMOD,1,7,1              !CONTACT NORMAL ALONG UY
MP,EX,1,1E3
MP,NUXY,1,.3
LOCAL,11,1,0,8,0        ! LOCAL CYLINDRICAL C.S. AT CENTERLINE
K,1,8,-90               ! DEFINE KEYPOINTS
K,2,8
K,3,7.5,-90
K,4,7.5
K,5
K,6,8,-82.65            ! PLACE KEYPOINT AND NODE AT EXPECTED CONTACT RADIUS
K,7,7.5,-82.65
L,1,3                   ! DEFINE LINES
L,2,4
L,6,7
LESIZE,ALL,,,1          ! DEFINE ELEMENT DIVISIONS ON ALL EXISTING LINES
A,1,6,7,3               ! DEFINE AREAS
A,6,2,4,7
A,3,7,4,5
LOCAL,12,0,0,8,0
ARSYM,Y,1,3,1           ! CREATE HALF-SYMMETRY MODEL
NUMMRG,KPOI
ESIZE,,4                ! DEFINE ELEMENT DIVISIONS ON REMAINING LINES
LESIZE,4,,,5
*REPEAT,2,1
LESIZE,6,,,8,8
LESIZE,7,,,8,(1/8)
LESIZE,10,,,1
*REPEAT,2,2
LESIZE,9,,,6,.2
TYPE,1                  ! CREATE NODES AND ELEMENTS
AMESH,1,2,1
AMESH,4,5,1
TYPE,2
MSHAPE,1,2D
MSHKEY,0
AMESH,3,6,3
CSYS,0
N,1001,-1,1E-8          !NODE 1001 IS THE GROUND
D,1001,ALL              !X POSITION DOES NOT MATTER IN THIS CASE BECAUSE
                        !THE CONTACT NORMAL IS ONLY ALONG UY
TYPE,3
REAL,1
EN,205,1001,2           !USE THE SAME ELEMENT NUMBERS AS VM63 FOR POST-PROC
EN,201,1001,4
EN,202,1001,6
EN,203,1001,8
EN,204,1001,10
EN,206,1001,31

MODMSH,NOCHECK
TYPE,1                  ! REMOVE MIDSIDE NODES ALONG CONTACT SURFACE
EMODIF,7,7,0
*REPEAT,6,1
MODMSH,CHECK
FINISH
/SOLU
NSEL,S,LOC,X,-.01,.01   ! BOUNDARY CONDITIONS AND LOADING
```

```
D,ALL,UX,0
NSEL,R,LOC,Y,0
D,ALL,UY,0
NSEL,ALL
LOAD=0
*CREATE,LOADSTEP        ! MACRO TO INCREMENTALLY APPLY LOAD
FK,8,FY,ARG1
SOLVE
*END
*DO,I,1,3
 LOAD=LOAD-10
 *USE,LOADSTEP,LOAD*6.2831853
*ENDDO
FINISH
/POST1                  ! POSTPROCESS
/OUT,
SET,3
ESEL,,TYPE,,3
ETABLE,RFOR,SMISC,1
NSLE
PRETAB,RFOR             ! PRINT REACTION FORCE TO DETERMINE CONTACT AREA
SSUM                    ! SUM OF REACTION FORCE
NLIST                   ! LIST COORDINATES OF NODES OF CONTACT SURFACE
PRNSOL,U,COMP           ! LIST DISPLACEMENTS OF NODES
/COM    CALCULATE RATIO OF A - ACTUAL TO A - TARGET
PI=(4*ATAN(1))
LOAD=-(LOAD)*(2*PI)
ATAR=(0.88*((LOAD*0.008)**(1/3)))   ! A - TARGET
*GET,EMAX,ELEM,,NUM,MAX
*DO,ENUM,201,EMAX                   ! START SEARCH FROM ELEM 201
 *GET,GRFR,ELEM,ENUM,ETAB,RFOR      ! FIND LAST ELEMENT IN CONTACT
 *IF,GRFR,EQ,0.0,EXIT
*ENDDO
ESEL,,ELEM,,(ENUM-1)    ! SELECT LAST CONTACTING ELEMENT
NSLE                    ! SELECT NODES ATTACHED TO SELECTED ELEMENTS
*GET,NMIN,NODE,0,NUM,MIN
NODX=NX(NMIN)
NODY=NY(NMIN)
NUX =UX(NMIN)
NUY =UY(NMIN)
AACT=NODX+NUX           ! A - ACTUAL
YCHK=NODY+NUY
RATA=(AACT/ATAR)        ! RATIO
*status,parm
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '      A,'
LABEL(1,2) = ' mm      '
*VFILL,VALUE(1,1),DATA,1.010
*VFILL,VALUE(1,2),DATA,AACT
*VFILL,VALUE(1,3),DATA,ABS(AACT/1.010)
/COM
/OUT,vm63,vrt,,append
/COM,------------------------------------------------------------------------
/COM,----------VM63 RESULTS COMPARISON (OBTAINED USING CONTACT178 ELEMENTS)-----
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,------------------------------------------------------------------------
/OUT
FINISH
*LIST,vm63,vrt
```

VM64 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
```

```
/VERIFY,VM64
/PREP7
/TITLE, VM64, THERMAL EXPANSION TO CLOSE A GAP AT A RIGID SURFACE
C***          INTRO. TO STRESS ANALYSIS, HARRIS, 1ST PRINTING, PAGE 58, PROB. 8
C***          USING CONTAC26 AND PLANE182 ELEMENTS
ANTYPE,STATIC                ! STATIC ANALYSIS
ET,1,CONTA175                ! CONTACT ELEMENT
R,1                          ! USE DEFAULTS
KEYOPT,1,12,4                ! NO SEPARATION
ET,2,PLANE182,2,,3
R,2,1                        ! THICKNESS = 1
ET,3,TARGE169                ! TARGET SURFACE
MP,EX,1,10.5E6
MP,ALPX,1,12.5E-6
MP,NUXY,1,0
N,1,2,1
N,2,3,1
N,3,3,4
N,4,2,4
N,11,1,0.998
N,12,4,0.998
TYPE,1
REAL,1
E,1                          ! CONTACT ELEMENTS
E,2
TYPE,3
REAL,1
TSHAP,LINE
E,11,12                      ! TARGET ELEMENT
TYPE,2
REAL,2
E,1,2,3,4                    ! BAR
TREF,70
BFUNIF,TEMP,170
D,3,ALL,,,4
D,1,UX,,,2,1
OUTPR,BASIC,LAST
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
ETABLE,STRSX,S,X
ETABLE,STRSY,S,Y
*GET,STRSSX,ELEM,4,ETAB,STRSX
*GET,STRSSY,ELEM,4,ETAB,STRSY
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'SIGX, (p','SIGY, (p'
LABEL(1,2) = 'si)     ','si)     '
*VFILL,VALUE(1,1),DATA,-13125,-6125
*VFILL,VALUE(1,2),DATA,STRSSX,STRSSY
*VFILL,VALUE(1,3),DATA,ABS(STRSSX/13125) ,ABS(STRSSY/6125)
/COM
/OUT,vm64,vrt
/COM,------------------- VM64 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,-------------------------------------------------------
/OUT
FINISH
*LIST,vm64,vrt
```

VM65 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM65
/PREP7
/TITLE, VM65, TRANSIENT RESPONSE OF A BALL IMPACTING A FLEXIBLE SURFACE
C***        VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND. PRINTING, PAGE 110,
C***        EX. 4.6-1, USING NON-LINEAR TRANSIENT DYNAMIC ANALYSIS
C***
/PREP7
ANTYPE,TRANS            ! NONLINEAR TRANSIENT DYNAMIC ANALYSIS
ET,1,MASS21, , ,4       ! 2-D MASS WITHOUT ROTARY INERTIA
ET,2,CONTA175,,1        ! 2-D NODE-TO-SURFACE CONTACT ELEMENT
ET,3,TARGE169           ! 2-D TARGET SEGMENT
R,1,.5                  ! MASS
R,2,,,-1973.92088       ! CONTACT SURFACE WITH STIFFNESS = 1973.92088
RMOD,2,6,-1.2           ! PIN BALL REGION
N,1,0,1
TYPE,1
REAL,1
E,1                     ! MASS ELEMENT
TYPE,2
REAL,2
E,1                     ! CONTACT ELEMENT
N,2,-1
N,3,1
TYPE,3
REAL,2
TSHAP,LINE
E,3,2                   ! TARGET ELEMENT
ALLSEL,ALL
FINISH
/SOLU
SOLCONTROL,0
NSUBST,10
ACEL,,386
KBC,1                   ! STEP ACCELERATION CHANGE
CNVTOL,F,1,1E-5         ! FORCE CONVERGENCE CRITERIA
TIME,1E-3               ! RELEASE MASS USING SMALL TIME STEP
/OUT,SCRATCH
SOLVE
OUTRES,,1
NSUBST,109              ! INTEGRATION TIME STEP OF 0.001 IN SECOND LOAD STEP
TIME,.11                ! TIME TO ALLOW THE MASS TO REACH ITS LARGEST DEFLECTION
SOLVE
FINISH
/POST26
/OUT,
NSOL,2,1,U,Y,UY
DERIV,3,2,1,,VEL1UY
PROD,4,3,3,,K.E.,,,,.5,.5  ! CALCULATE K.E. BY 1/2(MV**2)
PLVAR,2,3,4
PRVAR,2,3,4                ! PRINT DISP., VELOCITY AND KINETIC ENERGY
*GET,DISP,VARI,2,RTIME,.072
*GET,VELO,VARI,3,RTIME,.072
*GET,KENG,VARI,4,RTIME,.072
*GET,MAXY,VARI,2,EXTREM,VMIN
*GET,TMAX,VARI,2,EXTREM,TMIN
FINISH
/POST1
SET,,,,,0.072           ! DEFINE DATA SET AT TIME = 0.072
ETABLE,KENE,KENE        ! RETRIEVE KINETIC ENERGY
PRETAB,KENE             ! PRINT KINETIC ENERGY
*DIM,LABEL2,CHAR,4,2
*DIM,VALUE2,,4,3
LABEL2(1,1) = 'TIME,  s','Y DISP, ','Y VEL, i','K ENRG, '
LABEL2(1,2) = 'ec      ','in      ','n/sec   ','lb-in   '
*VFILL,VALUE2(1,1),DATA,.07198,-1,-27.79,193
*VFILL,VALUE2(1,2),DATA,.072,DISP,VELO,KENG
```

```
*VFILL,VALUE2(1,3),DATA,ABS(.072/.07198),ABS(DISP/1),ABS(VELO/27.79),ABS(KENG/193)
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'TIME,  s','MAXY DISP, '
LABEL(1,2) = 'ec      ',' in    '
*VFILL,VALUE(1,1),DATA,.10037,-1.5506
*VFILL,VALUE(1,2),DATA,TMAX,MAXY
*VFILL,VALUE(1,3),DATA,ABS(TMAX/.10037),ABS(MAXY/1.5506)
FINISH
/COM
/OUT,vm65,vrt
/COM,=================== VM65 RESULTS COMPARISON ==============
/COM,
/COM,
/COM,AT IMPACT         |  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL2(1,1),LABEL2(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,
/COM,
/COM,AT "ZERO" VELOCITY |  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,==========================================================
/OUT
FINISH
/NOPR
*LIST,vm65,vrt
```

VM66 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM66
/PREP7
SMRT,OFF
/TITLE, VM66, VIBRATION OF A FLAT PLATE
C***          VIBRATION PROBS. IN ENGR., TIMOSHENKO, 3RD. ED., PAGE 338, ART. 53
C***          USING SHELL63 ELEMENTS WITH SHELL OPTION
ANTYPE,MODAL                   ! MODE-FREQUENCY ANALYSIS
ET,1,SHELL63
R,1,1                          ! THICKNESS = 1
MXPAND,1                       ! EXPAND FIRST MODE
MODOPT,LANB,2,,,
MP,EX,1,30E6
MP,DENS,1,728E-6
MP,NUXY,1,0
K,1,,-2
K,2,16,-2
KGEN,2,1,2,1,,4
L,1,3
L,2,4
LESIZE,ALL,,,2
A,1,2,4,3
ESIZE,,4
AMESH,1
NSEL,S,LOC,X,16
D,ALL,ALL
NSEL,ALL
OUTPR,ALL,1
FINISH
*CREATE,SOLVIT,MAC             ! CREATE MACRO TO SOLVE AND RETRIEVE RESULTS
/out,scratch
/SOLU
SOLVE
/out
*GET,FREQ,MODE,1,FREQ
*DIM,LABEL,CHAR,1,2
```

```
*DIM,VALUE,,1,3
LABEL(1,1) = '     f, '
LABEL(1,2) = 'Hz      '
*VFILL,VALUE(1,1),DATA,128.09
*VFILL,VALUE(1,2),DATA,FREQ
*VFILL,VALUE(1,3),DATA,ABS(FREQ/128.09)
FINISH
*END
SOLVIT                         ! EXECUTE MACRO TO SOLVE AND RETRIEVE RESULTS
SAVE,TABLE_1
/CLEAR, NOSTART                ! CLEAR DATABASE FOR SECOND SOLUTION
/TITLE, VM66, VIBRATION OF A FLAT PLATE
C***          USING SOLSH190 ELEMENTS
/PREP7
SMRT,OFF
ANTYPE,MODAL                   ! MODE-FREQUENCY ANALYSIS
ET,1,SHELL181                  ! USED ONLY TO GENERATE AREA MESH AND THEN DELETED
ET,2,SOLSH190                  ! ANALYZE AGAIN USING 3-D SOLSH190
THICK   = 1                    ! THICKNESS = 1
THKDENS = 1                    ! THICKNESS DENSITY = 1
SECT,1,SHELL
SECD,1,1                       ! THICKNESS = 1
MXPAND,1                       ! EXPAND FIRST MODE
MODOPT,LANB,2,,
MP,EX,1,30E6
MP,DENS,1,728E-6
MP,NUXY,1,0
K,1,,-2
K,2,16,-2
KGEN,2,1,2,1,,4
L,1,3
L,2,4
LESIZE,ALL,,,2
A,1,2,4,3
ESIZE,,4
AMESH,1
ESIZE,0,THKDENS               ! THICKNESS DENSITY FOR SOLSH190
EXTOPT,ACLEAR,1               ! CLEAR AREA WHEN VOLUME GENERATION IS DONE
VOFFSET,1,THICK               ! GENERATES A VOLUME, OFFSET FROM A GIVEN AREA
NSEL,S,LOC,X,16
D,ALL,ALL
NSEL,ALL
OUTPR,ALL,1
FINISH
SOLVIT                        ! EXECUTE MACRO TO SOLVE AND RETRIEVE RESULTS
SAVE,TABLE_2
/CLEAR, NOSTART               ! CLEAR DATABASE FOR SECOND SOLUTION
/TITLE, VM66, VIBRATION OF A FLAT PLATE
C***          USING SHELL181 ELEMENTS
/PREP7
SMRT,OFF
ANTYPE,MODAL                   ! MODE-FREQUENCY ANALYSIS
ET,1,SHELL181
SECT,1,SHELL
SECD,1,1                       ! THICKNESS = 1
MXPAND,1                       ! EXPAND FIRST MODE
MODOPT,LANB,2,,,
MP,EX,1,30E6
MP,DENS,1,728E-6
MP,NUXY,1,0
K,1,,-2
K,2,16,-2
KGEN,2,1,2,1,,4
L,1,3
L,2,4
LESIZE,ALL,,,2
A,1,2,4,3
ESIZE,,4
AMESH,1
NSEL,S,LOC,X,16
D,ALL,ALL
NSEL,ALL
```

```
OUTPR,ALL,1
FINISH
SOLVIT                         ! EXECUTE MACRO TO SOLVE AND RETRIEVE RESULTS
SAVE,TABLE_3
/CLEAR, NOSTART                ! CLEAR DATABASE FOR SECOND SOLUTION
/TITLE, VM66, VIBRATION OF A FLAT PLATE
C***          USING SHELL281 ELEMENTS
/PREP7
SMRT,OFF
ANTYPE,MODAL                    ! MODE-FREQUENCY ANALYSIS
ET,1,SHELL281
SECT,1,SHELL
SECD,1,1                        ! THICKNESS = 1
MXPAND,1                        ! EXPAND FIRST MODE
MODOPT,LANB,2,,,
MP,EX,1,30E6
MP,DENS,1,728E-6
MP,NUXY,1,0
K,1,,-2
K,2,16,-2
KGEN,2,1,2,1,,4
L,1,3
L,2,4
LESIZE,ALL,,,2
A,1,2,4,3
ESIZE,,4
AMESH,1
NSEL,S,LOC,X,16
D,ALL,ALL
NSEL,ALL
OUTPR,ALL,1
FINISH
SOLVIT                         ! EXECUTE MACRO TO SOLVE AND RETRIEVE RESULTS
SAVE,TABLE_4
/NOPR
RESUME,TABLE_1
/COM
/OUT,vm66,vrt
/COM,------------------- VM66 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,
/COM, SHELL63
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM, SOLSH190
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM, SHELL181
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_4
/GOPR
/COM,
/COM, SHELL281
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,---------------------------------------------------------------
```

```
/OUT
FINISH
*LIST,vm66,vrt
/DELETE,SOLVIT,MAC
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
/DELETE,TABLE_4
```

VM67 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM67
/PREP7
/TITLE, VM67, RADIAL VIBRATIONS OF A CIRCULAR RING FROM AN AXISYMMETRIC MODEL
C***          VIBRATION PROBS. IN ENGR., TIMOSHENKO, 3RD. ED., PAGE  425, ART. 68
C***          (AXISYMMETRIC) AND 2
ANTYPE,MODAL           ! MODE-FREQUENCY ANALYSIS
ET,1,PLANE25
MXPAND,1               ! EXPAND FIRST MODE
MP,EX,1,30E6
MP,DENS,1,73E-5
MP,NUXY,1,0            ! POISSON'S RATIO IS ZERO
LOCAL,11,,9.975        ! DEFINE LOCAL C.S. AT INSIDE SURFACE OF THE RING
N,1
N,2,,.05
NGEN,2,2,1,2,1,.05
E,1,3,4,2
CP,1,UX,1,2            ! COUPLE RADIAL DOF'S
FINISH
/SOLU
OUTPR,ALL,1
D,ALL,UZ,0
D,1,UY,0
MODE,0,1
MODOPT,LANB,2
SOLVE
*GET,FREQ0,MODE,1,FREQ
FINISH
/SOLU
OUTPR,ALL,1
DDELE,ALL              ! DELETE DISPLACEMENT CONSTRAINTS
D,1,UY
MODE,2,1               ! SYMMETRIC LOADING FOR MODE 2
MXPAND,1,0,100         ! RANGE OF FREQUENCIES OF INTEREST
SOLVE
*GET,FREQ2,MODE,1,FREQ
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = '     f0,','     f2,'
LABEL(1,2) = ' Hz      ',' Hz      '
*VFILL,VALUE(1,1),DATA,3226.4,12.496
*VFILL,VALUE(1,2),DATA,FREQ0,FREQ2
*VFILL,VALUE(1,3),DATA,ABS(FREQ0/3226.4 ) ,ABS( FREQ2/12.496)
/COM
/OUT,vm67,vrt
/COM,------------------- VM67 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm67,vrt
```

VM68 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM68

/PREP7
/TITLE, VM68, PSD RESPONSE OF TWO DOF SPRING-MASS SYSTEM
!      "VIBRATION ANALYSIS" R.K. VIERK ,2ND EDITION ,(CHAPTER 7)
ET,1,COMBIN40              ! DISPLACEMENT ALONG X AXIS, MASS AT NODE I
R,1,42832.,,0.50
R,2,32416.,,1.0
MP,EX,1,1                  ! NOT USED, DUMMY PROPERTY
N,1                        ! DEFINE MODEL
N,2,1
N,3,2
E,2,1
REAL,2
E,3,2
D,1,UX,0.0                 ! CONSTRAINT THE BASE
OUTPR,ALL,ALL
FINISH

/SOLU
ANTYPE,MODAL               ! PERFORM A MODAL ANALYSIS
MODOPT,LANB,2              ! LANB EXTRACTION METHOD
                           ! EXTRACT 2 MODES FROM ENTIRE FREQUENCY RANGE
MXPAND,2,,,YES             ! EXPAND 2 MODES, DO ELEMENT STRESS CALCULATIONS
SOLVE
*GET,FREQ1,MODE,1,FREQ
*GET,FREQ2,MODE,2,FREQ
FINISH

/SOLU
ANTYPE,SPECTR              ! PERFORM SPECTRUM ANALYSIS
SPOPT,PSD,2,ON             ! USE FIRST 2 MODES FROM MODAL ANALYSIS

PSDUNIT,1,ACCG             ! USE G**2/HZ FOR PSD AND DIMENSION IN INCHES
D,1,UX,1.0                 ! APPLY SPECTRUM AT THE SUPPORT POINT
PSDFRQ,1,1,10.0,100.0      ! FREQUENCY RANGE OF 10 TO 100 HERTZ
PSDVAL,1,.1,.1             ! WHITE NOISE PSD, VALUES IN  G**2/HZ
PFACT,1,BASE               ! BASE EXCITATION

DMPRAT,0.02                ! 2% DAMPING
PSDCOM                     ! COMBINE MODES FOR PSD, USE DEFAULT SIGNIFICANCE LEVEL

PSDRES,ACEL,REL            ! CALCULATE RELATIVE ACCELERATION SOLUTIONS
SOLVE
FINISH

/POST1
LCDEF,6,5,1                ! DEFINE LOAD STEP AND SUBSTEP FOR LOAD FACTOR OPERATION
LCFACT,ALL,(1/386.4)       ! CONVERT ACCEL. RESULT TO G
LCASE,6
PRNSOL,U,COMP              ! PRINT NODAL SOLUTION RESULTS
*GET,M1STD,NODE,2,U,X
*GET,M2STD,NODE,3,U,X
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'f1,      ','f2,      ','MASS1,1S','MASS2,1S'
LABEL(1,2) = '      Hz','      Hz','IG.STDEV','IG.STDEV'
*VFILL,VALUE(1,1),DATA,20.57,64.88,9.059,10.63
*VFILL,VALUE(1,2),DATA,FREQ1,FREQ2,M1STD,M2STD
*VFILL,VALUE(1,3),DATA,ABS(FREQ1/20.57),ABS(FREQ2/64.88),ABS(M1STD/9.059),ABS(M2STD/10.63)
/COM
/OUT,vm68,vrt
/COM,------------------- VM68 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
```

```
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm68,vrt
```

VM69 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM69
/PREP7
/TITLE, VM69, SEISMIC RESPONSE
C***VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 78, EX 3.11-1
ET,1,COMBIN40,,,,,,2
R,1,9.8696,,1             ! SPRING CONSTANT = 9.8696, MASS = 1
N,1
N,2
E,1,2
!M,2,UX
FINISH
/SOLU
ANTYPE,MODAL              ! MODE-FREQUENCY SEISMIC RESPONSE
MXPAND,1,,,YES            ! EXPAND MODES;   ELEM STRESS
                          ! ONLY ONE MODE WILL BE USED IN SPECTRUM ANALYSIS
MODOPT,LANB,1             ! USE BLOCK LANCZOS EIGENVALUE EXTRACTION METHOD
D,1,UX
OUTPR,NSOL,ALL
OUTRES,ALL,ALL
SOLVE
*GET,FREQ,MODE,1,FREQ
FINISH
/SOLU
ANTYPE,SPECTR             ! SPECTRUM ANALYSIS
SPOPT,SPRS
SED,1                     ! GLOBAL X-AXIS AS SPECTRUM DIRECTION
SVTYP,3                   ! SEISMIC DISPLACEMENT SPECTRUM
FREQ,.4,.5,.6             ! FREQUENCY POINTS FOR SV V/S FREQ TABLE
SV,,1.01270849,1.02,1.02905569 ! SPECT. VALUES ASSOCIATED WITH FREQ. POINTS
OUTPR,NSOL,ALL
OUTRES,ALL,ALL
SOLVE
*GET,MC1,MODE,1,MCOEF     ! OBTAIN MODE COEFF. FOR THIS SPECTRUM & MODE 1
FINISH
/POST1
SET,1,1,MC1               ! MULTIPY DATABASE FOR MODE1 BY MODE COEFFICIENT
PRNSOL,U,X
*GET,AMP,NODE,2,U,X
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = '     f, ','     AE,'
LABEL(1,2) = '      Hz','      in'
*VFILL,VALUE(1,1),DATA,.5,1.02
*VFILL,VALUE(1,2),DATA,FREQ,AMP
*VFILL,VALUE(1,3),DATA,ABS(FREQ/.5),ABS(AMP/1.02)
/COM
/OUT,vm69,vrt
/COM,------------------- VM69 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL    |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm69,vrt
```

VM70 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM70
/PREP7
MP,PRXY,,0.3
/TITLE, VM70, SEISMIC RESPONSE OF A BEAM STRUCTURE
C***           INTRODUCTION TO STRUCT. DYNAMICS, BIGGS, PAGE 262, ART. 6.4
ET,1,BEAM189
HEIGHT=14
SECT,1,BEAM,ASEC
SECD,273.9726,(1000/3),,(1000/3),,1E-6  ! A = 273.9726, I = (1000/3), H = 14
MP,EX,1,30E6
MP,DENS,1,73E-5
K,1
K,2,240
L,1,2
ESIZE,,8
LMESH,1
NSEL,S,LOC,X,0
D,ALL,UY
NSEL,S,LOC,X,240
D,ALL,UX,,,,,UY
NSEL,ALL
D,ALL,ROTY,,,,,ROTX,UZ
FINISH
/out,scratch
/SOLU
ANTYPE,MODAL                 ! MODE-FREQUENCY ANALYSIS
MODOPT,LANB,3
MXPAND,3,,,YES               ! EXPAND FIRST MODE SHAPE, CALCULATE ELEMENT STRESSES
OUTPR,BASIC,1
SOLVE
/out
*GET,FREQ,MODE,1,FREQ
FINISH
/out,scratch
/SOLU
ANTYPE,SPECTR                ! SPECTRUM ANALYSIS
SPOPT,SPRS                   ! SINGLE POINT SPECTRUM
SED,,1                       ! GLOBAL Y-AXIS AS SPECTRUM DIRECTION
SVTYP,3                      ! SEISMIC DISPLACEMENT SPECTRUM
FREQ,.1,10                   ! FREQUENCY POINTS FOR SV VS. FREQ TABLE
SV,,.44,.44                  ! SPECTRUM VALUES ASSOCIATED WITH FREQUENCY POINTS
SOLVE
/out
*GET,MCOEF,MODE,1,MCOEF      ! GET MODE COEFFICIENT FOR FIRST FREQUENCY
FINISH
/POST1
SET,1,1,MCOEF                ! SCALE VALUES OF FIRST LOAD STEP
PRNSOL,DOF                   ! PRINT NODAL SOLUTION
PRRSOL,F                     ! PRINT REACTION SOLUTION
ETABLE,MOMENT_Z,SMISC,3
*GET,MZ,ELEM,5,ETAB,MOMENT_Z
STRSS=(-1*MZ*(HEIGHT/2))/(1000/3)
*GET,DEF,NODE,10,U,Y
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'f,      ','DEF.     ','SIG MAX,'
LABEL(1,2) = '      Hz','      in','     psi'
*VFILL,VALUE(1,1),DATA,6.0979,.56,20158
*VFILL,VALUE(1,2),DATA,FREQ,DEF,ABS(STRSS)
*VFILL,VALUE(1,3),DATA,ABS(FREQ/6.0979) ,ABS(DEF/.56), ABS(STRSS/20158)
/COM
/OUT,vm70,vrt
/COM,------------------- VM70 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
```

```
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F12.5,'  ',F16.5,'   ',1F15.3)
/COM,----------------------------------------------------------

/OUT
FINISH
*LIST,vm70,vrt
```

VM71 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM71
/PREP7
/TITLE, VM71, TRANSIENT RESPONSE OF A SPRING, MASS, DAMPING SYSTEM
C*** VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 41, EX 2.2-1
ET,1,COMBIN40,,,2          ! Y-DOF ELEMENT
R,1,30,3.52636,.02590673   ! VARIOUS SPRING CONST., DAMPING COEFFICIENTS, MASS
R,2,30,1.76318,.02590673
R,3,30,.352636,.02590673
R,4,30,0,.02590673
N,1
N,8
FILL
E,1,2
EGEN,4,2,1,1,1,,,1         ! GENERATE ELEMENTS WITH INCREMENTING REAL CONSTANT SET
D,2,UY,,,8,2
FINISH

/SOLU
ANTYPE,MODAL               ! PERFORM MODAL SOLVE
MODOPT,QRDAMP,4            ! USE QRDAMP EIGENSOLVER
MXPAND,4,,,YES
/OUT,SCRATCH
SOLVE
FINISH


/SOLU
ANTYPE,TRANSIENT
TRNOPT,MSUP,4,,,           ! PERFORM MSUP TRANSIENT SOLVE
DELTIM,1E-3
OUTRES,NSOL,1
OUTPR,NSOL,1
F,1,FY,30,,7,2             ! APPLY INITIAL FORCE
TIME,1E-3
KBC,1
SOLVE

TIME,95E-3                 ! TIME TO COVER ABOUT 1/2 THE PERIOD
F,1,FY,,,7,2               ! REMOVE FORCE
SOLVE
FINISH


/POST26
FILE,,rdsp
/OUT,
NSOL,2,1,U,Y,1UY           ! STORE UY DISPLACEMENTS OF APPROPRIATE NODES
NSOL,3,3,U,Y,3UY
NSOL,4,5,U,Y,5UY
NSOL,5,7,U,Y,7UY
NPRINT,10                  ! PRINT EVERY 10 POINTS
PRVAR,2,3,4,5              ! PRINT VARIABLES 2,3,4,5
/GRID,1                    ! TURN GRID ON
/AXLAB,Y,DISP              ! Y-AXIS LABEL DISP
PLVAR,2,3,4,5              ! DISPLAY VARIABLES 2,3,4,5
*GET,U_DAMP2,VARI,2,RTIME,.09
*GET,U_DAMP1,VARI,3,RTIME,.09
```

```
*GET,U_DAMP02,VARI,4,RTIME,.09
*GET,U_DAMP0,VARI,5,RTIME,.09
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'U,in  DA','U,in  DA','U,in  DA','U,in  DA'
LABEL(1,2) = 'MPRAT=2 ','MPRAT=1 ','MPRAT=.2','MPRAT=0 '
*VFILL,VALUE(1,1),DATA,.4742,.18998,-.52108,-.99688
*VFILL,VALUE(1,2),DATA,U_DAMP2,U_DAMP1,U_DAMP02,U_DAMP0
*VFILL,VALUE(1,3),DATA,U_DAMP2/.4742,U_DAMP1/.18998,ABS(U_DAMP02/.52108)
*VFILL,VALUE(4,3),DATA,ABS(U_DAMP0/.99688)
/COM
/OUT,vm71,vrt
/COM,------------------- VM71 RESULTS COMPARISON --------------
/COM,
/COM,                   |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm71,vrt
```

VM72 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM72
/PREP7
/TITLE, VM72, LOGARITHMIC DECREMENT
C*** VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 45, EX 2.3-1
ET,1,COMBIN40,,,2          ! Y DOF ELEMENT
R,1,30,.12,.02590673       ! SPRING CONSTANT = 30, C=.12, MASS=.02590673
N,1
N,2
E,1,2
D,2,UY,0
FINISH

/SOLU
ANTYPE,MODAL
MODOPT,QRDAMP,1            ! USE QRDAMP EIGENSOLVER
MXPAND,1,,,YES
SOLVE
FINISH

/SOLU
ANTYPE,TRANSIENT
TRNOPT,MSUP,1              ! PERFORM MODE SUPERPOSITION TRANSIENT SOLVE
DELTIM,.003                ! INTEGRATION TIME STEP SIZE
TIME,.003
KBC,1                      ! STEP BOUNDARY CONDITIONS
F,1,FY,30                  ! APPLY INITIAL FORCE
OUTPR,BASIC,1
OUTRES,NSOL,1
SOLVE                      ! STATIC SOLUTION AT FIRST LOAD STEP
TIME,.69                   ! TIME TO INCLUDE ALMOST FOUR CYCLES
F,1,FY,0                   ! REMOVE FORCE
SOLVE
FINISH

/POST26
FILE,,rdsp
NSOL,2,1,U,Y,UY            ! STORE UY DISPLACEMENTS OF NODE 1 AS UY
NPRINT,20                  ! PRINT EVERY 20 POINTS
/GRID,1                    ! TURN GRID ON
/AXLAB,Y,DISP              ! Y-AXIS LABEL AS DISP
PLVAR,2                    ! DISPLAY VARIABLE 2 V/S TIME
*GET,AMP1,VARI,2,RTIME,0
```

```
*GET,AMP2,VARI,2,RTIME,.186
*GET,AMP3,VARI,2,RTIME,.372
*GET,AMP4,VARI,2,RTIME,.558
R1_2 = AMP1/AMP2
R2_3 = AMP2/AMP3
R3_4 = AMP3/AMP4
TD1_2 = .186 - 0
TD2_3 = .372 - .186
TD3_4 = .558 - .372
*DIM,LABEL_1,CHAR,3,2
*DIM,VALUE_1,,3,4
LABEL_1(1,1) = 'PEAK NUM','MAX. AMP','TIME,    '
LABEL_1(1,2) = 'BER     ',', in    ',' sec    '
*VFILL,VALUE_1(1,1),DATA,1,AMP1,0
*VFILL,VALUE_1(1,2),DATA,2,AMP2,.186
*VFILL,VALUE_1(1,3),DATA,3,AMP3,.372
*VFILL,VALUE_1(1,4),DATA,4,AMP4,.558
*DIM,LABEL_2,CHAR,6,2
*DIM,VALUE_2,,6,3
LABEL_2(1,1) = '       R','       R','       R','       (','       (','       ('
LABEL_2(1,2) = ',1_2    ',',2_3    ',',3_4    ','TD)1_2  ','TD)2_3  ','TD)3_4  '
*VFILL,VALUE_2(1,1),DATA,1.5350,1.5350,1.5350,.18507,.18507,.18507
*VFILL,VALUE_2(1,2),DATA,R1_2,R2_3,R3_4,TD1_2,TD2_3,TD3_4
*VFILL,VALUE_2(1,3),DATA,ABS(R1_2/1.535),ABS(R2_3/1.5350),ABS(R3_4/1.535)
*VFILL,VALUE_2(4,3),DATA,ABS(TD1_2/.18507),ABS(TD2_3/.18507),ABS(TD3_4/.18507)
/COM
/OUT,vm72,vrt
/COM,------------------- VM72 RESULTS COMPARISON --------------
/COM,
*VWRITE,LABEL_1(1,1),LABEL_1(1,2),VALUE_1(1,1),VALUE_1(1,2),VALUE_1(1,3),VALUE_1(1,4)
(1X,A8,A8,'   ',F7.5,'  ',F7.5,'  ',F7.5,'  ',F7.5)
/COM,
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL_2(1,1),LABEL_2(1,2),VALUE_2(1,1),VALUE_2(1,2),VALUE_2(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm72,vrt
```

VM73 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM73
/PREP7
/TITLE, VM73, FREE VIBRATION WITH COULOMB DAMPING
C***           MECHANICAL VIBRATIONS, TSE, MORSE, AND HINKLE, PAGE 175, CASE 1
ET,1,COMBIN40,,,,,,2          ! MASS AT NODE J OF ELEMENT
R,1,1E4,,(10/386),,1.875,30
N,1
N,2
E,1,2
FINISH
/SOLU
SOLCONTROL,0
ANTYPE,TRANS                  ! NONLINEAR TRANSIENT DYNAMIC ANALYSIS
TRNOPT, , , , , ,HHT
D,1,UX
IC,2,UX,-1,0                  ! STRETCH SPRING
KBC,1                         ! STEP BOUNDARY CONDITION
CNVTOL,F,1,0.001              ! FORCE CONVERGENCE CRITERIA
TIME,.2025
NSUBST,404                    ! TO COMPLETE CIRCLE
OUTRES,,1
SOLVE
FINISH
```

```
/POST26
NSOL,2,2,U,X,UX              ! STORE UX DISPLACEMENT OF NODE 2
ESOL,3,1,,SMISC,1,F1         ! STORE FORCE F1 OF ELEMENT 1 AS VARIABLE 3
PRVAR,2,3                    ! PRINT VARIABLES 2 AND 3
/GRID,1                      ! TURN GRID ON
/AXLAB,Y,DISP                ! Y AXIS LABEL AS DISP
/GTHK,CURVE,2                ! CURVE LINES THICKNESS RATIO OF 2
PLVAR,2                      ! DISPLAY VARIABLE 2
/AXLAB,Y,FORCE               ! Y AXIS LABEL AS FORCE
PLVAR,3                      ! DISPLAY VARIABLE 3
*GET,U1,VARI,2,RTIME,.09
*GET,U2,VARI,2,RTIME,.102
*GET,U3,VARI,2,RTIME,.183
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'U,IN(T=0','U,IN(T=0','U,IN(T=0'
LABEL(1,2) = '.09sec) ','.102sec)','.183sec)'
*VFILL,VALUE(1,1),DATA,.87208,.83132,-.74874
*VFILL,VALUE(1,2),DATA,U1,U2,U3
*VFILL,VALUE(1,3),DATA,ABS(U1/.87208 ),ABS(U2/.83132 ),ABS(U1/.87208 )
/COM
/OUT,vm73,vrt
/COM,------------------- VM73 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm73,vrt
```

VM74 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM74
/PREP7
/TITLE, VM74, TRANSIENT RESPONSE TO AN IMPULSIVE EXCITATION
C*** VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 99, ART. 4.1
ET,1,COMBIN40,,,2,,,2    ! Y DOF ELEMENTS, MASS AT NODE J
R,1,200,,.5              ! TWO DAMPING RATIOS
R,2,200,14,.5
N,1
N,4
FILL
E,1,2
REAL,2
E,3,4
D,1,UY,,,3,2
FINISH

/SOLU
ANTYPE,MODAL             ! PERFORM MODAL SOLVE
MODOPT,QRDAMP,2          ! USE QRDAMP EIGENSOLVER
MXPAND,2
SOLVE
FINISH

/SOLU
ANTYPE,TRANSIENT
TRNOPT,MSUP,2            ! PERFORM MODE SUPERPOSITION TRANSIENT SOLVE
F,2,FY,0,,4,2
DELTIM,25E-4              ! INTEGRATION TIME STEP
KBC,1                     ! STEP BOUNDARY CONDITIONS
OUTPR,BASIC,1
SOLVE                    ! PSEUDO STATIC SOLVE
```

```
TIME,25E-4
F,2,FY,4000,,4,2        ! IMPULSE FORCE
KBC,1
SOLVE

TIME,.105                ! TIME TO ALLOW THE MASSES TO REACH LARGEST DEFLECTIONS
F,2,FY,,,4,2             ! REMOVE FORCE
SOLVE
FINISH
/POST26
FILE,,rdsp
NSOL,2,2,U,Y,2UY          ! STORE UY DISPLACEMENTS OF APPROPRIATE NODES
NSOL,4,4,U,Y,4UY
NPRINT,.25
PRVAR,2,4
*GET,Y1,VARI,2,RTIME,.08
*GET,Y2,VARI,2,RTIME,.1
*GET,Y3,VARI,4,RTIME,.1
*DIM,LABEL_1,CHAR,1,2
*DIM,VALUE_1,,1,3
LABEL_1(1,1) = 'Y,MAX in'
LABEL_1(1,2) = ' NODE=2 '
*VFILL,VALUE_1(1,1),DATA,.99957
*VFILL,VALUE_1(1,2),DATA,Y1
*VFILL,VALUE_1(1,3),DATA,ABS(Y1/.99957)
*DIM,LABEL_2,CHAR,2,2
*DIM,VALUE_2,,2,3
LABEL_2(1,1) = 'Y, in   ','Y, in   '
LABEL_2(1,2) = 'node=2  ','node=4  '
*VFILL,VALUE_2(1,1),DATA,.90930,.34180
*VFILL,VALUE_2(1,2),DATA,Y2,Y3
*VFILL,VALUE_2(1,3),DATA,ABS(Y2/.90930),ABS(Y3/.34180)
/COM
/OUT,vm74,vrt
/COM,------------------- VM74 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,TIME=.08 sec
/COM,
*VWRITE,LABEL_1(1,1),LABEL_1(1,2),VALUE_1(1,1),VALUE_1(1,2),VALUE_1(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,
/COM,TIME=.1 sec
/COM,
*VWRITE,LABEL_2(1,1),LABEL_2(1,2),VALUE_2(1,1),VALUE_2(1,2),VALUE_2(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm74,vrt
```

VM75 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM75
/PREP7
/TITLE, VM75, TRANSIENT RESPONSE TO A STEP EXCITATION
C*** VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 102, ART 4.3
ET,1,COMBIN40,,,2,,,2     ! Y DOF ELEMENTS, MASS AT NODE J
R,1,200,,.5               ! TWO DAMPING RATIOS
R,2,200,10,.5
N,1
N,4
FILL
E,1,2
REAL,2
E,3,4
```

```
D,1,UY,,,3,2
FINISH

/SOLU
ANTYPE,MODAL                ! PERFORM MODAL SOLVE
MODOPT,QRDAMP,2             ! USE QRDAMP EIGENSOLVER
MXPAND,2,,,YES
SOLVE
FINISH

/SOLU
ANTYPE,TRANSIENT
TRNOPT,MSUP,2              ! PERFORM MODE SUPERPOSITION TRANSIENT SOLVE
DELTIM,25E-4               ! INTEGRATION TIME STEP SIZE
KBC,1                      ! STEP BOUNDARY CONDITIONS
OUTPR,BASIC,1
OUTRES,NSOL,1
F,2,FY,,,4,2
SOLVE

TIME,.205                  ! TIME AT END OF LOAD STEP
F,2,FY,200,,4,2
SOLVE
FINISH

/POST26
FILE,,rdsp
NSOL,2,2,U,Y,2UY           ! STORE UY DISPLACEMENTS OF APPROPRIATE NODES
NSOL,3,4,U,Y,4UY
NPRINT,10                  ! PRINT EVERY 10 POINTS
PRVAR,2,3                  ! PRINT VARIABLES 2 AND 3
/GRID,1                    ! TURN GRID ON
/AXLAB,Y,DISP              ! Y-AXIS LABEL AS DISP
PLVAR,2,3                  ! DISPLAY VARIABLES 2 AND 3
*GET,UMAX,VARI,2,RTIME,.1575
*GET,U0,VARI,2,RTIME,.2
*GET,U5,VARI,3,RTIME,.2
*DIM,LABEL_1,CHAR,1,2
*DIM,VALUE_1,,1,3
LABEL_1(1,1) = 'UMAX,   '
LABEL_1(1,2) = 'in      '
*VFILL,VALUE_1(1,1),DATA,2
*VFILL,VALUE_1(1,2),DATA,UMAX
*VFILL,VALUE_1(1,3),DATA,ABS(UMAX/2)
*DIM,LABEL_2,CHAR,2,2
*DIM,VALUE_2,,2,3
LABEL_2(1,1) = 'U,in(DAM','U,in(DAM'
LABEL_2(1,2) = 'PING=0) ','PING=.5)'
*VFILL,VALUE_2(1,1),DATA,1.6536,1.1531
*VFILL,VALUE_2(1,2),DATA,U0,U5
*VFILL,VALUE_2(1,3),DATA,ABS(U0/1.6536),ABS(U5/1.1531)
/COM
/OUT,vm75,vrt
/COM,------------------- VM75 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,TIME = 0.1575 SEC:
*VWRITE,LABEL_1(1,1),LABEL_1(1,2),VALUE_1(1,1),VALUE_1(1,2),VALUE_1(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,
/COM,TIME = 0.20 SEC:
*VWRITE,LABEL_2(1,1),LABEL_2(1,2),VALUE_2(1,1),VALUE_2(1,2),VALUE_2(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm75,vrt
```

VM76 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM76
/PREP7
/TITLE, VM76, HARMONIC RESPONSE OF A GUITAR STRING
/COM, REFERENCE: BLEVINS, FORMULAS FOR NAT. FREQ. AND MODE SHAPE, TABLE 7-1.
ANTYPE,STATIC        ! STATIC ANALYSIS, PRESTRESS
ET,1,LINK180         ! TWO-DIMENSIONAL SPAR
SECTYPE,1,LINK
SECDATA,50671E-12    ! CROSS-SECTIONAL AREA OF STRING
MP,EX,1,190E9        ! MATERIAL, STAINLESS STEEL
MP,DENS,1,7920
N,1                  ! DEFINE NODES
N,31,.71
FILL
E,1,2                ! DEFINE ELEMENTS
EGEN,30,1,1
D,1,ALL              ! BOUNDARY CONDITIONS AND LOADING
D,2,UY,,,31
D,ALL,UZ
F,31,FX,84
FINISH
/OUT,SCRATCH
/SOLU
RESCONTROL,LINEAR,LAST,LAST
OUTPR,BASIC,1
SOLVE
FINISH
/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB
PERTURB,MODAL,,,PARKEEP
SOLVE,ELFORM

MODOPT,LANB,6        ! LANB EXTRACTION METHOD, 6 FREQ.
DDEL,2,UY,30
SOLVE
/OUT,
*GET,FREQ,MODE,1,FREQ
FINISH
PARSAV,ALL
/DELETE,,rstp
/OUT,SCRATCH
/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB
PERTURB,HARMONIC,,,PARKEEP
SOLVE,ELFORM

PARRES,CHANGE
HROPT,FULL
DDEL,2,UY,30
HROUT,OFF            ! AMPLITUDE, PHASE ANGLE PRINTOUT
F,8,FY,-1            ! FORCE AT X=.1657, NEAR QUARTER POINT
KBC,1                ! STEP CHANGE FORCE
HARFRQ,,2000         ! OBTAIN FREQUENCY EVERY EIGHT HERTZ
NSUBST,250
OUTPR,,NONE
OUTRES,,1
SOLVE
FINISH
/OUT,
/POST26              ! TIME-HISTORY POSTPROCESSOR
FILE,,rstp
NSOL,2,16,U,Y,DISP   ! RETRIEVE STRING MIDPOINT DISPLACEMENT RESPONSE
PRVAR,2
/AXLAB,Y,AMPL
PLCPLX,0             ! DISPLAY AMPLITUDE OF COMPLEX VARIABLE (DEFAULT)
PLVAR,2
*DIM,LABEL,CHAR,1,2
```

```
*DIM,VALUE,,1,3
LABEL(1,1) = '      f,'
LABEL(1,2) = ' Hz      '
*VFILL,VALUE(1,1),DATA,322.2
*VFILL,VALUE(1,2),DATA,FREQ
*VFILL,VALUE(1,3),DATA,ABS(FREQ/322.2 )
/COM
/OUT,vm76,vrt
/COM,------------------- VM76 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,-----------------------------------------------------------
/COM,
/COM,------------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM76  NOT CONTAINED IN
/COM,THIS TABLE
/COM,------------------------------------------------------------
/OUT
FINISH
*LIST,vm76,vrt
```

VM77 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM77
/OUT,SCRATCH
/PREP7
/TITLE, VM77, TRANSIENT RESPONSE TO A CONSTANT FORCE WITH A FINITE RISE TIME
C***           INTRODUCTION TO STRUCT. DYNAMICS, BIGGS, PAGE 50, EXAMPLE E
C***           DISPLACEMENT PASS USING BEAM188 AND MASS21 ELEMENTS
ET,1,BEAM188,,,3        ! BEAM USING CUBIC OPTION
SECTYPE,1,BEAM,RECT
SECDATA,18,1.647
SECCONTROL,,,2e15       ! OVERRIDE THE PROGRAM-CALCULATED TRANSVERSE SHEAR STIFFNESS
ET,2,MASS21,,,4         ! STRUCTURAL MASS
R,2,.0259067            ! MASS
MP,EX  ,1,30E3
MP,PRXY,1,0.3
N,1
N,3,240
FILL
E,1,2                   ! BEAM ELEMENTS
EGEN,2,1,1
TYPE,2
REAL,2
E,2                     ! TYPE 2 ELEMENT WITH REAL CONSTANT 2
D,1,UY
D,3,UX,,,,,UY
DSYM,SYMM,Z             ! PREVENT OUT-OF-PLANE DISPLACEMENT
FINISH

/SOLU
ANTYPE,MODAL
MODOPT,LANPCG,5         ! USE LANPCG EIGENSOLVER
MXPAND,5
SOLVE
FINISH

/SOLU
ANTYPE,TRANSIENT
TRNOPT,MSUP,5           ! PERFORM MODE SUPERPOSITION TRANSIENT SOLVE
DELTIM,.004             ! INTEGRATION TIME STEP SIZE
OUTPR,BASIC,1
OUTRES,ALL,1
F,2,FY,0                ! FORCE = 0 AT TIME = 0
```

```
SOLVE

TIME,.075               ! TIME AT END OF LOAD STEP
F,2,FY,20               ! FORCE IS RAMPED (KBC,0 IS DEFAULT) TO 20
SOLVE

TIME,.1                 ! CONSTANT FORCE UNTIL TIME = 0.1
SOLVE
FINISH

/SOLU
C***    EXPANSION PASS USING BEAM188 AND MASS21 ELEMENTS
EXPASS,ON               ! EXPANSION PASS ON
EXPSOL,,,0.092          ! TIME OF MAXIMUM RESPONSE
SOLVE
FINISH

/OUT,
/POST1
ETABLE,STRS,SMISC,33
*GET,STRSS,ELEM,2,ETAB,STRS
FINISH

/POST26
NSOL,2,2,U,Y
STORE
*GET,TMAX,VARI,2,EXTREM,TMAX
*GET,YMAX,VARI,2,EXTREM,VMAX
*DIM,LABEL_1,CHAR,2,2
*DIM,VALUE_1,,2,3
LABEL_1(1,1) = 'T_MAX, s','Y_MAX, i'
LABEL_1(1,2) = 'ec      ','n       '
*VFILL,VALUE_1(1,1),DATA,.092,.331
*VFILL,VALUE_1(1,2),DATA,TMAX,YMAX
*VFILL,VALUE_1(1,3),DATA,ABS(TMAX/.092),ABS(YMAX/.331)
*DIM,LABEL_2,CHAR,1,2
*DIM,VALUE_2,,1,3
LABEL_2(1,1) = 'SIG_BEND'
LABEL_2(1,2) = ', KSI   '
*VFILL,VALUE_2(1,1),DATA,-18.6
*VFILL,VALUE_2(1,2),DATA,STRSS
*VFILL,VALUE_2(1,3),DATA,ABS(STRSS/18.6)
/COM
/OUT,vm77,vrt
/COM,------------------- VM77 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,TRANSIENT:
/COM,
*VWRITE,LABEL_1(1,1),LABEL_1(1,2),VALUE_1(1,1),VALUE_1(1,2),VALUE_1(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.2)
/COM,
/COM,EXPANSION PASS:
/COM,
*VWRITE,LABEL_2(1,1),LABEL_2(1,2),VALUE_2(1,1),VALUE_2(1,2),VALUE_2(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.2)
/COM,---------------------------------------------------------
/OUT
FINISH
*LIST,vm77,vrt
```

VM78 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM78
/PREP7
/TITLE, VM78: TRANSVERSE SHEAR STRESSES IN A CANTILEVER BEAM
```

```
C***          THEORY OF ELASTICITY, TIMESHENKO, PG. 35, ARTICLE 20
ANTYPE,STATIC
ET,1,SHELL281       ! 8-NODE LAYERED SHELL; STRESS & STRAIN PRINTOUT
KEYOPT,1,8,2       ! STORE RESULTS FOR ALL LAYERS
SECTYPE,1,SHELL
SECDATA,0.5,1,0,5,LAYER1
SECDATA,0.5,1,0,5,LAYER2
SECDATA,0.5,1,0,5,LAYER3
SECDATA,0.5,1,0,5,LAYER4
MP,EX,1,30E6
MP,NUXY,1,0
/COM  --- INPUT  FAILURE STRESSES FOR MATERIAL #1 ---
/COM  --- COMPRESSION VALUES ARE LEFT TO DEFAULT  ---
N,1
N,3,,1
FILL
NGEN,11,3,1,3,1,1
E,1,7,9,3,4,8,6,2
EGEN,5,6,-1
NSEL,S,LOC,X                 ! SELECT NODES AT FIXED END AND CONSTRAIN
D,ALL,ALL
NSEL,S,LOC,X,10
CP,1,UZ,ALL                  ! COUPLE FREE END NODES
NSEL,R,LOC,Y
F,ALL,FZ,10000               ! APPLY END FORCE
NSEL,ALL
OUTPR,,1
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
ETABLE,SXZ,S,XZ       ! STRESS ALONG XZ
ETABLE,ILSXZ,SMISC,68        ! SXZ INTERLAMINAR SHEAR STRESS
ETABLE,ILMX,SMISC,60      ! INTERLAMINAR SHEAR STRESS VECTOR SUM
*GET,SIGXZ1,ELEM,4,ETAB,SXZ
*GET,SIGXZ2,ELEM,1,ETAB,ILSXZ
*GET,SIGXZ3,ELEM,1,ETAB,ILMX
FC,1,TEMP,,
FC,1,S,XTEN,25000
FC,1,S,XCMP,-25000,
FC,1,S,YTEN,3000
FC,1,S,YCMP,-3000,
FC,1,S,ZTEN,5000
FC,1,S,ZCMP,-5000,
FC,1,S,XY,500
FC,1,S,YZ,500,
FC,1,S,XZ,500,
FC,1,S,XYCP,
FC,1,S,YZCP,
FC,1,S,XZCP,
ESEL,S,ELEM,,1
NSLE,S
LAYER,FCMAX
*GET,FC3,NODE,9,S,TWSI,
ALLSEL,ALL
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'SIGXZ,ps','SIGXZ,ps','SIGXZ,ps','FC3MAX ('
LABEL(1,2) = 'i(Z=H/2)','i(Z=H/4)','i(Z= 0 )','FCMX) '
*VFILL,VALUE(1,1),DATA,0,5625,7500,225
*VFILL,VALUE(1,2),DATA,SIGXZ1,SIGXZ2,SIGXZ3,FC3
*VFILL,VALUE(1,3),DATA,0,ABS(SIGXZ2/5625),ABS(SIGXZ3/7500),ABS(FC3/225)
/COM
/OUT,vm78,vrt
/COM,------------------- VM78 RESULTS COMPARISON ---------------

/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
```

```
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm78,vrt
```

VM79 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM79
/PREP7
/TITLE, VM79, TRANSIENT RESPONSE OF A BI-LINEAR SPRING ASSEMBLY
C***VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 150,FIG 5.6-1
ET,1,COMBIN40,,,2,,,2    ! Y DOF ELEMENTS, MASS AT NODE J
R,1,200,,.5              ! K1 = 200; M = .5
N,1
N,2
E,1,2
GP,3,2,FY,-200,.75       ! GAP CONDITION
D,1,UY,,,3,2             ! CONSTRAIN UY DOF AT NODES 1 AND 3
FINISH

/SOLUTION
ANTYPE,MODAL
MODOPT,LANB,1           ! PERFORM MODAL SOLVE USING LANB EIGENSOLVER
MXPAND,1
SOLVE
FINISH

/SOLU
ANTYPE,TRANSIENT
TRNOPT,MSUP,1            ! PERFORM MODE SUPERPOSITION TRANSIENT SOLVE
DELTIM,25E-4             ! INTEGRATION TIME STEP
KBC,1                    ! STEP BOUNDARY CONDITIONS
F,2,FY
OUTPR,BASIC,1
SOLVE                    ! STATIC LOAD STEP

TIME,25E-4               ! TIME AT END OF LOAD STEP
F,2,FY,-4E3              ! APPLY 4000 LB. LOAD
SOLVE

TIME,.105
F,2,FY,0                 ! REMOVE LOAD
SOLVE
FINISH

/POST26
FILE,,rdsp
NSOL,2,2,U,Y,2UY          ! STORE UY DISPLACEMENTS OF APPROPRIATE NODES
PRVAR,2
*GET,Y1,VARI,2,RTIME,.09
*GET,Y2,VARI,2,RTIME,.04
*GET,Y3,VARI,2,RTIME,.07
*GET,Y4,VARI,2,RTIME,.085
*GET,Y5,VARI,2,RTIME,.105
*DIM,LABEL_1,CHAR,3,2
*DIM,VALUE_1,,3,4
LABEL_1(1,1) = 'TIME    ','Y, in   ','Y, in   '
LABEL_1(1,2) = 'sec     ','linear ','bilinear'
*VFILL,VALUE_1(1,1),DATA,.040,-.68122,Y2
*VFILL,VALUE_1(1,2),DATA,.070,-.97494,Y3
*VFILL,VALUE_1(1,3),DATA,.085,-.99604,Y4
*VFILL,VALUE_1(1,4),DATA,.105,-.88666,Y5
*DIM,LABEL_2,CHAR,1,2
*DIM,VALUE_2,,1,3
LABEL_2(1,1) = 'Y, in   '
```

```
LABEL_2(1,2) = 'MAX      '
*VFILL,VALUE_2(1,1),DATA,-1.0417
*VFILL,VALUE_2(1,2),DATA,Y1
*VFILL,VALUE_2(1,3),DATA,ABS(Y1/1.0417)
/COM
/OUT,vm79,vrt
/COM,------------------- VM79 RESULTS COMPARISON -----------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,TIME=.09 sec
/COM,
*VWRITE,LABEL_2(1,1),LABEL_2(1,2),VALUE_2(1,1),VALUE_2(1,2),VALUE_2(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F10.5,'   ',1F5.3)
/COM,
/COM,COMPARISON OF Mechanical APDL LINEAR (VM74) AND BILINEAR SPRING RESULTS
/COM,
*VWRITE,LABEL_1(1,1),LABEL_1(1,2),VALUE_1(1,1),VALUE_1(1,2),VALUE_1(1,3),VALUE_1(1,4)
(1X,A8,A8,'   ',F8.5,'  ',F8.5,'  ',F15.5,'  ',F15.5)
/COM,
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm79,vrt
```

VM80 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM80
/PREP7
/TITLE, VM80, PLASTIC RESPONSE TO A SUDDENLY APPLIED CONSTANT FORCE
C***           INTRODUCTION TO STRUCT. DYNAMICS, BIGGS, PAGE 69, ART. 2.7
ANTYPE,TRANS          ! FULL TRANSIENT DYNAMIC ANALYSIS
ET,1,LINK180
ET,2,MASS21,,,4       ! TWO-DIMENSIONAL MASS
SECTYPE,1,LINK
SECDATA,.278        ! AREA (A)
R,2,0.0259            ! MASS
MP,EX,1,30E3
TB,BKIN,1,1           ! BILINEAR KINEMATIC HARDENING STRESS-STRAIN CURVE
TBTEMP,0
TBDATA,1,162.9,0      ! YIELD STRESS AND TANGENT MODULUS
N,1
N,2,,-100
E,1,2
D,ALL,UZ
TYPE,2
REAL,2
E,1
FINISH
/SOLU
SOLCONTROL,0
KBC,1                 ! STEP BOUNDARY CONDITIONS
TIME,4E-3             ! TIME AT THE END OF LOAD STEP 1
D,1,UX,,,2
D,2,UY
F,1,FY,30             ! APPLY F1
NSUBST,10             ! 10 SUBSTEPS FOR  TIME STEP OF .0004
OUTPR,BASIC,1         ! PRINT BASIC SOLUTION FOR EACH SUBSTEP
OUTRES,NSOL,1         ! STORE NODAL SOLUTION FOR EACH SUBSTEP
/OUT,SCRATCH
SOLVE
TIME,.14              ! FINAL TIME SLIGHTLY MORE THAN 1 CYCLE OF VIBRATION
NSUBST,68             ! 68 REPEATS FOR TIME STEP OF 0.002
OUTPR,BASIC,8         ! PRINT BASIC SOLUTION FOR EVERY 8TH SUBSTEP
SOLVE
FINISH
/POST26
```

```
/OUT,
NSOL,2,1,U,Y,UY       ! STORE UY DISPLACEMENTS OF NODE 1 AGAINST TIME
PRVAR,2               ! PRINT VARIABLE 2 (DISPLACEMENT UY OF NODE 1) V/S TIME
/GRID,1               ! TURN THE GRID ON FOR DISPLAY
/AXLAB,Y,DISPLACEMENT ! MAKE Y-AXIS LABEL AS DISP FOR DISPLAY
PLVAR,2               ! DISPLAY VARIABLE 2 (DISPLACEMENT UY OF NODE 1) V/S TIME
*GET,YMAX,VARI,2,EXTREM,VMAX
*GET,TMAX,VARI,2,EXTREM,TMAX
*GET,YMIN,VARI,2,RTIME,.122
TMIN = .122
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'Y_MAX, i','TIME, se','Y_MIN, i','TIME, se'
LABEL(1,2) = 'n       ','c       ','n       ','c       '
*VFILL,VALUE(1,1),DATA,.806,.0669,.438,.122
*VFILL,VALUE(1,2),DATA,YMAX,TMAX,YMIN,TMIN
*VFILL,VALUE(1,3),DATA,ABS(YMAX/.806),ABS(TMAX/.0669),ABS(YMIN/.438),ABS(TMIN/.122)
/COM
/OUT,vm80,vrt
/COM,------------------- VM80 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm80,vrt
```

VM81 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM81
/PREP7
/TITLE, VM81, TRANSIENT RESPONSE OF A DROP CONTAINER (NONLINEAR)
C***        VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND. PRINTING, PAGE 110,
C***        EX. 4.6-1, USING NON-LINEAR TRANSIENT DYNAMIC ANALYSIS
ET,1,COMBIN40,,,2,,,2    ! SPRING, MASS, GAP COMBINATION ELEMENT
R,1,1973.92,,.5,1        ! SPRING STIFFNESS, MASS, AND GAP
N,1                      ! DEFINE NODES AND ELEMENT
N,2
E,2,1
FINISH
/SOLU
SOLCONTROL,0
ANTYPE,TRANS             ! NONLINEAR TRANSIENT DYNAMIC ANALYSIS
TIME,1E-6
D,2,UY
ACEL,,386                ! BOUNDARY CONDITIONS AND LOADING
KBC,1                    ! STEPPED BOUNDARY CONDITIONS
CNVTOL,F,1,0.001         ! FORCE CONVERGENCE CRITERIA
SOLVE
NSUBST,110
OUTPR,BASIC,LAST
OUTRES,NSOL,1
TIME,.11
SOLVE
FINISH
/POST26                  ! TIME-HISTORY POSTPROCESSOR
NSOL,2,1,U,Y
DERIV,3,2,1,,VEL_1UY     ! CALCULATE VELOCITY BY TAKING DERIVATIVE OF UY
PRVAR,2,3
*GET,Y1,VARI,2,RTIME,.072
*GET,V1,VARI,3,RTIME,.072
*GET,Y2,VARI,2,RTIME,.1
*GET,Y3,VARI,2,RTIME,.101
*DIM,LABEL1,CHAR,3,1
```

```
*DIM,VALUE1,,3,3
LABEL1(1,1) = 'TIME sec','Y, in   ','V,in/sec'
*VFILL,VALUE1(1,1),DATA,.07198,-1.00,-27.79
*VFILL,VALUE1(1,2),DATA,.072,Y1,V1
*VFILL,VALUE1(1,3),DATA,ABS(.072/.07198),ABS(Y1/1),ABS(V1/27.79)
*DIM,LABEL2,CHAR,2,2
*DIM,VALUE2,,2,3
LABEL2(1,1) = 't=.1 sec','t=1.01 s'
LABEL2(1,2) = ' Y, in  ','ec Y, in'
*VFILL,VALUE2(1,1),DATA,-1.5505,-1.5502
*VFILL,VALUE2(1,2),DATA,Y2,Y3
*VFILL,VALUE2(1,3),DATA,ABS(Y2/1.5505),ABS(Y3/1.5502)
SAVE,TABLE1
FINISH
/CLEAR, NOSTART ! CLEAR THE DATABASE
/PREP7
/TITLE, VM81, TRANSIENT RESPONSE OF A DROP CONTAINER (QUASI-LINEAR)
ET,1,MASS21,,,4          ! TWO-DIMENSIONAL MASS ELEMENT
R,1,.5                   ! MASS
N,1                      ! DEFINE NODE AND ELEMENT
E,1
D,1,UX
GP,2,1,FY,1973.92,1      ! GAP CONDITION
FINISH

/SOLU
ANTYPE,MODAL
MODOPT,LANB,1           ! PERFORM MODAL SOLVE USING LANB EIGENSOLVER
MXPAND,1
SOLVE
FINISH

/SOLU
SOLCONTROL,0
ANTYPE,TRANS             ! TRANSIENT DYNAMIC ANALYSIS
TRNOPT,MSUP,1            ! MODE SUPERPOSITION TRANSIENT ANALYSIS
DELTIM,1E-3
OUTPR,NSOL,LAST
SOLVE

OUTRES,NSOL,1
TIME,.110
KBC,1                    ! STEPPED BOUNDARY CONDITIONS
ACEL,,386                ! BOUNDARY CONDITIONS AND LOADING
SOLVE
FINISH


/POST26                  ! TIME-HISTORY POSTPROCESSOR
FILE,,rdsp               ! REDUCED DISPLACEMENTS FILE
NSOL,2,1,U,Y
DERIV,3,2,1,,VEL_1UY     ! CALCULATE VELOCITY
PRVAR,2,3
*GET,Y1,VARI,2,RTIME,.072
*GET,V1,VARI,3,RTIME,.072
*GET,Y2,VARI,2,RTIME,.1
*GET,Y3,VARI,2,RTIME,.101
*DIM,LABEL1,CHAR,3,1
*DIM,VALUE1,,3,3
LABEL1(1,1) = 'TIME sec','Y, in   ','V,in/sec'
*VFILL,VALUE1(1,1),DATA,.07198,-1.00,-27.79
*VFILL,VALUE1(1,2),DATA,.072,Y1,V1
*VFILL,VALUE1(1,3),DATA,ABS(.072/.07198),ABS(Y1/1),ABS(V1/27.79)
*DIM,LABEL2,CHAR,2,2
*DIM,VALUE2,,2,3
LABEL2(1,1) = 't=.1 sec','t=1.01 s'
LABEL2(1,2) = ' Y, in  ','ec Y, in'
*VFILL,VALUE2(1,1),DATA,-1.5505,-1.5502
*VFILL,VALUE2(1,2),DATA,Y2,Y3
*VFILL,VALUE2(1,3),DATA,ABS(Y2/1.5505),ABS(Y3/1.5502)
SAVE,TABLE2
RESUME,TABLE1
```

```
/COM
/OUT,vm81,vrt
/COM,------------------- VM81 RESULTS COMPARISON --------------
/COM,
/COM,FULL DYNAMIC     |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,AT IMAPACT
*VWRITE,LABEL1(1,1),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A8,'   ',F18.4,'  ',F14.4,'   ',1F15.3)
/COM,
/COM,AT ZERO VELOCITY
*VWRITE,LABEL2(1,1),LABEL2(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,TABLE2
/GOPR
/COM,
/COM,MODE SUPERPOSITION|   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,AT IMAPACT
*VWRITE,LABEL1(1,1),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A8,'   ',F18.4,'  ',F14.4,'   ',1F15.3)
/COM,
/COM,AT ZERO VELOCITY
*VWRITE,LABEL2(1,1),LABEL2(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)

/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm81,vrt
```

VM82 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM82
/OUT,SCRATCH
/PREP7
SMRT,OFF
/TITLE, VM82, SIMPLY SUPPORTED LAMINATED PLATE UNDER PRESSURE
C***    EXACT SOLUTIONS OF MODERATELY THICK LAMINATED SHELLS,
C***    J.N. REDDY, JNL. OF ENGR. MECHANICS, VOL 110, NO.5, MAY'84.
C*** USING SOLID185 WITH LAYERS
ANTYPE,STATIC
ET,1,185
KEYOPT,1,3,1      ! LAYERED SOLID ELEMENTS
KEYOPT,1,2,2                ! ENHANCED STRAIN FORMULATION
KEYOPT,1,8,1      ! STORE DATA FOR ALL LAYERS
SECTYPE,1,SHELL
SECDATA,0.025,1,0           ! LAYER 1: 0.025 THK, THETA 0
SECDATA,0.025,1,90          ! LAYER 2: 0.025 THK, THETA 90
SECDATA,0.025,1,90          ! LAYER 3: 0.025 THK, THETA 90
SECDATA,0.025,1,0           ! LAYER 4: 0.025 THK, THETA 0
MP,EX,1,25E6                ! ORTHOTROPIC MATERIAL PROPERTIES
MP,EY,1,1E6
MP,EZ,1,1E6                 ! EZ=EY ASSUMED
MP,GXY,1,5E5
MP,GYZ,1,2E5
MP,GXZ,1,5E5
MP,PRXY,1,0.25              ! MAJOR POISSONS RATIO
MP,PRYZ,1,0.01              ! MAJOR POISSONS RATIO
MP,PRXZ,1,0.25              ! MAJOR POISSONS RATIO
K,1                         ! CORNER KEYPOINTS OF QUADRANT (VOLUME)
K,2,5
K,3,5,5
K,4,,5
KGEN,2,1,4,1,,,0.1
L,1,5
```

```
*REPEAT,4,1,1
LESIZE,ALL,,,1
V,1,2,3,4,5,6,7,8
ESIZE,,6                    ! 6X6 MESH USING QUARTER SYMMETRY
VMESH,1
NSEL,S,LOC,X,0
DSYM,SYMM,X
NSEL,S,LOC,Y,0
DSYM,SYMM,Y
NSEL,S,LOC,X,5              ! FREELY SUPPORTED B.C.
D,ALL,UZ,,,,,UY
NSEL,S,LOC,Y,5
D,ALL,UZ,,,,,UX
NSEL,ALL
SFE,ALL,6,PRES,,1           ! APPLY UNIFORM PRESSURE ON TOP SURFACE
OUTPR,,1
FINISH
/OUT,SCRATCH
/SOLU
SOLVE
FINISH
/OUT
/POST1
NSEL,S,LOC,X                ! SELECT CENTER NODES
NSEL,R,LOC,Y
PRNSOL,U,Z                  ! PRINT CENTER DEFLECTION
*GET,DEF46,NODE,1,U,Z
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'DEF,m (S'
LABEL(1,2) = 'OLID185) '
*VFILL,VALUE(1,1),DATA,.0683
*VFILL,VALUE(1,2),DATA,ABS(DEF46)
*VFILL,VALUE(1,3),DATA,ABS(DEF46/.0683)
SAVE,INF1
FINISH
/CLEAR,NOSTART
/OUT,SCRATCH
/PREP7
SMRT,OFF
/TITLE, VM82, SIMPLY SUPPORTED LAMINATED PLATE UNDER PRESSURE
C*** USING SOLSH190
ANTYPE,STATIC
ET,1,SOLSH190               ! 8 NODE LAYERED SOLID-SHELL
KEYOPT,1,8,1                ! WRITE LAYER RESULTS
SECTYPE,1,SHELL
SECDATA,0.025,1,0           ! LAYER 1: 0.025 THK, THETA 0
SECDATA,0.025,1,90          ! LAYER 2: 0.025 THK, THETA 90
SECDATA,0.025,1,90          ! LAYER 3: 0.025 THK, THETA 90
SECDATA,0.025,1,0           ! LAYER 4: 0.025 THK, THETA 0
MP,EX,1,25E6                ! ORTHOTROPIC MATERIAL PROPERTIES
MP,EY,1,1E6
MP,EZ,1,1E6                 ! EZ=EY ASSUMED
MP,GXY,1,5E5
MP,GYZ,1,2E5
MP,GXZ,1,5E5
MP,PRXY,1,0.25              ! MAJOR POISSONS RATIO
MP,PRYZ,1,0.01              ! MAJOR POISSONS RATIO
MP,PRXZ,1,0.25              ! MAJOR POISSONS RATIO
K,1                         ! CORNER KEYPOINTS OF QUADRANT (VOLUME)
K,2,5
K,3,5,5
K,4,,5
KGEN,2,1,4,1,,,0.1
L,1,5
*REPEAT,4,1,1
LESIZE,ALL,,,1
V,1,2,3,4,5,6,7,8
VEORIENT,1,THIN
ESIZE,,6                    ! 6X6 MESH USING QUARTER SYMMETRY
VMESH,1
NSEL,S,LOC,X,0
```

```
DSYM,SYMM,X
NSEL,S,LOC,Y,0
DSYM,SYMM,Y
NSEL,S,LOC,X,5              ! FREELY SUPPORTED B.C.
D,ALL,UZ,,,,,UY
NSEL,S,LOC,Y,5
D,ALL,UZ,,,,,UX
NSEL,ALL
SFE,ALL,6,PRES,,1           ! APPLY UNIFORM PRESSURE ON TOP SURFACE
OUTPR,NSOL,1
OUTPR,RSOL,1
FINISH
/OUT,SCRATCH
/SOLU
SOLVE
FINISH
/OUT
/POST1
NSEL,S,LOC,X                ! SELECT CENTER NODES
NSEL,R,LOC,Y
PRNSOL,U,Z                  ! PRINT CENTER DEFLECTION
*GET,DEF46,NODE,1,U,Z
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'DEF,m (S'
LABEL(1,2) = 'OLID190) '
*VFILL,VALUE(1,1),DATA,.0683
*VFILL,VALUE(1,2),DATA,ABS(DEF46)
*VFILL,VALUE(1,3),DATA,ABS(DEF46/.0683)
SAVE,INF2
FINISH
/CLEAR,NOSTART
/OUT,SCRATCH
/PREP7
SMRT,OFF
/TITLE, VM82, SIMPLY SUPPORTED LAMINATED PLATE UNDER PRESSURE
C*** USING SOLID186
ANTYPE,STATIC
ET,1,SOLID186               ! 20-NODE SOLID ELEMENT
KEYOPT,1,3,1                ! LAYERED SOLID ELEMENT
KEYOPT,1,8,1                ! WRITE LAYER RESULTS
SECDATA,0.025,1,0           ! LAYER 1: 0.025 THK, THETA 0
SECDATA,0.025,1,90          ! LAYER 2: 0.025 THK, THETA 90
SECDATA,0.025,1,90          ! LAYER 3: 0.025 THK, THETA 90
SECDATA,0.025,1,0           ! LAYER 4: 0.025 THK, THETA 0
MP,EX,1,25E6                ! ORTHOTROPIC MATERIAL PROPERTIES
MP,EY,1,1E6
MP,EZ,1,1E6                 ! EZ=EY ASSUMED
MP,GXY,1,5E5
MP,GYZ,1,2E5
MP,GXZ,1,5E5
MP,PRXY,1,0.25              ! MAJOR POISSONS RATIO
MP,PRYZ,1,0.01              ! MAJOR POISSONS RATIO
MP,PRXZ,1,0.25              ! MAJOR POISSONS RATIO
K,1                         ! CORNER KEYPOINTS OF QUADRANT (VOLUME)
K,2,5
K,3,5,5
K,4,,5
KGEN,2,1,4,1,,,0.1
L,1,5
*REPEAT,4,1,1
LESIZE,ALL,,,1
V,1,2,3,4,5,6,7,8
ESIZE,,6                    ! 6X6 MESH USING QUARTER SYMMETRY
VMESH,1
NSEL,S,LOC,X,0
DSYM,SYMM,X
NSEL,S,LOC,Y,0
DSYM,SYMM,Y
NSEL,S,LOC,X,5              ! FREELY SUPPORTED B.C.
D,ALL,UZ,,,,,UY
NSEL,S,LOC,Y,5
```

```
D,ALL,UZ,,,,,UX
NSEL,ALL
SFE,ALL,6,PRES,,1              ! APPLY UNIFORM PRESSURE ON TOP SURFACE
OUTPR,NSOL,1
OUTPR,RSOL,1
FINISH
/SOLU
SOLVE
FINISH
/OUT
/POST1
NSEL,S,LOC,X                   ! SELECT CENTER NODES
NSEL,R,LOC,Y
PRNSOL,U,Z                     ! PRINT CENTER DEFLECTION
*GET,DEF191,NODE,1,U,Z
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'DEF,m (S'
LABEL(1,2) = 'OLID186) '
*VFILL,VALUE(1,1),DATA,.0683
*VFILL,VALUE(1,2),DATA,ABS(DEF191)
*VFILL,VALUE(1,3),DATA,ABS(DEF191/.0683)
SAVE,INF3
FINISH
/CLEAR,NOSTART
/OUT,SCRATCH
/PREP7
SMRT,OFF
/TITLE, VM82, SIMPLY SUPPORTED LAMINATED PLATE UNDER PRESSURE
C*** USING SHELL181
/OUT,SCRATCH
/PREP7
SMRT,OFF
ANTYPE,STATIC
ET,1,SHELL181                  ! 4 NODE LAYERED SHELL
KEYOPT,1,3,2                   ! FULL INTEGRATION
KEYOPT,1,8,1                   ! WRITE LAYER RESULTS
SECTYPE,1,SHELL
SECDATA,0.025,1,0              ! LAYER 1: 0.025 THK, THETA 0
SECDATA,0.025,1,90             ! LAYER 2: 0.025 THK, THETA 90
SECDATA,0.025,1,90             ! LAYER 3: 0.025 THK, THETA 90
SECDATA,0.025,1,0              ! LAYER 4: 0.025 THK, THETA 0
MP,EX,1,25E6                   ! ORTHOTROPIC MATERIAL PROPERTIES
MP,EY,1,1E6
MP,EZ,1,1E6                    ! EZ=EY ASSUMED
MP,GXY,1,5E5
MP,GYZ,1,2E5
MP,GXZ,1,5E5
MP,PRXY,1,0.25                 ! MAJOR POISSONS RATIO
MP,PRYZ,1,0.01                 ! MAJOR POISSONS RATIO
MP,PRXZ,1,0.25                 ! MAJOR POISSONS RATIO
K,1                            ! CORNER KEYPOINTS OF QUADRANT (AREA)
K,2,5
K,3,5,5
K,4,,5
A,1,2,3,4
ESIZE,,6                       ! 6X6 MESH USING QUARTER SYMMETRY
AMESH,1
NSEL,S,LOC,X,0
DSYM,SYMM,X
NSEL,S,LOC,Y,0
DSYM,SYMM,Y
NSEL,S,LOC,X,5                 ! APPLY FREELY SUPPORTED B.C.
D,ALL,UZ,,,,,UY
NSEL,S,LOC,Y,5
D,ALL,UZ,,,,,UX
NSEL,ALL
SFE,ALL,2,PRES,,1              ! APPLY UNIFORM PRESSURE
OUTPR,NSOL,1
OUTPR,RSOL,1
FINISH
/SOLU
```

```
SOLVE
FINISH
/OUT
/POST1
NSEL,S,LOC,X                ! SELECT CENTER NODE
NSEL,R,LOC,Y
PRNSOL,U,Z                  ! PRINT CENTER DEFLECTION
*GET,DEF99,NODE,1,U,Z
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'DEF,m (S'
LABEL(1,2) = 'HELL181)'
*VFILL,VALUE(1,1),DATA,.0683
*VFILL,VALUE(1,2),DATA,ABS(DEF99)
*VFILL,VALUE(1,3),DATA,ABS(DEF99/.0683)
SAVE,INF4
FINISH
FINISH
/CLEAR, NOSTART
/PREP7
SMRT,OFF
/TITLE, VM82, SIMPLY SUPPORTED LAMINATED PLATE UNDER PRESSURE
C*** USING SHELL281
/OUT,SCRATCH
/PREP7
SMRT,OFF
ANTYPE,STATIC
ET,1,SHELL281               ! 8 NODE LAYERED SHELL
KEYOPT,1,8,1                ! WRITE LAYER RESULTS
SECTYPE,1,SHELL
SECDATA,0.025,1,0           ! LAYER 1: 0.025 THK, THETA 0
SECDATA,0.025,1,90          ! LAYER 2: 0.025 THK, THETA 90
SECDATA,0.025,1,90          ! LAYER 3: 0.025 THK, THETA 90
SECDATA,0.025,1,0           ! LAYER 4: 0.025 THK, THETA 0
MP,EX,1,25E6                ! ORTHOTROPIC MATERIAL PROPERTIES
MP,EY,1,1E6
MP,EZ,1,1E6                 ! EZ=EY ASSUMED
MP,GXY,1,5E5
MP,GYZ,1,2E5
MP,GXZ,1,5E5
MP,PRXY,1,0.25              ! MAJOR POISSONS RATIO
MP,PRYZ,1,0.01              ! MAJOR POISSONS RATIO
MP,PRXZ,1,0.25              ! MAJOR POISSONS RATIO
K,1                         ! CORNER KEYPOINTS OF QUADRANT (AREA)
K,2,5
K,3,5,5
K,4,,5
A,1,2,3,4
ESIZE,,6                    ! 6X6 MESH USING QUARTER SYMMETRY
AMESH,1
NSEL,S,LOC,X,0
DSYM,SYMM,X
NSEL,S,LOC,Y,0
DSYM,SYMM,Y
NSEL,S,LOC,X,5              ! APPLY FREELY SUPPORTED B.C.
D,ALL,UZ,,,,,UY
NSEL,S,LOC,Y,5
D,ALL,UZ,,,,,UX
NSEL,ALL
SFE,ALL,2,PRES,,1           ! APPLY UNIFORM PRESSURE
OUTPR,NSOL,1
OUTPR,RSOL,1
FINISH
/SOLU
SOLVE
FINISH
/OUT
/POST1
NSEL,S,LOC,X                ! SELECT CENTER NODE
NSEL,R,LOC,Y
PRNSOL,U,Z                  ! PRINT CENTER DEFLECTION
*GET,DEF99,NODE,1,U,Z
```

```
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'DEF,m (S'
LABEL(1,2) = 'HELL281)'
*VFILL,VALUE(1,1),DATA,.0683
*VFILL,VALUE(1,2),DATA,ABS(DEF99)
*VFILL,VALUE(1,3),DATA,ABS(DEF99/.0683)
SAVE,INF5
RESUME,INF1
/COM
/OUT,vm82,vrt
/COM,------------------- VM82 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,INF2
/GOPR
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,INF3
/GOPR
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,INF4
/GOPR
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,INF5
/GOPR
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm82,vrt
/OUT,SCRATCH
/DELETE,INF1
/DELETE,INF2
/DELETE,INF3
/DELETE,INF4
/DELETE,INF5
```

VM83 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM83
/PREP7
/TITLE, VM83, IMPACT OF A BLOCK ON A SPRING SCALE
C***VECTOR MECHANICS FOR ENGINEERS, BEER AND JOHNSTON, 1962, PAGE 531, PROB 14.6
C*** WITH THANKS TO ALAN GOULD
ANTYPE,TRANS              ! NONLINEAR TRANSIENT DYNAMIC ANALYSIS
ET,1,COMBIN40,1,,2,,,2
ET,2,COMBIN40,,,2,,,2
R,1,100,,(25/386)         ! SPRING CONSTANT = 100, MASS = (25/386)
R,2,1E4,50.899,(50/386),71.75 ! SPRING CONSTANT = 1E4, C = 50.90,M=(50/386)
N,1,,-10
N,2
N,3,,72
TYPE,2
E,1,2
TYPE,1
REAL,2
```

```
E,2,3
ACEL,,386                 ! GRAVITY
FINISH
/SOLU
TIMINT,OFF                ! TIME INTEGRATION TURNED OFF
KBC,1                     ! STEP THE LOAD
NSUBST,2                  ! TWO SUBSTEPS TO GET ZERO INITIAL VELOCITY
                          !  AND ACCELERATION
D,1,UY,,,3,2
TIME,1E-8                 ! NEAR ZERO TIME FOR FIRST LOAD STEP
/OUT,SCRATCH
SOLVE
TIMINT,ON                 ! TIME INTEGRATION TURNED ON
DDELE,3,UY                ! REMOVE THE CONSTRAINT AT NODE 3 (RELEASE THE BLOCK)
AUTOTS,ON                 ! AUTO TIME STEPPING ON
NSUBST,1400               ! MAXIMUM 1400 SUBSTEPS
OUTRES,NSOL,1
TIME,.7
SOLVE
FINISH
/POST26
/OUT,
NSOL,2,2,U,Y,UY           ! STORE DISPLACEMENTS UY OF APPROPRIATE NODES
NSOL,3,3,U,Y,UY
FILLDATA,4,,,,71.75       ! DEFINE VARIABLE 4 AS CONSTANT
ADD,5,3,4,,3OFFSET        ! CALCULATE VARIABLE 5 AS 3UY + 71.75
PRTIME,.65,.7             ! LIMIT TIME INTERVAL TO BE PRINTED
PRVAR,2,3                 ! PRINT VARIABLES 2 AND 3
/AXLAB,Y,INCH
PLVAR,2,5                 ! DISPLAY VARIABLES 2 AND 5
*GET,DEF_N2,VARI,2,RTIME,0.68897
*GET,DEF_N3,VARI,3,RTIME,0.68897
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = '   DEF, ','   Y,    '
LABEL(1,2) = 'in       ','in       '
*VFILL,VALUE(1,1),DATA,-7.7,-79.450
*VFILL,VALUE(1,2),DATA,DEF_N2,DEF_N3
*VFILL,VALUE(1,3),DATA,ABS(DEF_N2/7.7) ,ABS(DEF_N3/79.450)
/COM
/OUT,vm83,vrt
/COM,------------------- VM83 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm83,vrt
```

VM84 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM84
/PREP7
/TITLE, VM84, DISPLACEMENT PROPAGATION ALONG A BAR WITH FREE ENDS
C***      VIBRATION PROBS. IN ENGR., TIMOSHENKO, 3RD. ED., PAGE 311, PROB. 2
ET,1,LINK180
SECTYPE,1,LINK
SECDATA,2                ! AREA = 2
MP,EX,1,3E7
MP,DENS,1,7202E-7
N,1
N,17,48E3
FILL
E,1,2
```

```
EGEN,16,1,1
D,ALL,UZ
D,ALL,UY
FINISH
/OUT,SCRATCH
/SOLU
ANTYPE,MODAL
MODOPT,LANB,17          ! PERFORM MODAL SOLVE USING LANB EIGENSOLVER
MXPAND,17
SOLVE
FINISH
/SOLU
ANTYPE,TRANSIENT
TRNOPT,MSUP,17           ! PERFORM MODE SUPERPOSITION TRANSIENT SOLVE
DELTIM,5E-3              ! INTEGRATION TIME STEP SIZE
KBC,1                    ! STEP LOADING CONDITION
OUTPR,BASIC,LAST
F,17,FX                  ! DEFINE NULL FX LOAD AT NODE 17
SOLVE

OUTPR,BASIC,2
OUTRES,NSOL,1
TIME,.24                 ! FINAL TIME INCLUDES 1/2 OF THE FUNDAMENTAL PERIOD
F,17,FX,6000             ! APPLY FULL LOAD TO NODE 17
SOLVE
FINISH

/OUT,
/POST26
FILE,,rdsp               ! REDUCED DISPLACEMENTS FILE
NSOL,2,1,U,X,1UX         ! STORE APPROPRIATE NODAL DISPLACEMENTS
NSOL,3,9,U,X,9UX
NSOL,4,17,U,X,17UX
DERIV,5,2,,,1VX          ! COMPUTE VELOCITIES
DERIV,6,3,,,9VX
DERIV,7,4,,,17VX
/GRID,1                  ! TURN GRID ON
/AXLAB,Y,DISP            ! Y-AXIS LABEL DISP
PLVAR,2,3,4              ! DISPLAY VARIABLES 2, 3 AND 4
/AXLAB,Y,VELO            ! Y-AXIS LABEL VELO
PLVAR,5,6,7              ! DISPLAY VARIABLES 5, 6 AND 7
PRTIME,0.230,0.240       ! APPROPRIATE TIME RANGE (.23 TO .24)
PRVAR,4                  ! PRINT VARIABLE 4 (UX AT NODE 17)
*GET,DEF,VARI,4,RTIME,.240
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '    DEF,'
LABEL(1,2) = 'in      '
*VFILL,VALUE(1,1),DATA,4.8
*VFILL,VALUE(1,2),DATA,DEF
*VFILL,VALUE(1,3),DATA,ABS(DEF/4.8)
/COM
/OUT,vm84,vrt
/COM,------------------- VM84 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm84,vrt
```

VM85 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM85
```

```
/PREP7
/TITLE, VM85, TRANSIENT DISPLACEMENTS IN A SUDDENLY STOPPED MOVING BAR
C***      VIBRATION PROBS. IN ENGR., TIMOSHENKO, 3RD. ED., PAGE 305, PROB. NO. 3
ET,1,LINK180
SECTYPE,1,LINK
SECDATA,1                   ! AREA
MP,EX,1,30E6
MP,DENS,1,.00073
N,1
N,17,10000
FILL
E,1,2
EGEN,16,1,1
ALLSEL,ALL
D,ALL,UZ,0
D,ALL,UY,0
GP,1,20,FX,3E7,.64          ! GAP CONDITION
FINISH
/SOLU
ANTYPE,MODAL
MODOPT,LANB,17              ! PERFORM MODAL SOLVE USING LANB EIGENSOLVER
MXPAND,17
/OUT,SCRATCH
SOLVE
FINISH
/SOLU
ANTYPE,TRANSIENT
TRNOPT,MSUP,17              ! PERFORM MODE SUPERPOSITION TRANSIENT SOLVE
DELTIM,.0001                ! ITS DEFINITION
KBC,1                       ! STEP BOUNDARY CONDITION
F,1,FX,,,17                 ! DEFINE NULL FORCES ON ALL BAR NODES
SOLVE

TIME,.0004
F,1,FX,57031.25,,17,16      ! FORCES REQUIRED TO ACHIEVE INITIAL VELOCITY
F,2,FX,114062.5,,16
SOLVE

TIME,.06
F,1,FX,,,17                 ! REMOVE FORCES ("COAST")
SOLVE

FINISH
/POST26
FILE,,rdsp                  ! REDUCED DISPLACEMENTS FILE
NSOL,2,1,U,X
NSOL,3,17,U,X
NSOL,5,9,U,X
ADD,4,2,3,,REL_DISP,,,-1    ! COMPUTE RELATIVE DISPLACEMENTS
PRTIME,.053,.057
PRVAR,2,3,4,5
/AXLAB,Y,DISPLACEMENTS
PLVAR,2,3,4,5
DERIV,6,2,,,1 VX            ! COMPUTE VELOCITIES
DERIV,7,3,,,17VX
DERIV,8,5,,,9 VX
/AXLAB,Y,VELOCITY
/OUT,
PLVAR,6,7,8
*GET,D_0544,VARI,4,RTIME,.0544
*GET,D_0557,VARI,4,RTIME,.0557

*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'D,in(T=.','D,in(T=.','D,in(T=.'
LABEL(1,2) = '05573sec','0544sec)','0557sec)'
*VFILL,VALUE(1,1),DATA,4.9329,0,0
*VFILL,VALUE(1,2),DATA,0,D_0544,D_0557
*VFILL,VALUE(1,3),DATA,0,ABS(D_0544/4.9329),ABS(D_0557/4.9329)
FINISH
/SOLU
EXPASS,ON                   ! EXPANSION PASS
```

```
EXPSOL,,,0.0557             ! EXPAND SOLUTION AT TIME CLOSEST TO THE THEORETICAL TIME POINT
OUTPR,,1
/OUT,SCRATCH
SOLVE
FINISH
/POST1
SET,LAST
/OUT,
ETABLE,STRS,LS,1
*GET,STRSS,ELEM,1,ETAB,STRS
*DIM,LABEL_2,CHAR,2,2
*DIM,VALUE_2,,2,3
LABEL_2(1,1) = 'SIGX,PSI','SIGX,PSI'
LABEL_2(1,2) = 'T=.05573',' T=.0557'
*VFILL,VALUE_2(1,1),DATA,14799,0
*VFILL,VALUE_2(1,2),DATA,0,STRSS
*VFILL,VALUE_2(1,3),DATA,0,ABS(STRSS/14799)
/COM
/OUT,vm85,vrt
/COM,------------------- VM85 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,MODE SUPERPOSITION TRANSIENT DYNAMIC:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,
/COM,EXPANSION PASS:
/COM,
*VWRITE,LABEL_2(1,1),LABEL_2(1,2),VALUE_2(1,1),VALUE_2(1,2),VALUE_2(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm85,vrt
```

VM86 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM86
/PREP7
/TITLE, VM86, HARMONIC RESPONSE OF A DYNAMIC SYSTEM
C*** VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 56, EX 3.1-2
C***                BY VISCOUS DAMPING APPROACH
ANTYPE,HARMIC       ! HARMONIC RESPONSE ANALYSIS
HROPT,FULL
HROUT,OFF           ! PRINT COMPLEX DISP. AS AMPLITUDES AND PHASE ANGLES
ET,1,COMBIN40,,,3,,,2
R,1,200,6,.5        ! SPRING STIFFNESS = 200, C = 6, M = .5
N,1
N,2
E,1,2
OUTPR,BASIC,1
HARFRQ,,3.1831      ! HARMONIC FREQUENCY RANGE
D,1,UZ
F,2,FZ,10
FINISH
/SOLU
SOLVE
FINISH
/POST26
FILE,,rst
NSOL,2,2,U,Z,2UX
PRVAR,2
*GET,A,VARI,2,ITIME,3.1831
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
```

```
LABEL(1,1) = 'AMPLITUD'
LABEL(1,2) = 'E, in   '
*VFILL,VALUE(1,1),DATA,.0833
*VFILL,VALUE(1,2),DATA,ABS(A)
*VFILL,VALUE(1,3),DATA,ABS(A/.0833)
/COM
/OUT,vm86,vrt
/COM,------------------- VM86 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,----------------------------------------------------------
/COM,
/COM,----------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM86  NOT CONTAINED IN
/COM,THIS TABLE
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm86,vrt
```

VM87 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM87
/PREP7
/TITLE, VM87, EQUIVALENT STRUCTURAL DAMPING
C***         VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND. PRINTING, PAGE 72,
C***         ART. 3.9, AND PAGE 56, EX. 3.1-2
ANTYPE,HARMIC            ! HARMONIC RESPONSE ANALYSIS
HROPT,FULL               ! FULL HARMONIC RESPONSE
HROUT,OFF                ! PRINT COMPLEX DISP. AS AMPLITUDES AND PHASE ANGLES
ET,1,COMBIN40,,,3,,,2
BETAD,.03                ! EQUIVALENT STRUCTURAL DAMPING
R,1,200,,.5              ! SPRING STIFFNESS = 200, C = 0, M = 0.5
N,1
N,2
E,1,2
OUTPR,BASIC,1
HARFRQ,,3.1831           ! HARMONIC FREQUENCY RANGE
D,1,UZ
F,2,FZ,10
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST26
FILE,,rst
/OUT,
NSOL,2,2,U,Z,2UX
PRVAR,2
*GET,A,VARI,2,ITIME,3.1831
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'AMPLITUD'
LABEL(1,2) = 'E, in   '
*VFILL,VALUE(1,1),DATA,.0833
*VFILL,VALUE(1,2),DATA,ABS(A)
*VFILL,VALUE(1,3),DATA,ABS(A/.0833)
/COM
/OUT,vm87,vrt
/COM,------------------- VM87 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
```

```
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,----------------------------------------------------------
/COM,
/COM,----------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM87  NOT CONTAINED IN
/COM,THIS TABLE
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm87,vrt
```

VM88 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM88
/PREP7
/TITLE, VM88, RESPONSE OF AN ECCENTRIC WEIGHT EXCITER
! VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 60, EX 3.3-1
ANTYPE,HARMIC              ! HARMONIC RESPONSE ANALYSIS
HROPT,FULL                 ! FULL HARMONIC RESPONSE
HROUT,OFF                  ! PRINT COMPLEX DISP. AS AMPLITUDES AND PHASE ANGLES
ET,1,COMBIN40
R,1,30,.11754533,.02590673 ! K = 30, C = .11754533, M = .02590673
N,1
N,2
E,2,1
FINISH
/SOLU
OUTPR,BASIC,1
HARFRQ,,5.415947           ! FREQUENCY RANGE FROM 0 TO 5.415947 HZ.
D,1,UX
F,2,FX,2.4
SOLVE
HARFRQ,,541.5947           ! FREQUENCY RANGE FROM 0 TO 541.5947 HZ.
F,2,FX,24000
SOLVE
FINISH
/POST26
FILE,,rst
NSOL,2,2,U,X,2UX
PRVAR,2
*GET,A1,VARI,2,ITIME,5.4159
*GET,A2,VARI,2,RTIME,541.59
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'AMP f=fn','AMP f=10'
LABEL(1,2) = ', in    ','0fn, in '
*VFILL,VALUE(1,1),DATA,.6,.08
*VFILL,VALUE(1,2),DATA,ABS(A1),ABS(A2)
*VFILL,VALUE(1,3),DATA,ABS(A1/.6),ABS(A2/.08)
/COM
/OUT,vm88,vrt
/COM,------------------- VM88 RESULTS COMPARISON ---------------

/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,----------------------------------------------------------
/COM,
/COM,----------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM88  NOT CONTAINED IN
/COM,THIS TABLE
/COM,----------------------------------------------------------
/OUT
FINISH
```

```
*LIST,vm88,vrt
```

VM89 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM89
/PREP7
/TITLE, VM89, NATURAL FREQUENCIES OF A TWO-MASS-SPRING SYSTEM
C*** VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 163,EX 6.2-2
ANTYPE,MODAL        ! MODE-FREQUENCY ANALYSIS
MODOPT,LANB,2
ET,1,COMBIN14,,,2
ET,2,MASS21,,,4
R,1,200             ! SPRING CONSTANT = 200
R,2,800             ! SPRING CONSTANT = 800
R,3,.5              ! MASS = .5
R,4,1               ! MASS = 1
N,1
N,4,1
FILL
E,1,2               ! SPRING ELEMENT (TYPE,1) AND K = 200 (REAL,1)
TYPE,2
REAL,3
E,2                 ! MASS ELEMENT (TYPE,2) AND MASS = .5 (REAL,3)
TYPE,1
REAL,2
E,2,3               ! SPRING ELEMENT (TYPE,1) AND K = 800 (REAL,2)
TYPE,2

REAL,4
E,3                 ! MASS ELEMENT (TYPE,2) AND MASS = 1 (REAL,4)
TYPE,1
REAL,1
E,3,4               ! SPRING ELEMENT (TYPE,1) AND K = 200 (REAL,1)
OUTPR,BASIC,1
D,1,UY,,,4
D,1,UX,,,4,3
FINISH
/SOLU
SOLVE

/post1
SET,1,1
*GET,UX2_F1,NODE,2,U,X
*GET,UX3_F1,NODE,3,U,X
SET,1,2
*GET,UX2_F2,NODE,2,U,X
*GET,UX3_F2,NODE,3,U,X

*GET,FREQ1,MODE,1,FREQ
*GET,FREQ2,MODE,2,FREQ

*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,4

LABEL(1,1) = 'f1'

LABEL(1,2) = '(Hz)'

LABEL(2,1) = 'f2'
LABEL(2,2) = '(Hz)'

LABEL(3,1) = 'A1/A2 @1'
LABEL(3,2) = ' '

LABEL(4,1) = 'A1/A2 @2'
LABEL(4,2) = ' '
```

```
*VFILL,VALUE(1,1),DATA,2.5814
*VFILL,VALUE(1,2),DATA,FREQ1
*VFILL,VALUE(1,3),DATA,ABS(FREQ1/2.5814 )

*VFILL,VALUE(2,1),DATA,8.3263
*VFILL,VALUE(2,2),DATA,FREQ2
*VFILL,VALUE(2,3),DATA,ABS( FREQ2/8.3263)

*VFILL,VALUE(3,1),DATA,0.92116
*VFILL,VALUE(3,2),DATA,ux2_f1/ux3_f1
*VFILL,VALUE(3,3),DATA,ABS(ux2_f1/ux3_f1/0.92116)

*VFILL,VALUE(4,1),DATA,-2.1711
*VFILL,VALUE(4,2),DATA,ux2_f2/ux3_f2
*VFILL,VALUE(4,3),DATA,ABS(ux2_f2/ux3_f2/2.1711)

/COM
/OUT,vm89,vrt
/COM,------------------- VM89 RESULTS COMPARISON ---------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,
/COM,----------------------------------------------------------
/COM,
/OUT
FINISH
*LIST,vm89,vrt
```

VM90 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM90
/PREP7
/TITLE, VM90, HARMONIC RESPONSE OF A TWO-MASS-SPRING SYSTEM
C*** VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 178,EX 6.6-1
ANTYPE,HARMIC              ! HARMONIC RESPONSE ANALYSIS
HROPT,FULL                 ! FULL HARMONIC RESPONSE
HROUT,OFF                  ! PRINT RESULTS AS AMPLITUDES AND PHASE ANGLES
ET,1,COMBIN14,,,2
ET,2,MASS21,,,4
R,1,200                    ! SPRING CONSTANT = 200
R,2,.5                     ! MASS = 0.5
N,1
N,4,1
FILL
E,1,2
TYPE,2
REAL,2
E,2                        ! MASS ELEMENT
TYPE,1
REAL,1
E,2,3                      ! SPRING ELEMENT
TYPE,2
REAL,2
E,3                        ! MASS ELEMENT
TYPE,1
REAL,1
E,3,4                      ! SPRING ELEMENT
OUTPR,BASIC,1
NSUBST,30                  ! 30 INTERVALS WITHIN FREQ. RANGE
HARFRQ,,7.5                ! FREQUENCY RANGE FROM 0 TO 7.5 HZ
KBC,1                      ! STEP BOUNDARY CONDITION
D,1,UY,,,4
D,1,UX,,,4,3
```

```
F,2,FX,200
FINISH
/SOLU
SOLVE
FINISH
/POST26
FILE,,rst
NSOL,2,2,U,X,2UX          ! STORE UX DISPLACEMENTS
NSOL,3,3,U,X,3UX
PRVAR,2,3
*GET,X1,VARI,2,RTIME,1.5
*GET,X2,VARI,3,RTIME,1.5
*GET,X3,VARI,2,RTIME,4
*GET,X4,VARI,3,RTIME,4
*GET,X5,VARI,2,RTIME,6.5
*GET,X6,VARI,3,RTIME,6.5
/GRID,1                   ! TURN GRID ON
/AXLAB,Y,DISP             ! Y-AXIS LABEL DISP
PLVAR,2,3                 ! DISPLAY VARIABLES 2 AND 3
*DIM,LABEL,CHAR,6,2
*DIM,VALUE,,6,3
LABEL(1,1) = 'X1, in  ','X2, in  ','X1, in  ','X2, in  ','X1, in  ','X2, in  '
LABEL(1,2) = 'f=1.5 Hz','f=1.5 Hz','f=4 Hz  ','f=4 Hz  ','f=6.5 Hz','f=6.5 Hz'
*VFILL,VALUE(1,1),DATA,.82272,.46274,.51145,1.2153,.58513,.26966
*VFILL,VALUE(1,2),DATA,ABS(X1),ABS(X2),ABS(X3),ABS(X4),ABS(X5),ABS(X6)
V1 = ABS(X1/.82272)
V2 = ABS(X2/.46274)
V3 = ABS(X3/.51145)
V4 = ABS(X4/1.2153)
V5 = ABS(X5/.58513)
V6 = ABS(X6/.26965)
*VFILL,VALUE(1,3),DATA,V1,V2,V3,V4,V5,V6
/COM
/OUT,vm90,vrt
/COM,------------------- VM90 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,-----------------------------------------------------------
/COM,
/COM,-----------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM90  NOT CONTAINED IN
/COM,THIS TABLE
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm90,vrt
```

VM91 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM91
/PREP7
/TITLE, VM91, LARGE ROTATION OF A SWINGING PENDULUM
C*** VIBRATION THEORY AND APPLICATIONS, THOMSON, 2ND PRINTING, PAGE 138,EX 5.4-1
/NOPR
ANTYPE,TRANS            ! NONLINEAR TRANSIENT DYNAMIC ANALYSIS
NLGEOM,ON               ! LARGE DEFLECTION OPTION
ET,1,LINK180
ET,2,MASS21,,,2
SECTYPE,1,LINK
SECDATA,0.1             ! AREA = .1
R,2,.5                  ! MASS = 0.5
MP,EX,1,3E7
N,1
N,2,60,-80
```

```
E,1,2                 ! ROD
TYPE,2
REAL,2
E,2                   ! MASS
SAVE
FINISH
*CREATE,SLV
/out,scratch
/SOLU
ACEL,,386
KBC,1                 ! STEP BOUNDARY CONDITION
D,1,UZ,,,2
D,1,UX,,,,,UY
TIME,.01              ! INITIAL L.S. TO ATTAIN FINAL ACCELERATION
NSUBST,5
OUTRES,,1
LSWRITE,1             ! WRITE LOAD STEP FILE 1
TIME,.82071           ! SUCCEEDING LOAD STEPS AT T/4 INCREMENTS
NSUBST,8
OUTRES,,1
LSWRITE,2             ! WRITE LOAD STEP FILE 2
TIME,1.64142
LSWRITE,3             ! WRITE LOAD STEP FILE 3
TIME,2.46213
LSWRITE,4             ! WRITE LOAD STEP FILE 4
TIME,3.28284
LSWRITE,5             ! WRITE LOAD STEP FILE 5
LSSOLVE,1,5,1         ! READ IN LOAD STEP FILES 1 THROUGH 5 AND SOLVE
FINISH
/out
*END
*USE,SLV
*CREATE,P26
/POST26
NSOL,2,2,U,X,UX2       ! STORE NODE 2 DISPLACEMENTS
NSOL,3,2,U,Y,UY2
PRVAR,2,3              ! PRINT DISPLACEMENTS VS. TIME
/AXLAB,Y,DISPLACEMENTS ! Y-AXIS LABEL
PLVAR,2,3              ! DISPLAY DISPLACEMENTS VS. TIME.
T = 3.28284
*GET,DEFX_Q,VARI,2,RTIME,T/4
*GET,DEFY_Q,VARI,3,RTIME,T/4
*GET,DEFX_H,VARI,2,RTIME,T/2
*GET,DEFY_H,VARI,3,RTIME,T/2
*GET,DEFX_3Q,VARI,2,RTIME,3*T/4
*GET,DEFY_3Q,VARI,3,RTIME,3*T/4
*GET,DEFX_F,VARI,2,RTIME,T
*GET,DEFY_F,VARI,3,RTIME,T
*DIM,LABEL,CHAR,8,2
*DIM,VALUE,,8,3
LABEL(1,1) = 'DEFX,in ','DEFY,in ','DEFX,in ','DEFY,in ','DEFX,in ','DEFY,in '
LABEL(7,1) = 'DEFX,in ','DEFY,in '
LABEL(1,2) = 'TIME=T/4','TIME=T/4','TIME=T/2','TIME=T/2','TIM=3T/4','TIM=3T/4'
LABEL(7,2) = 'TIME= T ','TIME= T '
*END
*USE,P26
*VFILL,VALUE(1,1),DATA,-60,-20,-120,0,-60,-20,0,0
*VFILL,VALUE(1,2),DATA,DEFX_Q,DEFY_Q,DEFX_H,DEFY_H,DEFX_3Q,DEFY_3Q,DEFX_F,DEFY_F
*VFILL,VALUE(1,3),DATA,ABS(DEFX_Q/60),ABS(DEFY_Q/20),ABS(DEFX_H/120),0,ABS(DEFX_3Q/60)
*VFILL,VALUE(6,3),DATA,ABS(DEFY_3Q/20),0,0
SAVE,TABLE1
FINISH
RESUME,TABLE1
/OUT,vm91,vrt
/COM,
/COM,------------------- VM91 RESULTS COMPARISON---------------
/COM,
/COM, LINK180 Results |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,-----------------------------------------------------------
```

```
/OUT
FINISH
/DELETE,vm91,s01
/DELETE,vm91,s02
/DELETE,vm91,s03
/DELETE,vm91,s04
/DELETE,vm91,s05
FINISH
*LIST,vm91,vrt
```

VM92 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM92
/PREP7
/TITLE, VM92, INSULATED WALL TEMPERATURE
C***        PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 32, EX. 2-5
ANTYPE,STATIC                ! THERMAL ANALYSIS
ET,1,LINK34
ET,2,LINK33
R,1,1                        ! AREA = 1
MP,KXX,1,.8
MP,HF,1,12
MP,KXX,2,.1
MP,HF,2,2
N,1
N,2
N,3,.75
N,4,(14/12)                  ! 14 INCHES TO FEET
N,5,(14/12)
E,1,2
TYPE,2
E,2,3
MAT,2
E,3,4
TYPE,1
E,4,5
D,1,TEMP,3000
D,5,TEMP,80
FINISH
/SOLU
SOLVE
FINISH
/POST1
PRNSOL,TEMP                  ! PRINT NODAL TEMPERATURES
PRNLD,HEAT                   ! PRINT HEAT FLOW RATES
*GET,TI,NODE,2,TEMP
*GET,TO,NODE,4,TEMP
FINISH
/POST26
ESOL,2,4,5,HEAT,,HEAT
STORE
*GET,HEAT,VARI,2,EXTREM,VMAX
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'Q, BTU/h','TI,     ','TO,     '
LABEL(1,2) = 'r       ','F       ','F       '
*VFILL,VALUE(1,1),DATA,513,2957,336
*VFILL,VALUE(1,2),DATA,HEAT,TI,TO
*VFILL,VALUE(1,3),DATA,ABS(HEAT/513) ,ABS(TI/2957),ABS(TO/336)
/COM
/OUT,vm92,vrt
/COM,------------------- VM92 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
```

```
/COM,---------------------------------------------------------
/OUT
FINISH
*LIST,vm92,vrt
```

VM93 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM93
/PREP7
/TITLE, VM93, TEMPERATURE DEPENDENT CONDUCTIVITY
C***        PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 25, EX. 2-2
ANTYPE,STATIC
ET,1,LINK33
MP,KXX,1,.031,31E-6      ! TEMPERATURE-DEPENDENT CONDUCTIVITY
R,1,1                    ! AREA = 1
N,1
N,2,.25
E,1,2
OUTPR,ALL,1
OUTPR,VENG,NONE
KBC,1                    ! STEP BOUNDARY CONDITIONS
D,1,TEMP,300
D,2,TEMP,100
FINISH
/SOLU
SOLVE
FINISH
/POST26
ESOL,2,1,2,HEAT,,HEAT
STORE
*GET,HEAT,VARI,2,EXTREM,VMAX
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'Q, BTU/h'
LABEL(1,2) = 'r       '
*VFILL,VALUE(1,1),DATA,29.760
*VFILL,VALUE(1,2),DATA,HEAT
*VFILL,VALUE(1,3),DATA,ABS(HEAT/29.760 )
/COM
/OUT,vm93,vrt
/COM,------------------- VM93 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,---------------------------------------------------------
/OUT
FINISH
*LIST,vm93,vrt
```

VM94 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM94
/PREP7
/TITLE, VM94, HEAT GENERATING PLATE
C***        PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 42, EX. 2-9
ANTYPE,STATIC
ET,1,LINK33
ET,2,LINK34
R,1,1                        ! AREA = 1
MP,KXX,1,25                  ! CONDUCTIVITY
```

```
MP,HF,1,13.969738            ! CONVECTION COEFFICIENT
N,1
N,5,((.5/12)*.5)
FILL
N,6,((.5/12)*.5)
E,1,2                        ! LINK32 ELEMENTS (CONDUCTION)
EGEN,4,1,1
TYPE,2
E,5,6                        ! LINK34 ELEMENT (CONVECTION)
D,6,TEMP,150                 ! SPECIFY "FLUID" TEMPERATURES
ESEL,S,ELEM,,1,4
BFE,ALL,HGEN,,1E5            ! HEAT GENERATION
ESEL,ALL
FINISH
/SOLU
SOLVE
FINISH
/POST1
PRNSOL,TEMP                  ! PRINT NODAL TEMPERATURES
PRNLD,HEAT                   ! PRINT NODAL HEAT FLOW RATES
FINISH
/POST1
*GET,TC,NODE,1,TEMP
FINISH
/POST26
ESOL,2,5,6,HEAT,,HEAT
STORE
*GET,HEAT,VARI,2,EXTREM,VMAX
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'Qf, BTU/','Tc,      '
LABEL(1,2) = 'hr      ',' F       '
*VFILL,VALUE(1,1),DATA,2083.3,299.1
*VFILL,VALUE(1,2),DATA,HEAT,TC
*VFILL,VALUE(1,3),DATA,ABS(HEAT/2083.3) ,ABS(TC/299.1)
/COM
/OUT,vm94,vrt
/COM,------------------- VM94 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm94,vrt
```

VM95 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM95
/PREP7
/TITLE, VM95, HEAT TRANSFER FROM A COOLING SPINE
C***  PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 48, EQNS. 2-44,45
C***  USING LINK33 AND LINK34 ELEMENTS
ANTYPE,STATIC
ET,1,LINK33
ET,2,LINK34
R,1,(1/144)                     ! CONVERT AREAS INTO SQUARE FT. UNITS
R,2,(1/72)
R,3,(4/144)
MP,KXX,1,25
MP,HF,1,1
N,1
N,9,(8/12)
FILL
N,11
```

```
N,19
FILL
E,1,2                           ! DEFINE ELEMENTS
TYPE,2
REAL,2
E,1,11
TYPE,1
REAL,1
E,2,3
TYPE,2
REAL,3
E,2,12
EGEN,7,1,3,4
REAL,2
E,9,19
D,1,TEMP,100                    ! DEFINE WALL AND TIP TEMPERATURES
D,11,TEMP,,,19
FINISH
/SOLU
SOLVE
FINISH
/POST1
PRNSOL,TEMP                     ! PRINT NODAL TEMPERATURES
NSEL,S,NODE,,1                  ! SELECT NODE 1
PRNLD,HEAT                      ! PRINT NODAL HEAT FLOWS
FSUM                            ! PRINT HEAT FLOW SUMMATION
ALLSEL
*GET,TL,NODE,9,TEMP
/POST26
ESOL,2,2,1,HEAT,,HEAT
ESOL,3,1,1,HEAT,,HEAT
STORE
*GET,HEAT,VARI,2,EXTREM,VMAX
*GET,HEAT2,VARI,3,EXTREM,VMAX
HTTOT=(ABS(HEAT+HEAT2))
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = '      TL','Q,  BTU/'
LABEL(1,2) = ', F     ','hr  '
*VFILL,VALUE(1,1),DATA,68.594,17.504
*VFILL,VALUE(1,2),DATA,TL,HTTOT
*VFILL,VALUE(1,3),DATA,ABS(TL/68.594),ABS(HTTOT/17.504)
SAVE,TABLE1
FINISH

/CLEAR, NOSTART ! CLEAR DATABASE BEFORE STARTING PART 2
/PREP7
C***  USING SOLID70 ELEMENTS
ANTYPE,STATIC
ET,1,SOLID70
MP,KXX,1,25
LOCAL,11,0,,(-.5/12),(-.5/12)
N,1
N,9,(8/12)
FILL
NGEN,2,10,1,9,1,,,(1/12)
NGEN,2,20,1,19,1,,(1/12)
E,1,2,22,21,11,12,32,31
EGEN,8,1,1
CP,1,TEMP,2,12,22,32             ! COUPLE APPROPRIATE NODAL TEMPERATURES
CPSGEN,8,1,1                     ! GENERATE 8 COUPLED SETS
NSEL,S,LOC,X,0
D,ALL,TEMP,100
NSEL,ALL
SFE,ALL,1,CONV,,1
SFE,ALL,2,CONV,,1
SFE,ALL,4,CONV,,1
SFE,ALL,6,CONV,,1
sfe,all,1,conv,2,0.0   ! bulk temperature
sfe,all,2,conv,2,0.0   ! bulk temperature
sfe,all,4,conv,2,0.0   ! bulk temperature
sfe,all,6,conv,2,0.0   ! bulk temperature
```

```
FINISH
/SOLU
SOLVE
FINISH
/POST1
NSEL,S,LOC,X,(8/12)             ! SELECT NODES AT X=L
PRNSOL,TEMP
NSEL,ALL                        ! PRINT NODAL TEMPERATURES
PRNLD,HEAT                      ! PRINT NODAL HEAT FLOWS AT WALL
NSEL,S,LOC,X,0                  ! SELECT NODES AT X=0
FSUM                            ! PRINT HEAT FLOW SUMMATION
ALLSEL
*GET,TL,NODE,9,TEMP
/POST26
ESOL,2,1,11,HEAT,,HEAT
ESOL,3,1,1,HEAT,,HEAT
ESOL,4,1,21,HEAT,,HEAT
ESOL,5,1,31,HEAT,,HEAT
STORE
*GET,HEAT,VARI,2,EXTREM,VMAX
*GET,HEAT2,VARI,3,EXTREM,VMAX
*GET,HEAT3,VARI,4,EXTREM,VMAX
*GET,HEAT4,VARI,5,EXTREM,VMAX
HTTOT=(ABS(HEAT+HEAT2+HEAT3+HEAT4))
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = '      TL','Q,  BTU/'
LABEL(1,2) = ', F      ','hr   '
*VFILL,VALUE(1,1),DATA,68.594,17.504
*VFILL,VALUE(1,2),DATA,TL,HTTOT
*VFILL,VALUE(1,3),DATA,ABS(TL/68.594),ABS(HTTOT/17.504)
SAVE,TABLE2
RESUME,TABLE1
/COM
/OUT,vm95,vrt
/COM,------------------- VM95 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,LINK33&LINK34:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/NOPR
RESUME,TABLE2
/GOPR
/COM,
/COM,SOLID70:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm95,vrt
```

VM96 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM96
/PREP7
smrt,off
MOPT,VMESH,MAIN
/TITLE, VM96, TEMPERATURE DISTRIBUTION IN A SHORT SOLID CYLINDER
C***      CONDUCTION HEAT TRANSFER, SCHNEIDER, 2ND. PRINTING, PAGE 134, FIG. 6-7
ANTYPE,STATIC
ET,1,SOLID87
MP,KXX,1,1
```

```
CSYS,1                  ! CYLINDRICAL COORDINATE SYSTEM
K,1
K,2,.5,-22.5
K,3,.5,22.5
KGEN,2,ALL,,,,,.5
L,1,4
LESIZE,ALL,,,4          ! SET LINE SEGMENT DIVISIONS TO FOUR
V,1,2,3,1,4,5,6,4       ! DEFINE VOLUME
ESIZE,,6
MSHK,0
MSHA,1
VMESH,1
NSEL,S,LOC,Z
NSEL,A,LOC,X,.5         ! SELECT BOTTOM AND WALL NODES
D,ALL,TEMP
NSEL,S,LOC,Z,.5         ! SELECT NODES AT TOP OF CYLINDER
D,ALL,TEMP,40
NSEL,ALL
FINISH
/SOLU
SOLVE
FINISH
/POST1
/VIEW,1,.2,-1,.4
/ANGLE,1,-29,ZS
/CTYPE,1
/EDGE,1,1
/COM                    *** THE FOLLOWING ANNOTATION COMMANDS ARE ***
/COM                    *** TYPICALLY GENERATED INTERACTIVELY ***
/ANUM,1,1,-.78943,-.82532         ! ANNOTATION NUMBER, TYPE AND HOT SPOT
/TSPEC,15,1.000,2,0,0             ! TEXT ATTRIBUTES
/TLABEL,-.911,-.826,THERMAL       ! ANNOTATION LOCATION AND TEXT
/ANUM,2,1,-.72083,-.89575
/TLABEL,-.913,-.896,ISOSURFACES
/ANUM,3,4,-.54504,-.60828
/LSPEC,15,0,1.000                 ! LINE ATTRIBUTES
/LINE,-.599,-.667,-.491,-.550     ! ANNOTATION LINE DEFINITION
/ANUM,4,4,-.55957,-.76672
/LINE,-.520,-.723,-.599,-.811
/ANUM,5,4,-.56409,-.69934
/LINE,-.541,-.697,-.587,-.703
/ANUM,6,8,-.53174,-.71106
/LARC,-.532,-.711,.016,315,468    ! ANNOTATION ARC DEFINITION
/ANUM,7,8,-.59338,-.68469
/LARC,-.593,-.685,.016,111,281
/ANUM,8,11,-.49353,-.55261
/LSYMBOL,-.494,-.553,48,1,1.000  ! ANNOTATION SYMBOL DEFINITION - ARROW
PLNSOL,TEMP             ! PLOT NODAL TEMPERATURES AS ISOSURFACES
CSYS,1
NSEL,S,LOC,X            ! SELECT CENTERLINE NODES
NSEL,U,LOC,Z,.0625      ! UNSELECT MIDSIDE NODES
NSEL,U,LOC,Z,.1875
NSEL,U,LOC,Z,.3125
NSEL,U,LOC,Z,.4375
NSORT,Z                 ! SORT RESULTS BASED ON Z COORDINATES
NLIST,ALL
PRNSOL,TEMP             ! PRINT NODAL TEMPERATURES FOR CENTERLINE NODES (R=0)
N0 = node(0,0,0.000)
N1 = node(0,0,0.125)
N2 = node(0,0,0.250)
N3 = node(0,0,0.375)
N4 = node(0,0,0.500)
*GET,TA,NODE,N0,TEMP
*GET,TB,NODE,N1,TEMP
*GET,TC,NODE,N2,TEMP
*GET,TD,NODE,N3,TEMP
*GET,TE,NODE,N4,TEMP
*DIM,LABEL,CHAR,5,2
*DIM,VALUE,,5,3
LABEL(1,1) = 'Z=0.0 ft','Z=.125ft','Z=.25 ft','Z=.375ft','Z=0.5 ft'
LABEL(1,2) = ' T, F   ',' T, F   ',' T, F   ',' T, F   ',' T, F   '
*VFILL,VALUE(1,1),DATA,0,6.8,15.6,26.8,40.0
```

```
*VFILL,VALUE(1,2),DATA,TA,TB,TC,TD,TE
*VFILL,VALUE(1,3),DATA,0,ABS(TB/6.8),ABS(TC/15.6),ABS(TD/26.8),ABS(TE/40.0)
/COM
/OUT,vm96,vrt
/COM,------------------- VM96 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm96,vrt
```

VM97 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM97
/PREP7
/TITLE, VM97, TEMPERATURE DISTRIBUTION ALONG A STRAIGHT FIN
C***       PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 57, EX. 2-13
ANTYPE,STATIC
ET,1,SHELL131,,,2,1        ! CONDUCTING SHELL ELEMENTS
ET,2,LINK34                ! CONVECTION ELEMENTS
L=(4/12)                   ! FIN LENGTH
B=(1/12)                   ! FIN WIDTH
SECTYPE,1,SHELL            ! SECTION INFORMATION
SECD,B
R,2,B/2                    ! CROSS-SECTIONAL AREA OF CONVECTION ELEMENTS
MP,KXX,1,15                ! CONDUCTIVITY
MP,HF,1,15                 ! CONVECTION COEFFICIENT
N,1
N,11,L
FILL
N,12,L
NGEN,2,20,1,12,1,,1
E,1,2,22,21
EGEN,10,1,1
TYPE,2
REAL,2
E,11,12                    ! CONVECTION ELEMENTS AT THE TIP OF THE FIN
EGEN,2,20,11
D,12,TEMP,100,,32,20       ! DEFINE TEMPERATURE FOR CONVECTION ELEMENTS
NSEL,S,LOC,X,0
D,ALL,TEMP,1100            ! APPLY WALL TEMPERATURE
NSEL,ALL
ESEL,S,TYPE,,1
SFE,ALL,1,CONV,,15         ! H = 15 AND TBULK = 100
SFE,ALL,1,CONV,2,100
SFE,ALL,2,CONV,,15
SFE,ALL,2,CONV,2,100
ESEL,ALL
FINISH
/SOLU
SOLVE
FINISH
/POST26
ESOL,2,1,1,HEAT,,HEAT
ESOL,3,1,21,HEAT,,HEAT
STORE
*GET,HEAT,VARI,2,EXTREM,VMAX
*GET,HEAT2,VARI,3,EXTREM,VMAX
HTTOT=(ABS(HEAT+HEAT2))
/POST1
*DIM,VALUE,,12,3
*VFILL,VALUE(1,1),DATA,1100,955,835,740,660,595,535,490,460,430
*VFILL,VALUE(11,1),DATA,416,5820
```

```
*DO,I,0,1,0.1              ! PRINT NODAL TEMPERATURES FOR NODES
NSEL,S,LOC,X,(I*L)         !  ALONG INCREMENTS OF 0.1*L
PRNSOL,TEMP
NNUM = NODE (I*L,0,0)
*GET,VAL,NODE,NNUM,TEMP
*VFILL,VALUE(I*10+1,2),DATA,VAL
*VFILL,VALUE(I*10+1,3),DATA,ABS(VALUE(I*10+1,2) / VALUE(I*10+1,1) )
*ENDDO
*VFILL,VALUE(12,2),DATA,HTTOT
*VFILL,VALUE(12,3),DATA,ABS(HTTOT/5820)
NSEL,S,LOC,X,0             ! SELECT NODES TO GET HEAT DISSIPATION RATE (Q)
PRRSOL,HEAT                ! PRINT NODAL HEAT FLOW REACTIONS
*DIM,LABEL,CHAR,12,2
LABEL(1,1) = 'T,F(AT X','T,F(AT X','T,F(AT X','T,F(AT X','T,F(AT X','T,F(AT X','T,F(AT X'
LABEL(8,1) = 'T,F(AT X','T,F(AT X','T,F(AT X','T,F(AT X','q,   BTU'
LABEL(1,2) = '/L = 0.0','/L = 0.1','/L = 0.2','/L = 0.3','/L = 0.4','/L = 0.5','/L = 0.6'
LABEL(8,2) = '/L = 0.7','/L = 0.8','/L = 0.9','/L = 1.0','/hr    '
/COM
/OUT,vm97,vrt
/COM,------------------- VM97 RESULTS COMPARISON ---------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm97,vrt
```

VM98 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM98
/PREP7
/TITLE, VM98, TEMPERATURE DISTRIBUTION ALONG A TAPERED FIN
C***       PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 57, EX. 2-13
C***       USING PLANE55 ELEMENTS
ANTYPE,STATIC
ET,1,PLANE55
MP,KXX,1,15
L=(4/12)                      ! FIN LENGTH
B=(1/12)                      ! FIN HEIGHT AT WALL
N,1,,-(B/2)
N,11,L
FILL
N,21,,(B/2)
N,31,L
FILL
E,21,1,2,22
EGEN,9,1,1
E,30,10,11,11
NSEL,S,LOC,X,0
D,ALL,TEMP,1100
NSEL,S,NODE,,1,11
SF,ALL,CONV,15,100
NSEL,S,NODE,,21,30
NSEL,A,NODE,,11
SF,ALL,CONV,15,100
NSEL,ALL
FINISH
/SOLU
SOLVE
FINISH
/POST26
ESOL,2,1,1,HEAT,,HEAT
ESOL,3,1,21,HEAT,,HEAT
STORE
```

```
*GET,HEAT,VARI,2,EXTREM,VMAX
*GET,HEAT2,VARI,3,EXTREM,VMAX
HTTOT=(ABS(HEAT+HEAT2))
/POST1
*DIM,VALUE,,12,3
*VFILL,VALUE(1,1),DATA,1100,970,850,750,655,575,495,430,370,315
*VFILL,VALUE(11,1),DATA,265,5050
*DO,I,0,1,.1                  ! CREATE DO LOOP TO PRINT TEMPS IN
NSEL,S,LOC,X,(I*L)            ! INCREMENTS OF 0.1*L
PRNSOL,TEMP
NNUM = NODE (I*L,(-(B/2)),0)
*GET,VAL,NODE,NNUM,TEMP
*VFILL,VALUE(I*10+1,2),DATA,VAL
*VFILL,VALUE(I*10+1,3),DATA,ABS(VALUE(I*10+1,2) / VALUE(I*10+1,1) )
*ENDDO
*VFILL,VALUE(12,2),DATA,HTTOT
*VFILL,VALUE(12,3),DATA,ABS(HTTOT/5050)
NSEL,ALL
PRNLD,HEAT                    ! PRINT NODAL HEAT FLOW RATES
*DIM,LABEL,CHAR,12,2
LABEL(1,1) = 'T,F(AT X','T,F(AT X','T,F(AT X','T,F(AT X','T,F(AT X','T,F(AT X','T,F(AT X'
LABEL(8,1) = 'T,F(AT X','T,F(AT X','T,F(AT X','T,F(AT X','q,   BTU'
LABEL(1,2) = '/L = 0.0','/L = 0.1','/L = 0.2','/L = 0.3','/L = 0.4','/L = 0.5','/L = 0.6'
LABEL(8,2) = '/L = 0.7','/L = 0.8','/L = 0.9','/L = 1.0','/hr   '
/COM
/OUT,vm98,vrt
/COM,------------------- VM98 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm98,vrt
```

VM99 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM99
/PREP7
/TITLE, VM99, TEMPERATURE DISTRIBUTION IN A TRAPEZOIDAL FIN
C***      CONDUCTION HEAT TRANSFER, SCHNEIDER, 2ND. PRINTING, PAGE 164, ART. 7-8
ANTYPE,STATIC
ET,1,PLANE55
MP,KXX,1,18
W=(.96/12)                         ! FIN LENGTH
N,7
N,8,(W/2)
N,3,W
N,1,W,-((2*W)/6)
FILL,1,3
N,6,,-(W/6)
FILL,2,7,1,5
FILL,1,6,1,4
E,6,4,5
E,7,6,5
E,7,5,8
E,5,3,8
E,5,2,3
E,4,2,5
E,4,1,2
NSEL,S,LOC,X,W
D,ALL,TEMP,100                     ! DEFINE WALL TEMPERATURE
NSEL,S,NODE,,1,4,3
NSEL,A,NODE,,6,7
SF,ALL,CONV,500,0.0
```

```
NSEL,ALL
FINISH
/SOLU
SOLVE
FINISH
/POST1
PRNSOL,TEMP                     ! PRINT NODAL TEMPERATURES
PRNLD,HEAT                      ! PRINT HEAT FLOW RATES
FSUM,,,
*GET,TN4,NODE,4,TEMP
*GET,TN5,NODE,5,TEMP
*GET,TN6,NODE,6,TEMP
*GET,TN7,NODE,7,TEMP
*GET,HEAT,FSUM,0,ITEM,HEAT

*DIM,LABEL,CHAR,5,2
*DIM,VALUE,,5,3
LABEL(1,1) = 'T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','q,Btu/hr'
LABEL(1,2) = 'NODE 4) ','NODE 5) ','NODE 6) ','NODE 7) '
*VFILL,VALUE(1,1),DATA,27.6,32.7,9.5,10.7,3545
*VFILL,VALUE(1,2),DATA,TN4,TN5,TN6,TN7,-1*HEAT*2
*VFILL,VALUE(1,3),DATA,ABS(TN4/27.6),ABS(TN5/32.7),ABS(TN6/9.5),ABS(TN7/10.7),ABS(-1*HEAT*2/3545)
/COM
/OUT,vm99,vrt
/COM,------------------- VM99 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,-----------------------------------------------------------
/COM,
/OUT
FINISH
*LIST,vm99,vrt
```

VM100 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM100
/PREP7
/TITLE, VM100, HEAT CONDUCTION ACROSS A CHIMNEY SECTION
C***       PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 102, EX. 3-4
ANTYPE,STATIC                 ! THERMAL ANALYSIS
ET,1,PLANE55
MP,KXX,1,1
N,1
N,3,1
FILL
NGEN,5,3,1,5,1,,.5
E,4,1,2,5
E,3,6,5,2
EGEN,2,3,1,2,1
E,11,7,8,8
E,9,12,11,8
E,12,15,11,11
OUTPR,ALL,1
OUTPR,VENG,NONE
NSEL,S,LOC,X
SF,ALL,CONV,12,100            ! INNER CONVECTION SURFACE
NSEL,S,LOC,X,1
SF,ALL,CONV,3,0               ! OUTER CONVECTION SURFACE
NSEL,ALL
FINISH
/SOLU
SOLVE
FINISH
/POST1
```

```
PRNSOL,TEMP                   ! PRINT NODAL TEMPERATURES
ESEL,S,ELEM,,1,3,2            ! SELECT ELEMENTS 1 AND 3
FSUM                          ! PERFORM FORCE AND MOMENT SUMMATIONS
*GET,HT13,FSUM,,ITEM,HEAT     ! ADD HEAT FLOW RATES OF ELEMENTS 1 AND 3
HEAT=HT13*8                   ! COMPUTE TOTAL HEAT FLOW RATE
ESEL,ALL
/CLABEL,,1                    ! LABEL CONTOUR LINES
/CONTOUR,,20                  ! USE 20 CONTOUR LINES
PLNSOL,TEMP                   ! DISPLAY TEMPERATURE CONTOURS
*DIM,VALUE,,13,3
*VFILL,VALUE(1,1),DATA,93.7,56.3,22.2,93.2,54.6,21.4,87.6,47.5,18.3
*VFILL,VALUE(10,1),DATA,29.6,11.7,4.7,775.2
*DO,I,1,9,1
*GET,TN,NODE,I,TEMP
*VFILL,VALUE(I,2),DATA,TN
*VFILL,VALUE(I,3),DATA,ABS(VALUE(I,2)/VALUE(I,1))
*ENDDO
*VFILL,VALUE(13,2),DATA,HEAT
*VFILL,VALUE(13,3),DATA,ABS(HEAT/775.2)
*GET,TN11,NODE,11,TEMP
*GET,TN12,NODE,12,TEMP
*GET,TN15,NODE,15,TEMP
*VFILL,VALUE(10,2),DATA,TN11,TN12,TN15
*VFILL,VALUE(10,3),DATA,ABS(TN11/29.6),ABS(TN12/11.7),ABS(TN15/4.7)
*DIM,LABEL,CHAR,13,2
LABEL(1,1) = 'T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT '
LABEL(8,1) = 'T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','q,   BTU'
LABEL(1,2) = 'NODE 1) ','NODE 2) ','NODE 3) ','NODE 4) ','NODE 5) ','NODE 6) ','NODE 7) '
LABEL(8,2) = 'NODE 8) ','NODE 9) ','NODE 11)','NODE 12)','NODE 15)','/hr     '
/COM
/OUT,vm100,vrt
/COM,------------------- VM100 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F10.1,'   ',1F5.2)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm100,vrt
```

VM101 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM101
/PREP7
/TITLE, VM101, TEMPERATURE DISTRIBUTION IN A SHORT SOLID CYLINDER
C***    CONDUCTION HEAT TRANSFER, SCHNEIDER, 2ND. PRINTING, PAGE 134, FIG. 6-7
ANTYPE,STATIC
ET,1,SOLID70
MP,KXX,1,1
CSYS,1
N,1,1E-10,-5                ! ZERO RADIUS WITH NON-ZERO THETA IS NOT PERMITTED
N,5,.5,-5
FILL
N,6,1E-10,5                 ! ZERO RADIUS WITH NON-ZERO THETA IS NOT PERMITTED
N,10,.5,5
FILL
NGEN,5,10,1,10,1,,,.125
E,1,2,7,7,11,12,17,17
E,2,3,8,7,12,13,18,17
EGEN,3,1,2
EGEN,4,10,1,4
OUTPR,,1
D,1,TEMP,,,10                ! APPLY TEMPERATURES
D,15,TEMP,,,40,5
D,41,TEMP,40,,50
```

```
NUMMRG,NODE                  ! MERGE COINCIDENT NODE NUMBERS
FINISH
/SOLU
SOLVE
FINISH
/POST1
/VIEW,,,-1
!/DEVICE,VECTOR,ON
PLNSOL,TEMP
CSYS,1
NSEL,S,LOC,X,0
PRNSOL,TEMP                  ! TEMPERATURES ALONG AXIS (R=0)
NSEL,S,LOC,X,0.25
NSEL,R,LOC,Y,-5
PRNSOL,TEMP                  ! TEMPERATURES ALONG R=0.25 FT
ALLSEL
*GET,TN11,NODE,11,TEMP
*GET,TN21,NODE,21,TEMP
*GET,TN31,NODE,31,TEMP
*GET,TN13,NODE,13,TEMP
*GET,TN23,NODE,23,TEMP
*GET,TN33,NODE,33,TEMP
*DIM,LABEL_1,CHAR,3,2
*DIM,VALUE_1,,3,3
LABEL_1(1,1) = '   NODE ','   NODE ','   NODE '
LABEL_1(1,2) = '11      ','21      ','31      '
*VFILL,VALUE_1(1,1),DATA,6.8,15.6,26.8
*VFILL,VALUE_1(1,2),DATA,TN11,TN21,TN31
*VFILL,VALUE_1(1,3),DATA,ABS(TN11/6.8),ABS(TN21/15.6),ABS(TN31/26.8)
*DIM,LABEL_2,CHAR,3,2
*DIM,VALUE_2,,3,3
LABEL_2(1,1) = '   NODE ','   NODE ','   NODE '
LABEL_2(1,2) = '13      ','23      ','33      '
*VFILL,VALUE_2(1,1),DATA,5.2,12.8,24
*VFILL,VALUE_2(1,2),DATA,TN13,TN23,TN33
*VFILL,VALUE_2(1,3),DATA,ABS(TN13/5.2),ABS(TN23/12.8),ABS(TN33/24)
/COM
/OUT,vm101,vrt
/COM,------------------- VM101 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,T, F (CENTERLINE):
/COM,
*VWRITE,LABEL_1(1,1),LABEL_1(1,2),VALUE_1(1,1),VALUE_1(1,2),VALUE_1(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F10.1,'   ',1F5.2)
/COM,
/COM,T, F (MID-RADIUS):
/COM,
*VWRITE,LABEL_2(1,1),LABEL_2(1,2),VALUE_2(1,1),VALUE_2(1,2),VALUE_2(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F10.1,'   ',1F5.2)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm101,vrt
```

VM102 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM102
/PREP7
/TITLE, VM102, CYLINDER WITH TEMPERATURE DEPENDENT CONDUCTIVITY
C***    CONDUCTION HEAT TRANSFER, SCHNEIDER, 2ND. PRINTING, PAGE 166, ART. 7-9
ANTYPE,STATIC
ET,1,PLANE55,,,1                    ! AXISYMMETRIC OPTION
MP,KXX,1,50                         ! CONSTANT CONDUCTIVITY
N,1,(1/24)
N,6,(1/12)
```

```
FILL
NGEN,2,10,1,6,1,,.01
E,1,2,12,11
EGEN,5,1,1
OUTPR,,1
KBC,1                              ! STEP BOUNDARY CONDITIONS
D,1,TEMP,100,,11,10
D,6,TEMP,,,16,10
FINISH
/SOLU
SOLVE
FINISH
/POST1
SET,1
NSEL,S,LOC,Y
PRNSOL,TEMP                        ! RADIAL TEMPERATURES FOR CONSTANT K
*GET,TN2,NODE,2,TEMP
*GET,TN3,NODE,3,TEMP
*GET,TN4,NODE,4,TEMP
*GET,TN5,NODE,5,TEMP
*DIM,LABEL_1,CHAR,4,2
*DIM,VALUE_1,,4,3
LABEL_1(1,1) = '   NODE ','   NODE ','   NODE ','   NODE '
LABEL_1(1,2) = '2       ','3       ','4       ','5       '
*VFILL,VALUE_1(1,1),DATA,73.8,51.5,32.2,15.3
*VFILL,VALUE_1(1,2),DATA,TN2,TN3,TN4,TN5
*VFILL,VALUE_1(1,3),DATA,ABS(TN2/73.8),ABS(TN3/51.5),ABS(TN4/32.2),ABS(TN5/15.3)
NSEL,ALL
FINISH

/PREP7
MP,KXX,1,50,0.5                    ! TEMPERATURE-DEPENDENT CONDUCTIVITY
FINISH
/SOLU
SOLVE
FINISH
/POST1
SET,1
NSEL,S,LOC,Y
PRNSOL,TEMP                        ! RADIAL TEMPERATURES FOR K(T)
*GET,TN2,NODE,2,TEMP
*GET,TN3,NODE,3,TEMP
*GET,TN4,NODE,4,TEMP
*GET,TN5,NODE,5,TEMP
*DIM,LABEL_2,CHAR,4,2
*DIM,VALUE_2,,4,3
LABEL_2(1,1) = '   NODE ','   NODE ','   NODE ','   NODE '
LABEL_2(1,2) = '2       ','3       ','4       ','5       '
*VFILL,VALUE_2(1,1),DATA,79.2,59.6,40.2,20.8
*VFILL,VALUE_2(1,2),DATA,TN2,TN3,TN4,TN5
*VFILL,VALUE_2(1,3),DATA,ABS(TN2/79.2),ABS(TN3/59.6),ABS(TN4/40.2),ABS(TN5/20.8)
/COM
/OUT,vm102,vrt
/COM,------------------- VM102 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,T, F (K=CONSTANT);FIRST LOAD STEP:
/COM,
*VWRITE,LABEL_1(1,1),LABEL_1(1,2),VALUE_1(1,1),VALUE_1(1,2),VALUE_1(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F10.1,'   ',1F5.2)
/COM,
/COM,T, F (K=K(T);SECOND LOAD STEP:
/COM,
*VWRITE,LABEL_2(1,1),LABEL_2(1,2),VALUE_2(1,1),VALUE_2(1,2),VALUE_2(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F10.1,'   ',1F5.2)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm102,vrt
```

VM103 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM103
/PREP7
/TITLE, VM103, THIN PLATE WITH CENTRAL HEAT SOURCE
C*** CONDUCTION HEAT TRANSFER, SCHNEIDER, 2ND. PRINTING, PAGE 173, ART. 8-1
C*** USING SHELL131 ELEMENTS
ANTYPE,STATIC                ! THERMAL ANALYSIS
ET,1,SHELL131,,,2
SECT,1,SHELL
SECD,.1
MP,KXX,1,5
CSYS,1                       ! CYLINDRICAL COORDINATE SYSTEM
N,1,.1,-5
N,8,.8,-5
FILL
NGEN,2,10,1,8,1,,10
N,21
N,9,(2/15),-5
N,10,(1/6),-5
NGEN,2,10,9,10,1,,10
E,21,1,11                    ! 7 TRIANGULAR ELEMENTS
E,1,9,11
E,19,11,9
E,9,10,20
E,20,19,9
E,10,2,20
E,12,20,2
E,12,2,3,13                  ! 6 QUADRILATERAL ELEMENTS
EGEN,6,1,8
CP,1,TEMP,1,11               ! COUPLE NODAL TEMPS TANGENTIALLY
CPSGEN,10,1,1
OUTPR,BASIC,1
ESEL,S,ELEM,,2,13,1
SFE,ALL,1,CONV,,30
SFE,ALL,1,CONV,2,100
SFE,ALL,2,CONV,,20
SFE,ALL,2,CONV,2,0
ESEL,ALL
BFE,1,HGEN,,250E3            ! HEAT SOURCE
FINISH
/SOLU
SOLVE
FINISH
/POST1
*DIM,VALUE,,10,3
*VFILL,VALUE(1,1),DATA,226.3,103.2,73.8,65.8,62.8,60.8,60.2,60,173.1
*VFILL,VALUE(10,1),DATA,130.7
*DO,I,1,10,1
*GET,TN,NODE,I,TEMP
*VFILL,VALUE(I,2),DATA,TN
*VFILL,VALUE(I,3),DATA,ABS(VALUE(I,2)/VALUE(I,1))
*ENDDO
*DIM,LABEL,CHAR,10,2
LABEL(1,1) = 'T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT '
LABEL(8,1) = 'T,F (AT ','T,F (AT ','T,F (AT '
LABEL(1,2) = 'NODE 1) ','NODE 2) ','NODE 3) ','NODE 4) ','NODE 5) ','NODE 6) ','NODE 7) '
LABEL(8,2) = 'NODE 8) ','NODE 9) ','NODE 10)'
SAVE,INF1
FINISH
/CLEAR,NOSTART



/TITLE, VM103, THIN PLATE WITH CENTRAL HEAT SOURCE
C*** USING SHELL132 ELEMENTS
/PREP7
```

```
ANTYPE,STATIC               ! THERMAL ANALYSIS
ET,1,SHELL132,,,2
SECT,1,SHELL
SECD,.1
MP,KXX,1,5
CSYS,1                      ! CYLINDRICAL COORDINATE SYSTEM
N,1,.05,-5
N,16,.8,-5
FILL
NGEN,3,30,1,16,1,,5
N,91
N,17,(7/60),-5
N,21,(11/60),-5
FILL
NGEN,3,30,17,21,1,,5
E,91,2,62,62,1,32,62,61     ! 1 TRIANGULAR ELEMENT
E,2,18,78,62,17,48,77,32    ! 9 QUADRILATERAL ELEMENTS
E,18,20,80,78,3,50,63,48
E,20,4,64,80,21,34,81,50
E,4,6,66,64,5,36,65,34
EGEN,6,2,5
NSLE      ! DELETE UNUSED NODES
NSEL,INVE
NDELE,ALL
NSEL,ALL
CP,1,TEMP,2,32,62           ! COUPLE NODAL TEMPS TANGENTIALLY
CPSGEN,21,1,1
OUTPR,BASIC,1
ESEL,S,ELEM,,2,9,1
SFE,ALL,1,CONV,,30
SFE,ALL,1,CONV,2,100
SFE,ALL,2,CONV,,20
SFE,ALL,2,CONV,2,0
ESEL,ALL
BFE,1,HGEN,,250E3           ! HEAT SOURCE
FINISH
/SOLU
SOLVE
FINISH
/POST1
*DIM,VALUE,,10,3
*VFILL,VALUE(1,1),DATA,226.3,103.2,73.8,65.8,62.8,60.8,60.2,60,173.1
*VFILL,VALUE(10,1),DATA,130.7
*DO,I,1,10,1
*GET,TN,NODE,(I*2),TEMP
*VFILL,VALUE(I,2),DATA,TN
*VFILL,VALUE(I,3),DATA,ABS(VALUE(I,2)/VALUE(I,1))
*ENDDO
*DIM,LABEL,CHAR,10,2
LABEL(1,1) = 'T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT '
LABEL(8,1) = 'T,F (AT ','T,F (AT ','T,F (AT '
LABEL(1,2) = 'NODE 1) ','NODE 2) ','NODE 3) ','NODE 4) ','NODE 5) ','NODE 6) ','NODE 7) '
LABEL(8,2) = 'NODE 8) ','NODE 9) ','NODE 10)'
SAVE,INF2

RESUME,INF1
/COM
/OUT,vm103,vrt
/COM,------------------- VM103 RESULTS COMPARISON --------------
/COM,
/COM,                |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,--SHELL131--
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F10.1,'   ',1F5.2)
/COM,
/NOPR
RESUME,INF2
/COM,--SHELL132--
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F10.1,'   ',1F5.2)
/COM,-----------------------------------------------------------
```

```
/OUT
FINISH
*LIST,vm103,vrt
```

VM104 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM104
/PREP7
SMRT,OFF
/TITLE, VM104, LIQUID-SOLID PHASE CHANGE
C***    DANTZIG,J.A., IJNME, VOL 28, 1989, PAGE 1773-1775.
ANTYPE,TRANS
ET,1,PLANE55
MP,DENS,1,1000
MP,KXX,1,0.6
MPTEMP,1,-10,-1,0,10
MPDATA,ENTH,1,1,0,37.8E6,79.8E6,121.8E6  ! ENTHALPY
K,1
K,2,0.01
K,3,0.01,0.001
K,4,,0.001
L,2,3
L,1,4
LESIZE,ALL,,,1
A,1,2,3,4
ESIZE,,15
AMESH,1
FINISH
/SOLU
OUTRES,,ALL
BFUNIF,TEMP                              ! INITIAL TEMPERATURE
NSEL,S,LOC,X
D,ALL,TEMP,-5.0                          ! SURFACE TEMPERATURE
NSEL,ALL
KBC,1                                    ! STEP LOAD
AUTOTS,ON
DELTIM,3,3,10
TIME,900                                 ! FINAL TIME
SOLVE
FINISH
/POST1
SET,,,,,500
*GET,T1,NODE,5,TEMP
*GET,T2,NODE,8,TEMP
PATH,TPATH,2,,48                         ! DEFINE PATH WITH NAME = "TPATH"
PPATH,1,1                                ! DEFINE PATH POINTS BY NODE
PPATH,2,2
PDEF,TEMP,TEMP
PLPATH,TEMP
NSEL,S,LOC,Y
PRNSOL,TEMP                              ! NODAL TEMPERATURES
FINISH
/POST26
NSOL,2,2,TEMP,,T2
NSOL,3,3,TEMP,,T3
NSOL,4,4,TEMP,,T4
NSOL,5,5,TEMP,,T5
NSOL,6,6,TEMP,,T6
NSOL,7,7,TEMP,,T7
PLVAR,2,3,4,5,6,7                        ! DISPLAY TEMPERATURE HISTORY
PRTIME,700,900
PRVAR,2,3,4,5,6,7
FINISH
*DIM,VALUE,,2,3
*DIM,LABEL,CHAR,2,2
*VFILL,VALUE(1,1),DATA,-3.64,-2.32
*VFILL,VALUE(1,2),DATA,T1,T2
```

```
*VFILL,VALUE(1,3),DATA,ABS(T1/3.64),ABS(T2/2.32)
LABEL(1,1) = 'T,C (X=0','T,C (X=0'
LABEL(1,2) = '.002 m) ','004 m)  '
/OUT,vm104,vrt
/COM,------------------- VM104 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F10.2,'   ',1F5.3)
/COM,-----------------------------------------------------------
/COM,
/COM,-----------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM104 NOT CONTAINED IN
/COM,THIS TABLE
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm104,vrt
```

VM105 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM105
/PREP7
/TITLE, VM105, HEAT GENERATING COIL WITH TEMP. DEPENDENT CONDUCTIVITY
C***    CONDUCTION HEAT TRANSFER, SCHNEIDER, 2ND. PRINTING, PAGE 193, ART. 8-8
ANTYPE,STATIC
ET,1,PLANE55                 ! THERMAL SOLID
MP,KXX,1,10,.075
CSYS,1
N,1,(1/48),-5                ! RADIAL SECTOR ONE-ELEMENT WIDE
N,10,(1/12),-5
FILL
NGEN,2,10,1,10,1,,10
E,1,2,12,11
EGEN,9,1,1
OUTPR,BASIC,1
KBC,1                        ! STEP LOAD
D,1,TEMP,0,,11,10            ! INNER WALL TEMPERATURE
D,10,TEMP,0,,20,10           ! OUTER WALL TEMPERATURE
BFE,ALL,HGEN,,1E6            ! APPLY HEAT GENERATION RATES
FINISH
/SOLU
SOLVE
FINISH
/POST1
CSYS,1
NSEL,S,LOC,Y,-5              ! SELECT NODES ALONG RADIUS AT THETA=-5
PRNSOL,TEMP                  ! PRINT TEMPERATURE DISTRIBUTION
NSEL,S,NODE,,ALL
PATH,TPATH,2,,48             ! DEFINE PATH WITH NAME = "TPATH"
PPATH,1,1                    ! DEFINE PATH POINTS BY NODE
PPATH,2,10
PDEF,TEMP,TEMP
PLPATH,TEMP
*DIM,VALUE,,8,3
*VFILL,VALUE(1,1),DATA,23.3,35.9,42.2,44,42.2,37,28.6,16.5
*DO,I,2,9,1
*GET,TN,NODE,I,TEMP
*VFILL,VALUE(I-1,2),DATA,TN
*VFILL,VALUE(I-1,3),DATA,ABS(VALUE(I-1,2)/VALUE(I-1,1))
*ENDDO
*DIM,LABEL,CHAR,8,2
LABEL(1,1) = 'T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT ','T,F (AT '
LABEL(7,1) = 'T,F (AT ','T,F (AT '
LABEL(1,2) = 'NODE 2) ','NODE 3) ','NODE 4) ','NODE 5) ','NODE 6) ','NODE 7) '
LABEL(7,2) = 'NODE 8) ','NODE 9) '
```

```
/COM
/OUT,vm105,vrt
/COM,------------------- VM105 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F10.1,'   ',1F5.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm105,vrt
```

VM106 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM106
/PREP7
/TITLE, VM106, RADIANT ENERGY EMISSION
C***   PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 22, PROB. 1-8(B)
ANTYPE,STATIC                   ! THERMAL ANALYSIS
ET,1,LINK31
R,1,144,1,1
N,1                             ! TWO COINCIDENT NODES
N,2
E,1,2
OUTPR,ALL,1
OUTPR,VENG,NONE
KBC,1
TOFFST,460                      ! OFFSET TEMPERATURE
D,1,TEMP,3000                   ! DEFINE NODAL TEMPERATURES
D,2,TEMP,0
FINISH
/SOLU
SOLVE
FINISH
/POST26
ESOL,2,1,1,HEAT,,HEAT
STORE
*GET,HEAT,VARI,2,EXTREM,VMAX
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'q, BTU/h'
LABEL(1,2) = 'r       '
*VFILL,VALUE(1,1),DATA,2.4559E5
*VFILL,VALUE(1,2),DATA,ABS(HEAT)
*VFILL,VALUE(1,3),DATA,ABS(HEAT/245590)
/COM,
/OUT,vm106,vrt
/COM,------------------ VM106 RESULTS COMPARISON ---------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',E11.4,'  ',E11.4,'   ',1F5.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm106,vrt
```

VM107 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM107
```

```
/PREP7
/TITLE, VM107, THERMOCOUPLE RADIATION
C***    HEAT TRANSFER, CHAPMAN, 1ST. PRINTING, PAGE 396, ART. 13.5
ANTYPE,STATIC         ! STATIC ANALYSIS
ET,1,LINK34
ET,2,LINK31
R,1,1
R,2,1,1,.5, 0.174E-8
MP,HF,1,11.85         ! FILM COEFFICIENT
N,1
N,3
FILL
E,1,2
TYPE,2
REAL,2
E,2,3
OUTPR,BASIC,1
OUTPR,NLOAD,1         ! PRINT NODAL HEAT FLOWS
KBC,1                 ! STEP CHANGE LOADS
TOFFST,460            ! OFFSET TEMPERATURE
D,1,TEMP,1309
D,3,TEMP,300
FINISH
/SOLU
SOLVE
FINISH
/POST1
*GET,TN2,NODE,2,TEMP
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '      TT,'
LABEL(1,2) = ' F       '
*VFILL,VALUE(1,1),DATA,1000
*VFILL,VALUE(1,2),DATA,TN2
*VFILL,VALUE(1,3),DATA,ABS(TN2/1000 )
/COM
/OUT,vm107,vrt
/COM,------------------- VM107 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F10.2,'   ',1F5.3)
/COM,----------------------------------------------------------
/COM,
/COM,----------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM107 NOT CONTAINED IN
/COM,THIS TABLE
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm107,vrt
```

VM108 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM108
/PREP7
/TITLE, VM108, TEMPERATURE GRADIENT ACROSS A SOLID CYLINDER
C***    HILDEBRAND, ADVANCED CALCULUS, PAGE 447, EQUATIONS 38-44
ANTYPE,STATIC
ET,1,PLANE75            ! AXISYMMETRIC HARMONIC THERMAL SOLID
MP,KXX,1,1
N,1
N,5,20
FILL
NGEN,2,5,1,5,1,,5       ! AXIAL LENGTH IS ARBITRARY
E,1,2,7,6               ! FOUR ELEMENTS ALONG RADIUS AT THETA=0
```

```
EGEN,4,1,1
OUTPR,BASIC,1
MODE,1,1                  ! ANTISYMMETRIC MODE (ISYM=1)
D,5,TEMP,80,,10,5         ! DEFINE PEAK TEMPERATURE
FINISH
/SOLU
SOLVE
FINISH
/POST1
*GET,TN1,NODE,1,TEMP
*GET,TN2,NODE,2,TEMP
*GET,TN3,NODE,3,TEMP
*GET,TN4,NODE,4,TEMP
*DIM,VALUE,,4,3
*DIM,LABEL,CHAR,4,2
*VFILL,VALUE(1,1),DATA,0,20,40,60
*VFILL,VALUE(1,2),DATA,TN1,TN2,TN3,TN4
*VFILL,VALUE(1,3),DATA,0,ABS(TN2/20),ABS(TN3/40),ABS(TN4/60)
LABEL(1,1) = 'NODE 1 T','NODE 2 T','NODE 3 T','NODE 4 T'
LABEL(1,2) = ', F     ',', F     ',', F     ',', F     '
/COM
/OUT,vm108,vrt
/COM,------------------- VM108 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F12.1,'   ',1F15.2)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm108,vrt
```

VM109 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM109
/PREP7
/TITLE, VM109, TEMPERATURE RESPONSE OF A SUDDENLY COOLED WIRE
C***    PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 120, EX. 4-1
ANTYPE,TRANS              ! THERMAL ANALYSIS
ET,1,MASS71,,,1
ET,2,LINK34
R,1,2.7046E-4             ! THERMAL CAPACITANCE PER UNIT LENGTH
R,2,0.0081812             ! SURFACE AREA PER UNIT LENGTH
MP,HF,1,2                 ! FILM COEFFICIENT
N,1                       ! COINCIDENT NODES AT ORIGIN
N,2
E,1
TYPE,2
REAL,2
E,1,2
FINISH
/SOLU
OUTRES,,ALL
AUTOTS,ON
OUTPR,BASIC,LAST
DELTIM,0.00125
TIME,.0125
BFUNIF,TEMP,300           ! UNIFORM INITIAL TEMPERATURE
KBC,1
D,2,TEMP,100              ! AIR TEMPERATURE
SOLVE
TIME,.0325
SOLVE
TIME,0.05
SOLVE
FINISH
```

```
/POST26
NSOL,2,1,TEMP
PRVAR,2                 ! PRINT TEMPERATURE
/GRID,1
/AXLAB,Y,TEMP
PLVAR,2                 ! DISPLAY TEMP OF NODE 1 VS. TIME
*GET,T1,VARI,2,RTIME,.0125
*GET,T2,VARI,2,RTIME,.0325
*GET,T3,VARI,2,RTIME,.05
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'T,F AT 0','T,F AT 0','T,F AT 0'
LABEL(1,2) = '.0125 hr','.0325 hr','.05   hr'
*VFILL,VALUE(1,1),DATA,193.89,128,109.71
*VFILL,VALUE(1,2),DATA,T1,T2,T3
*VFILL,VALUE(1,3),DATA,ABS(T1/193.89),ABS(T2/128),ABS(T3/109.71)
/COM
/OUT,vm109,vrt
/COM,------------------- VM109 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL    |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F12.2,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm109,vrt
```

VM110 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM110
/PREP7
/TITLE, VM110, TRANSIENT TEMPERATURE DISTRIBUTION IN A SLAB
C***    PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 140, EX. 4-4
ANTYPE,TRANS              ! TRANSIENT ANALYSIS
ET,1,LINK33               ! HEAT CONDUCTING BAR
ET,2,LINK34               ! CONVECTION LINK
R,1,1                     ! UNIT AREA
MP,KXX,1,.54              ! PROPERTIES OF WALL
MP,DENS,1,144
MP,C,1,.20
MP,HF,1,5                 ! CONVECTION COEFFICIENT
N,1
N,11,1
FILL
N,12,1
E,1,2
EGEN,10,1,1               ! TEN BAR ELEMENTS ACROSS WALL THICKNESS
TYPE,2
E,11,12                   ! ONE CONVECTION LINK AT GAS END
FINISH
/SOLU
OUTRES,,ALL
TIME,14.5                 ! TIME AT END OF LOAD STEP
NSUBST,80
BFUNIF,TEMP,100
D,12,TEMP,1600
KBC,1                     ! STEP BOUNDARY CONDITION
AUTOTS,ON
OUTPR,BASIC,LAST
TINTPAR,,,,0.5             ! USE CENTRAL DIFFERENCE
SOLVE
FINISH
/POST26
ESOL,2,11,,SMISC,1,HEAT   ! HEAT RATE FOR ELEMENT 11
INT1,3,2,1,,TOTAL_HT      ! INTEGRATE HEAT RATE OVER TIME SPAN
```

```
PRVAR,2,3
*GET,QTOT,VARI,3,RTIME,14.5
FINISH
/POST1
*GET,T1,NODE,1,TEMP
*GET,T3,NODE,3,TEMP
*GET,T5,NODE,5,TEMP
*GET,T7,NODE,7,TEMP
*GET,T9,NODE,9,TEMP
*GET,T11,NODE,11,TEMP
*DIM,LABEL,CHAR,7,2
*DIM,VALUE,,7,3
LABEL(1,1) = 'T, F (NO','T, F (NO','T, F (NO','T, F (NO','T, F (NO','T, F (NO','Q, BTU/f'
LABEL(1,2) = 'DE 1 )  ','DE 3 )  ','DE 5 )  ','DE 7 )  ','DE 9 )  ','DE 11)  ','t^2     '
*VFILL,VALUE(1,1),DATA,505,550,670,865,1135,1435,-20736
*VFILL,VALUE(1,2),DATA,T1,T3,T5,T7,T9,T11,QTOT
*VFILL,VALUE(1,3),DATA,ABS(T1/505),ABS(T3/550),ABS(T5/670),ABS(T7/865),ABS(T9/1135)
*VFILL,VALUE(6,3),DATA,ABS(T11/1435),ABS(QTOT/20736)
/COM
/OUT,vm110,vrt
/COM,------------------- VM110 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F15.0,'   ',1F15.2)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm110,vrt
```

VM111 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM111
/PREP7
/TITLE, VM111, COOLING OF A SPHERICAL BODY
!       PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 143, EX. 4-5
!       USING PLANE55 ELEMENTS (QUAD. ELEMENTS)
ANTYPE,TRANS
ET,1,PLANE55,,,1      ! AXISYMMETRIC ELEMENTS
MP,KXX,1,(1/3)
MP,DENS,1,62
MP,C,1,1.0752677
CSYS,1                ! CYLINDRICAL COORDINATE SYSTEM
N,1
N,2,(1/18),-7.5
N,4,(1/6),-7.5
FILL
NGEN,2,20,1,4,1,,15
E,2,22,1,1
E,3,23,22,2
EGEN,2,1,2
CP,1,TEMP,2,22        ! COUPLING TO ENSURE CIRCUMFERENTIAL SYMMETRY
CPSGEN,3,1,1
AUTOTS,ON             ! USE AUTOMATIC TIME STEPPING
DELTIM,.01            ! MIN TIME STEP SIZE
OUTPR,BASIC,LAST      ! PRINT LAST SUBSTEP
TIME,6
TUNIF,65
KBC,1                 ! STEP BOUNDARY CONDITIONS
NSEL,S,LOC,X,(1/6)
SF,ALL,CONV,2,25      ! CONVECTION ON ELEMENT SURFACE
NSEL,ALL
FINISH
/SOLU
SOLVE
FINISH
```

```
/POST1
PRNSOL,TEMP           ! PRINT NODAL TEMPERATURES
*GET,TEMP,NODE,1,TEMP
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '       T'
LABEL(1,2) = ', F      '
*VFILL,VALUE(1,1),DATA,28
*VFILL,VALUE(1,2),DATA,TEMP
*VFILL,VALUE(1,3),DATA,ABS(TEMP/28)
/COM
/OUT,vm111,vrt
/COM,------------------- VM111 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F12.2,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm111,vrt
```

VM112 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM112
/PREP7
/TITLE, VM112, COOLING OF A SPHERICAL BODY
C***       PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 143, EX. 4-5
C***       USING PLANE77 ELEMENTS (MULTI-NODE ELEMENTS)
ANTYPE,TRANS                    ! THERMAL ANALYSIS
ET,1,PLANE77,,,1                ! AXISYMMETRIC ELEMENTS
MP,KXX,1,(1/3)
MP,DENS,1,62
MP,C,1,1.0752677
CSYS,1                          ! CYLINDRICAL COORDINATE SYSTEM
N,1
N,2,(1/18),-7.5
N,4,(1/6),-7.5
FILL
NGEN,2,20,1,4,1,,15
N,14,(1/6)
E,2,22,1,1
E,3,23,22,2
E,4,24,23,3,14
CP,1,TEMP,2,22                  ! COUPLING TO ENSURE CIRCUMFERENTIAL SYMMETRY
CPSGEN,2,1,1
CP,3,TEMP,4,14,24
AUTOTS,ON                       ! USE AUTOMATIC TIME STEPPING
OUTPR,BASIC,LAST
TIME,6
DELTIM,0.15
BFUNIF,TEMP,65
KBC,1                           ! STEP BOUNDARY CONDITIONS
NSEL,S,LOC,X,(1/6)
SF,ALL,CONV,2,25                ! CONVECTION ON ELEMENT SURFACE
NSEL,ALL
FINISH
/SOLU
SOLVE
FINISH
/POST1
PRNSOL,TEMP                     ! PRINT NODAL TEMPERATURES
*GET,TEMP,NODE,1,TEMP
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '       T'
```

```
LABEL(1,2) = ', F      '
*VFILL,VALUE(1,1),DATA,28
*VFILL,VALUE(1,2),DATA,TEMP
*VFILL,VALUE(1,3),DATA,ABS(TEMP/28)
/COM
/OUT,vm112,vrt
/COM,------------------- VM112 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F12.1,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm112,vrt
```

VM113 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM113
/PREP7
smrt,off
/TITLE, VM113, TRANSIENT TEMP. DISTRIBUTION IN AN ORTHOTROPIC METAL BAR
C***    CONDUCTION HEAT TRANSFER, SCHNEIDER, 2ND. PRINTING, PAGE 261, EX. 10-7
ANTYPE,TRANS
ET,1,PLANE55                ! THERMAL SOLID
MP,KXX,1,20                 ! ORTHOTROPIC CONDUCTIVITIES
MP,KYY,1,3.6036
MP,DENS,1,400
MP,C,1,.009009
K,1                         ! USE SOLID MODEL
K,2,(2/12)
KGEN,2,1,2,1,,(1/12)
L,1,2
*REPEAT,2,2,2
LESIZE,ALL,,,6,(1/3)
L,1,3
*REPEAT,2,1,1
LESIZE,3,,,5,(1/3)
LESIZE,4,,,5,(1/3)
A,1,3,4,2
AMESH,1
TIME,(3/3600)
NSUBST,40
AUTOTS,ON                   ! USE AUTOMATIC TIME STEPPING
OUTPR,,LAST
BFUNIF,TEMP,500
KBC,1                       ! STEP BOUNDARY CONDITIONS
NSEL,S,LOC,X,(2/12)
NSEL,A,LOC,Y,(1/12)
SF,ALL,CONV,240,100         ! CONVECTION SURFACE
NSEL,ALL
FINISH
/SOLU
EQSLV,JCG                   ! USE JACOBI CONJUGATE GRADIENT SOLVER
/OUT,SCRATCH
SOLVE
FINISH
/POST1
NSEL,S,LOC,X
NSEL,A,LOC,X,(2/12)         ! SELECT NODES OF INTEREST
NSEL,U,LOC,Y,.01,(.99/12)
/OUT,
PRNSOL,TEMP                 ! PRINT NODAL TEMPERATURES
*get,tn1,node,1,temp
*get,tn7,node,7,temp
*get,tn13,node,13,temp
```

```
*get,tn2,node,2,temp
*dim,label,char,4,2
*dim,value,,4,3
label(1,1) = 'T,F (nod','T,F (nod','T,F (nod','T,F (nod'
label(1,2) = 'e  1)    ','e  7)    ','e 13)    ','e  2)    '
*vfill,value(1,1),data,459,151,279,202
*vfill,value(1,2),data,tn1,tn7,tn13,tn2
*vfill,value(1,3),data,abs(tn1/459),abs(tn7/151),abs(tn13/279),abs(tn2/202)
/com

/OUT,vm113,vrt
/com,-------------------(VM113)RESULTS COMPARISON---------------
/com,
/com,                 |   TARGET   |   Mechanical APDL   |   RATIO
/com,
*vwrite,label(1,1),label(1,2),value(1,1),value(1,2),value(1,3)
(1x,a8,a8,'   ',f10.0,'  ',f12.0,'   ',1f15.2)
/com,----------------------------------------------------------
/OUT
FINISH
*LIST,vm113,vrt
```

VM114 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM114
/PREP7
/TITLE, VM114, TEMPERATURE RESPONSE TO A LINEARLY RISING SURFACE TEMPERATURE
C***    CONDUCTION HEAT TRANSFER, SCHNEIDER, 2ND. PRINTING, PAGE 274, ART 11-2
ANTYPE,TRANS
ET,1,LINK33          ! HEAT CONDUCTING BAR
R,1,1                ! UNIT AREA ASSUMED
MP,KXX,1,10
MP,DENS,1,500
MP,C,1,0.2
K,1
K,2,.3               ! LENGTH OF MODEL FROM SURFACE
L,1,2
LESIZE,1,,,8,3       ! NON-UNIFORM MESH WITH 8 DIVISIONS
LMESH,1
FINISH
/SOLU
SOLCONTROL,0
AUTOTS,ON
OUTPR,,LAST
OUTRES,,ALL
TIME,(2/60)          ! TIME PERIOD OF 2 MIN. CONVERTED TO HR.
NSUBST,20
DK,1,TEMP,120        ! TEMPERATURE SPECIFICATION AT KEY POINT 1
SOLVE
FINISH
/POST26
NSOL,2,1,TEMP        ! TEMPERATURE HISTORY AT NODES NEAR SURFACE
NSOL,3,3,TEMP
NSOL,4,4,TEMP
NSOL,5,5,TEMP
NSOL,6,6,TEMP
PRVAR,2,3,4,5,6      ! PRINT NODAL TEMPERATURE VARIATION WITH TIME
/GRID,1
/AXLAB,Y,TEMP
PLVAR,2,4,5,6,3      ! DISPLAY NODAL TEMPERATURE HISTORIES
FINISH
/POST1
SET,1
NSORT,TEMP           ! SORT NODES BY DESCENDING TEMPERATURE VALUES
NLIST                ! LIST NODES TO VERIFY X-COORDINATE LOCATION
PRNSOL,TEMP          ! PRINT NODAL TEMPERATURE DISTRIBUTION
*GET,TN1,NODE,1,TEMP
```

```
*GET,TN3,NODE,3,TEMP
*GET,TN4,NODE,4,TEMP
*GET,TN5,NODE,5,TEMP
*GET,TN6,NODE,6,TEMP
*GET,TN2,NODE,2,TEMP
*DIM,LABEL,CHAR,6,2
*DIM,VALUE,,6,3
LABEL(1,1) = 'T,F (NOD','T,F (NOD','T,F (NOD','T,F (NOD','T,F (NOD','T,F (NOD'
LABEL(1,2) = 'E 1)    ','E 3)    ','E 4)    ','E 5)    ','E 6)    ','E 2)    '
*VFILL,VALUE(1,1),DATA,120,79.32,46.62,23.44,9.51,0
*VFILL,VALUE(1,2),DATA,TN1,TN3,TN4,TN5,TN6,TN2
*VFILL,VALUE(1,3),DATA,ABS(TN1/120),ABS(TN3/79.32),ABS(TN4/46.62),ABS(TN5/23.44)
*VFILL,VALUE(5,3),DATA,ABS(TN6/9.51),0
/COM
/OUT,vm114,vrt
/COM,------------------- VM114 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F12.2,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm114,vrt
```

VM115 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM115
/PREP7
/TITLE, VM115, THERMAL RESPONSE OF A HEAT GENERATING SLAB
C***    CONDUCTION HEAT TRANSFER, SCHNEIDER, 2ND. PRINTING, PAGE 283, EQN 11-21
ANTYPE,TRANS
ET,1,LINK33        ! HEAT CONDUCTING BAR
R,1,1
MP,KXX,1,20
MP,DENS,1,500
MP,C,1,.2
K,1                ! SURFACE KEYPOINT
K,2,.5             ! CENTERLINE KEYPOINT
L,1,2              ! UNIFORM MESH
LESIZE,1,,,5
LMESH,1
AUTOTS,ON
OUTPR,,LAST
TIME,(12/60)       ! CONVERT 12 MIN TO HRS
DELTIM,0.01
BFUNIF,TEMP,60     ! INITIAL UNIFORM TEMPERATURE
KBC,1              ! APPLY STEP LOADS
DK,1,TEMP,32       ! SURFACE TEMPERATURE APPLIED TO KEYPOINT 1
BFK,ALL,HGEN,4E4   ! HEAT GENERATION SPECIFIED AT KEYPOINTS 1 & 2
FINISH
/SOLU
SOLVE
/POST1
*GET,TN1,NODE,1,TEMP
*GET,TN3,NODE,3,TEMP
*GET,TN4,NODE,4,TEMP
*GET,TN5,NODE,5,TEMP
*GET,TN6,NODE,6,TEMP
*GET,TN2,NODE,2,TEMP
*DIM,LABEL,CHAR,6,2
*DIM,VALUE,,6,3
LABEL(1,1) = 'T,F (NOD','T,F (NOD','T,F (NOD','T,F (NOD','T,F (NOD','T,F (NOD'
LABEL(1,2) = 'E 1)    ','E 3)    ','E 4)    ','E 5)    ','E 6)    ','E 2)    '
*VFILL,VALUE(1,1),DATA,32,75.75,103.99,120.80,129.46,132.1
*VFILL,VALUE(1,2),DATA,TN1,TN3,TN4,TN5,TN6,TN2
```

```
*VFILL,VALUE(1,3),DATA,ABS(TN1/32 ),ABS(TN3/75.75),ABS(TN4/103.99),ABS(TN5/120.80)
*VFILL,VALUE(5,3),DATA,ABS(TN6/129.46),ABS(TN2/132.1)
/COM
/OUT,vm115,vrt
/COM,------------------- VM115 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F12.2,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm115,vrt
```

VM116 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM116
/PREP7
/TITLE, VM116, HEAT CONDUCTING PLATE WITH SUDDEN COOLING
C***    PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 161, EX. 4-11
ANTYPE,TRANS
ET,1,LINK34,,3        ! CONVECTION LINK, USE (TI-TJ) FOR HF EVALUATION
ET,2,LINK33           ! HEAT CONDUCTION BAR
R,1,1                 ! UNIT AREA ASSUMED
MP,KXX,1,2            ! CONDUCTIVITY, DENSITY AND SPECIFIC HEAT
MP,DENS,1,800         !  INPUT USED BY CONDUCTION ELEMENTS
MP,C,1,0.833
MP,HF,1,2,.02         ! TEMPERATURE DEPENDENT HF (USED FOR ELEM 1)
N,1                   ! NODES 1 AND 2 DEFINE THE CONVECTION LINK
N,2                   !  (ARBIRARY LENGTH)
N,10,(8/12)           ! CONDUCTION LENGTH IN FT.
FILL
E,1,2                 ! ELEMENT 1 IS CONVECTION LINK
TYPE,2                ! ELEMENTS 2 THROUGH 9 ARE CONDUCTION BARS
E,2,3
EGEN,8,1,-1
FINISH
/SOLU
D,2,TEMP,500          ! INITIAL SURFACE TEMPERATURES
D,10,TEMP,100
OUTPR,,LAST
OUTRES,,ALL
TIMINT,OFF            ! TURN OFF TIME INTEGRATION FOR
TIME,0.001            !  INITIAL STEADY-STATE CONDITION
SOLVE
TIMINT,ON             ! TURN ON TIME INTEGRATION ON FOR
TIME,7                !  TRANSIENT OVER 7 HRS
DDELE,2,TEMP          ! DELETE NODAL TEMPERATURE
D,1,TEMP,100          ! ENVIRONMENT TEMPERATURE IS DECREASED
KBC,1                 !  SUDDENLY
AUTOTS,ON
NSUBST,20
SOLVE
FINISH

/POST26
NSOL,2,2,TEMP
PRVAR,2               ! PRINT TEMPERATURE HISTORY AT NODE 2
/AXLAB,Y,TEMP
/GRID,1
PLVAR,2
FINISH

/POST1
ETABLE,TI,SMISC,2     ! NODAL TEMPERATURES FOR CONDUCTION ELEMENTS
ETABLE,TJ,SMISC,3
```

```
PLLS,TI,TJ         ! DISPLAY TEMPERATURE VARIATION ACROSS PLATE (AT 7 HRS)
PRNSOL,TEMP
*GET,TN2,NODE,2,TEMP
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'T,F(AT X'
LABEL(1,2) = '=0.0 in)'
*VFILL,VALUE(1,1),DATA,285
*VFILL,VALUE(1,2),DATA,TN2
*VFILL,VALUE(1,3),DATA,ABS(TN2/285)
/COM
/OUT,vm116,vrt
/COM,------------------- VM116 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F12.0,'   ',1F15.2)
/COM,---------------------------------------------------------
/OUT
FINISH
*LIST,vm116,vrt
```

VM117 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM117
/PREP7
/TITLE, VM117, ELECTRIC CURRENT FLOWING IN A NETWORK
C*** BASIC ELECTRICAL ENGR, FITZGERALD AND HIGGIN BOTHAM, 2ND ED, P. 22, EX. 1-11
ANTYPE,STATIC
ET,1,LINK68               ! THERMAL-ELECTRICAL LINE ELEMENT
MP,RSVX,1,1               ! UNIT RESISTIVITY
R,1,(1/20)                ! AREAS INPUT TO GIVE REQUIRED RESISTANCE
R,2,(1/10)                !  AS PER RESISTANCE=RSVX*L/AREA
R,3,(SQRT(2)/9)
R,4,(1/30)
R,5,(1/90)
N,1
N,2,,1
NGEN,2,2,1,2,1,1
E,1,2                     ! BRANCH 1-2, 20 OHM
REAL,2                    ! BRANCH 1-3, 10 OHM
E,1,3
REAL,3                    ! BRANCH 2-3, 9  OHM
E,2,3
REAL,4                    ! BRANCH 2-4, 30 OHM
E,2,4
REAL,5                    ! BRANCH 3-4, 90 OHM
E,3,4
KBC,1                     ! STEP BOUNDARY CONDITIONS
D,4,VOLT,100              ! NODAL VOLTAGE
D,1,VOLT,0                ! GROUND NODE
OUTPR,ALL,1
OUTPR,VENG,NONE
FINISH
/SOLU
SOLVE
FINISH
/POST1
ETABLE,CUR,NMISC,5
PRETAB,CUR                ! PRINT CURRENT FOR ALL BRANCHES
*GET,I42,ELEM,4,ETAB,CUR ! CURRENT IN BRANCH 4-2
*GET,I43,ELEM,5,ETAB,CUR ! CURRENT IN BRANCH 4-3
I14=I42+I43               ! CURRENT THROUGH BATTERY (BRANCH 1-4)
*GET,I21,ELEM,1,ETAB,CUR
*GET,I31,ELEM,2,ETAB,CUR
*GET,I23,ELEM,3,ETAB,CUR
```

```
*GET,V1,NODE,1,VOLT
*GET,V2,NODE,2,VOLT
*GET,V3,NODE,3,VOLT
*GET,V4,NODE,4,VOLT
*DIM,LABEL,CHAR,10,2
*DIM,VALUE,,10,3
LABEL(1,1) = 'V1, VOLT','V2, VOLT','V3, VOLT','V4, VOLT','I2_1, AM'
LABEL(1,2) = 'S       ','S       ','S       ','S       ','PS      '
LABEL(6,1) = 'I3_1, AM','I2_3, AM','I4_2, AM','I4_3, AM','I1_4, AM'
LABEL(6,2) = 'PS      ','PS      ','PS      ','PS      ','PS      '
*VFILL,VALUE(1,1),DATA,0,28,19,100,1.4,1.9,1,2.4,.9,3.3
*VFILL,VALUE(1,2),DATA,V1,V2,V3,V4,ABS(I21),ABS(I31),ABS(I23),ABS(I42),ABS(I43),ABS(I14)
*VFILL,VALUE(1,3),DATA,0,ABS(V2/28),ABS(V3/19),ABS(V4/100),ABS(I21/1.4),ABS(I31/1.9)
*VFILL,VALUE(7,3),DATA,ABS(I23/1),ABS(I42/2.4 ),ABS(I43/.9),ABS(I14/3.3)
SAVE,TABLE_1
FINISH
/CLEAR,NOSTART
/PREP7
ANTYPE,STATIC
ET,1,CIRCU124,0
ET,2,CIRCU124,4
MP,RSVX,1,1              ! UNIT RESISTIVITY
R,1,20
R,2,10
R,3,9
R,4,30
R,5,90
R,6,100
N,1
N,2,,1
NGEN,2,2,1,2,1,1
N,5,2,.5
E,1,2                    ! BRANCH 1-2, 20 OHM
REAL,2                   ! BRANCH 1-3, 10 OHM
E,1,3
REAL,3                   ! BRANCH 2-3, 9  OHM
E,2,3
REAL,4                   ! BRANCH 2-4, 30 OHM
E,2,4
REAL,5                   ! BRANCH 3-4, 90 OHM
E,3,4
TYPE,2
REAL,6
E,4,1,5
KBC,1                    ! STEP BOUNDARY CONDITIONS
D,1,VOLT,0               ! GROUND NODE
OUTPR,ALL,1
OUTPR,VENG,NONE
FINISH
/SOLU
SOLVE
FINISH
/POST1
ETABLE,CUR,SMISC,2
PRETAB,CUR               ! PRINT CURRENT FOR ALL BRANCHES
*GET,I42,ELEM,4,ETAB,CUR ! CURRENT IN BRANCH 4-2
*GET,I43,ELEM,5,ETAB,CUR ! CURRENT IN BRANCH 4-3
I14=I42+I43              ! CURRENT THROUGH BATTERY (BRANCH 1-4)
*GET,I21,ELEM,1,ETAB,CUR
*GET,I31,ELEM,2,ETAB,CUR
*GET,I23,ELEM,3,ETAB,CUR
*GET,V1,NODE,1,VOLT
*GET,V2,NODE,2,VOLT
*GET,V3,NODE,3,VOLT
*GET,V4,NODE,4,VOLT
*DIM,LABEL,CHAR,10,2
*DIM,VALUE,,10,3
LABEL(1,1) = 'V1, VOLT','V2, VOLT','V3, VOLT','V4, VOLT','I2_1, AM'
LABEL(1,2) = 'S       ','S       ','S       ','S       ','PS      '
LABEL(6,1) = 'I3_1, AM','I2_3, AM','I4_2, AM','I4_3, AM','I1_4, AM'
LABEL(6,2) = 'PS      ','PS      ','PS      ','PS      ','PS      '
*VFILL,VALUE(1,1),DATA,0,28,19,100,1.4,1.9,1,2.4,.9,3.3
```

```
*VFILL,VALUE(1,2),DATA,V1,V2,V3,V4,ABS(I21),ABS(I31),ABS(I23),ABS(I42),ABS(I43),ABS(I14)
*VFILL,VALUE(1,3),DATA,0,ABS(V2/28),ABS(V3/19),ABS(V4/100),ABS(I21/1.4),ABS(I31/1.9)
*VFILL,VALUE(7,3),DATA,ABS(I23/1),ABS(I42/2.4 ),ABS(I43/.9),ABS(I14/3.3)
SAVE,TABLE_2
RESUME,TABLE_1
/COM
/OUT,vm117,vrt
/COM,------------------- VM117 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,LINK68:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F12.3,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,CIRCU124:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F12.3,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
/DELETE,TABLE_1
/DELETE,TABLE_2
FINISH
*LIST,vm117,vrt
```

VM118 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM118
/PREP7
/TITLE, VM118, CENTERLINE TEMP. OF A HEAT GENERATING WIRE
C***      HEAT, MASS AND MOMENTUM TRANS., ROHSENOW AND CHOI, 2ND. PR., PAGE 106,
C***      EX. 6.5, USING PLANE55 ELEMENTS (PLANE ELEMENTS)
ANTYPE,STATIC                ! THERMAL ANALYSIS
ET,1,PLANE55
MP,KXX,1,13
CSYS,1                       ! CYLINDRICAL COORDINATE SYSTEM
N,1,1E-10,-5                 ! USE NON-ZERO RADIUS SINCE NODE IS NOT AT THETA=0
N,6,(.375/12),-5
FILL
NGEN,2,10,1,6,1,,10
E,1,2,12,12
E,2,3,13,12
EGEN,4,1,2
CP,1,TEMP,2,12                ! COUPLING TO ENSURE CIRCUMFERENTIAL SYMMETRY
CPSGEN,5,1,1
NSEL,S,LOC,X,(0.375/12)
SF,ALL,CONV,5,70
NSEL,ALL
BFE,ALL,HGEN,,111311.7        ! ELEMENT HEAT GENERATION
OUTPR,BASIC,1
FINISH
/SOLU
SOLVE
FINISH
/POST1
*GET,TEMP,NODE,6,TEMP          ! GET TEMPERATURE AT SURFACE NODE
PI=2*ASIN(1)
AREA=36*2*(0.375/12)*SIN(PI/36) ! COMPUTE AREA OF OUTER BOUNDARY
HRATE=AREA*5.0*(TEMP-70)       ! TOTAL HEAT DISSIPATION RATE
PRNSOL,TEMP                    ! PRINT NODAL TEMPERATURES
*status,parm                        ! SHOW STATUS
```

```
*GET,TCL,NODE,1,TEMP
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'T CL,   ','T S,    ','q,   BTU'
LABEL(1,2) = 'DEGREE F','DEGREE F','/hr     '
*VFILL,VALUE(1,1),DATA,419.9,417.9,341.5
*VFILL,VALUE(1,2),DATA,TCL,TEMP,HRATE
*VFILL,VALUE(1,3),DATA,ABS(TCL/419.9) ,ABS( TEMP/417.9 ),ABS(HRATE/341.5)
SAVE,TABLE1
FINISH

/PREP7
C***      USING SOLID70 ELEMENTS (SOLID ELEMENTS)
EDELE,ALL                       ! DELETE PLANE55 ELEMENTS
ET,1,SOLID70                    ! CHANGE ELEMENT TYPE
NGEN,2,20,1,16,1,,,-1           ! GENERATE 2ND PLANE OF NODES
NUMCMP,ELEM
E,1,2,12,12,21,22,32,32
E,2,3,13,12,22,23,33,32
EGEN,4,1,2
CPDELE,1,6,1                    ! REMOVE PREVIOUS COUPLING SPECIFICATIONS
CP,1,TEMP,1,21                  ! COUPLING TO ENSURE AXIAL SYMMETRY
CP,2,TEMP,2,12,22,32            ! COUPLING TO ENSURE CIRCUMFERENTIAL SYMMETRY
CPSGEN,5,1,2
CSYS,1
NSEL,S,LOC,X,(0.375/12)
SF,ALL,CONV,5,70
NSEL,ALL
BFE,ALL,HGEN,1,111311.7         ! ELEMENT HEAT GENERATION
FINISH
/SOLU
SOLVE
FINISH
/POST1
*GET,TEMP,NODE,6,TEMP            ! GET TEMPERATURE AT SURFACE NODE
PI=2*ASIN(1)
AREA=36*2*(0.375/12)*SIN(PI/36)  ! LENGTH ALONG 10 DEG ON OUTER FACE
HRATE=AREA*5.0*(TEMP-70)         ! TOTAL HEAT DISSIPATION RATE
PRNSOL,TEMP                      ! PRINT NODAL TEMPERATURES
*status,parm                          ! SHOW PARAMETER STATUS
*GET,TCL,NODE,1,TEMP
LABEL(1,1) = 'T CL,   ','T S,    ','q,   BTU'
LABEL(1,2) = 'DEGREE F','DEGREE F','/hr     '
*VFILL,VALUE(1,1),DATA,419.9,417.9,341.5
*VFILL,VALUE(1,2),DATA,TCL,TEMP,HRATE
*VFILL,VALUE(1,3),DATA,ABS(TCL/419.9) ,ABS( TEMP/417.9 ), ABS(HRATE/341.5)
SAVE,TABLE2
RESUME,TABLE1
/COM
/OUT,vm118,vrt
/COM,------------------- VM118 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,STIF55 RESULTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F12.1,'   ',1F15.3)
/NOPR
RESUME,TABLE2
/GOPR
/COM,
/COM,STIF70 RESULTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F12.1,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm118,vrt
```

VM119 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM119
/PREP7
/TITLE, VM119, CENTERLINE TEMP. OF AN ELECTRICAL WIRE
C***      HEAT, MASS AND MOMENTUM TRANS., ROHSENOW AND CHOI, 2ND. PR., PAGE 106,
C***      USING PLANE223 ELEMENTS (PLANE ELEMENTS)
!
ANTYPE,STATIC                  ! THERMAL (ELECTRICAL) ANALYSIS
ET,1,PLANE223,110,,1           ! AXISYMMETRIC ELEMENTS
MP,KXX,1,13                    ! CONDUCTIVITY
MP,RSVX,1,8.983782E-8          ! RESISTIVITY
N,1
N,6,(.375/12)
FILL
NGEN,2,10,1,6,1,,1
E,11,1,2,12
EGEN,5,1,1
CP,1,TEMP,1,11                 ! COUPLING TO ENSURE AXIAL SYMMETRY
CPSGEN,6,1,1
CP,7,VOLT,1,2,3,4,5,6  ! DEFINE GROUND ELECTRODE
CP,8,VOLT,11,12,13,14,15,16 ! DEFINE CURRENT LOAD ELECTRODE
D,1,VOLT,0    ! APPLY ZERO POTENTIAL TO GROUND ELECTRODE
F,11,AMPS,-1000*3.415  ! APPLY TOTAL CURRENT (X CONVERSION FACTOR) TO THE MASTER NODE
NSEL,S,LOC,X,(0.375/12)
SF,ALL,CONV,5,70
NSEL,ALL
FINISH
/SOLU
OUTPR,ALL,1                    ! USE TIME STEP OPTIMIZATION
OUTPR,VENG,NONE
KBC,1                          ! STEP BOUNDARY CONDITIONS
SOLVE
FINISH
/POST1
*GET,TEMP,NODE,6,TEMP          ! GET TEMPERATURE AT SURFACE NODE
PI=2*ASIN(1)
AREA=2*PI*(0.375/12)           ! COMPUTE AREA OF OUTER FACE (360 DEG)
HRATE=AREA*5.0*(TEMP-70)       ! TOTAL HEAT DISSIPATION RATE
PRNSOL,TEMP                    ! PRINT NODAL TEMPERATURES
*GET,TCL,NODE,1,TEMP
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'T CL,    ','T S,     ','q,   BTU'
LABEL(1,2) = 'DEGREE F','DEGREE F','/hr     '
*VFILL,VALUE(1,1),DATA,419.9,417.9,341.5
*VFILL,VALUE(1,2),DATA,TCL,TEMP,HRATE
*VFILL,VALUE(1,3),DATA,ABS(TCL/419.9) ,ABS( TEMP/417.9 ),ABS (HRATE/341.5)
SAVE,TABLE1
FINISH
!
/CLEAR, NOSTART ! CLEAR DATABASE FOR SOLID69 MODEL

/PREP7
/TITLE, VM119, CENTERLINE TEMP. OF AN ELECTRICAL WIRE
C***      USING SOLID226 ELEMENTS (SOLID ELEMENTS)
ANTYPE,STATIC                  ! THERMAL (ELECTRICAL) ANALYSIS
ET,1,SOLID226,110
MP,KXX,1,13                    ! CONDUCTIVITY
MP,RSVX,1,8.983782E-8          ! RESISTIVITY
CSYS,1                         ! CYLINDRICAL COORDINATE SYSTEM
N,1,1E-10,-5                   ! USE NON-ZERO RADIUS SINCE NODE IS NOT AT THETA=0
N,6,(.375/12),-5
FILL
N,11,1E-10,5
N,16,.03125,5
FILL
NGEN,2,20,1,16,1,,,-1
```

```
E,1,2,12,12,21,22,32,32
E,2,3,13,12,22,23,33,32
EGEN,4,1,2
CP,1,TEMP,1,21                ! COUPLING TO ENSURE AXIAL SYMMETRY
CP,2,TEMP,2,12,22,32          ! COUPLING TO ENSURE CIRCUMFERENTIAL SYMMETRY
CPSGEN,5,1,2
NSEL,S,LOC,Z,0
CP,6,VOLT,ALL   ! DEFINE GROUND ELECTRODE
NSEL,ALL
NSEL,S,LOC,Z,-1
CP,7,VOLT,ALL   ! DEFINE CURRENT LOAD ELECTRODE
NSEL,ALL
D,1,VOLT,0    ! APPLY ZERO POTENTIAL TO GROUND ELECTRODE
F,21,AMPS,-1000*3.415/36 ! APPLY TOTAL CURRENT CORRESPONDING TO THE 10 DEGREE SECTOR
     ! (X CONVERSION FACTOR) TO THE MASTER NODE
NSEL,S,LOC,X,(0.375/12)
SF,ALL,CONV,5,70
NSEL,ALL
FINISH
/SOLU
OUTPR,ALL,1
OUTPR,VENG,NONE
SOLVE
FINISH
/POST1
*GET,TEMP,NODE,6,TEMP         ! GET TEMPERATURE AT SURFACE NODE
PI=2*ASIN(1)
LENG=2*(0.375/12)*SIN(PI/36)  ! LENGTH ALONG 10 DEG ON OUTER FACE
AREA=LENG*36                  ! COMPUTE AREA OF OUTER FACE (360 DEG)
HRATE=AREA*5.0*(TEMP-70)      ! TOTAL HEAT DISSIPATION RATE
PRNSOL,TEMP                   ! PRINT NODAL TEMPERATURES
*status,parm                       ! SHOW PARAMETER STATUS
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
*GET,TCL,NODE,1,TEMP
LABEL(1,1) = 'T CL,   ','T S,    ','q,   BTU'
LABEL(1,2) = 'DEGREE F','DEGREE F','/hr     '
*VFILL,VALUE(1,1),DATA,419.9,417.9,341.5
*VFILL,VALUE(1,2),DATA,TCL,TEMP,HRATE
*VFILL,VALUE(1,3),DATA,ABS(TCL/419.9) ,ABS( TEMP/417.9 ),ABS (HRATE/341.5)
SAVE,TABLE2
!
RESUME,TABLE1
/COM
/OUT,vm119,vrt
/COM,------------------- VM119 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,
/COM,PLANE223 RESULTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F12.1,'   ',1F15.3)
/COM,----------------------------------------------------------
/NOPR
RESUME,TABLE2
/GOPR
/COM,
/COM,SOLID226 RESULTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F12.1,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm119,vrt
```

VM120 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM120
/PREP7
SMRT,OFF
/TITLE, VM120,  MICROSTRIP TRANSMISSION LINE ANALYSIS
! BEREN AND KAIRES (REF. 56)
ANTYPE,STATIC                        ! ELECTROSTATIC ANALYSIS
ET,1,PLANE121                        ! USE 2-D 8-NODE ELECTROSTATIC ELEMENT
PER=8.85E-14                         ! DEFINE FREE-SPACE PERMITTIVITY
EMUNIT,EPZRO,PER
V1=1.5                               ! DEFINE STRIP POTENTIAL
V0=0.5                               ! DEFINE GROUND POTENTIAL
MP,PERX,1,10                         ! SUBSTRATE PERMITTIVITY
MP,PERX,2,1                          ! FREE SPACE PERMITTIVITY
K,1
K,2,5
K,3,,1
K,4,.5,1                             ! DEFINE GEOMETRY
K,5,5,1
K,6,,10
K,7,5,10
DESIZE,8,5,30
L,1,2
L,2,5
L,5,4
L,4,3
L,3,1
L,5,7
L,7,6
L,6,3
AL,1,2,3,4,5
AL,4,3,6,7,8
ASEL,S,AREA,,2
AATT,2
ASEL,ALL                            ! SET AREA ATTRIBUTES FOR AIR
AMESH,ALL
NSEL,S,LOC,Y,1                      ! SELECT NODES ON MICROSTRIP
NSEL,R,LOC,X,0,.5
CM,CON1,NODE
!D,ALL,VOLT,V1                       ! APPLY STRIP POTENTIAL
NSEL,S,LOC,Y,0
NSEL,A,LOC,Y,10
NSEL,A,LOC,X,5                      ! SELECT EXTERIOR NODES
CM,CON2,NODE
!D,ALL,VOLT,V0                       ! APPLY GROUND POTENTIAL
NSEL,ALL
FINISH
/SOLUTION
CMATRIX,2,'CON',2,0                 ! CALCULATE CAPACITANCE USING CMATRIX MACRO
FINISH
/POST1
SET,LAST
ETABLE,EFX,EF,X                     ! STORE POTENTIAL FIELD GRADIENTS
ETABLE,EFY,EF,Y
/NUMBER,1
PLNSOL,VOLT                         ! DISPLAY EQUIPOTENTIAL LINES
/DIST,1,2.2                         ! FOCUS IN ON MICROSTRIP REGION
/FOCUS,1,2,1.5
PLVECT,EFX,EFY                      ! DISPLAY VECTOR ELECTRIC FIELD (VECTOR)
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'CAPACITA'
LABEL(1,2) = 'NCE,pF/m'
*VFILL,VALUE(1,1),DATA,178.1
*VFILL,VALUE(1,2),DATA,CMATRIX(1,1,1)*1E14
*VFILL,VALUE(1,3),DATA,ABS((CMATRIX(1,1,1)*1E14)/178.1)
/COM
```

```
/OUT,vm120,vrt
/COM,------------------- VM120 RESULTS COMPARISON -------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F12.1,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm120,vrt
```

VM121 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM121
/TITLE,VM121,VOLTAGE FORCED COIL (1/8 SYMMETRY)
/VIEW,1,1,1,1
/VUP,1,Z
/COM,   REFERENCE (BENCHMARK DESCRIPTION AND EXPECTED RESULTS):
/COM,   "VOLTAGE FORCED COILS FOR 3D FINITE-ELEMENT ELECTROMAGNETIC MODELS,"
/COM,   IEEE TRANSACTIONS ON MAGNETICS, VOL. 24, NO.6 (1988)
/OUT,SCRATCH
C*** PARAMETERS (GEOMETRY, MESH SIZE)
PI=ACOS(-1)
RI=0.087    ! COIL INNER RADIUS (M)
RO=0.116    ! COIL OUTER RADIUS (M)
H=0.028        ! COIL HEIGHT (M)
A=0.240        ! PLATE EDGE LENGTH (M)
T=0.0127    ! PLATE THICKNESS (M)
GAP=0.03435    ! GAP BETWEEN PLATES (M)
D_DMN=0.100    ! DEPTH OF SURROUNDING DOMAIN (M)
ESZ1=0.0095    ! MESH SIZE, COIL
ESZ2=5*ESZ1    ! MESH SIZE, ENCLOSURE

C*** OTHER PARAMETERS
C*** DETERMINATION OF COIL REAL CONSTANTS/RESISTIVITY
C*** SERIES RESISTOR, PLATE RESISTIVITY, EXCITATION
R_COIL=12.4    ! TARGET COIL DC RESISTANCE (OHM)
TURNS=700    ! COIL # OF TURNS
XC=(RI+RO)/2   ! COIL AVERAGE RADIUS
CARE=(RO-RI)*H   ! COIL CROSS SECTION AREA (M^2)
VOLU=H*PI*(RO**2-RI**2)  ! COIL VOLUME (M^3)
RSV_PLATE=1/3.28E7  ! PLATE RESISTIVITY (OHM-M)
V=20     ! STEP APPLIED VOLTAGE
T_FINAL=0.07   ! END OF TRANSIENT (S)

C*** CREATE GEOMETRY
/PREP7
WPCS,-1,0    ! COIL CYLINDRICAL ESYS
CSWP,11,1
CSYS
VSEL,NONE    ! COIL
CYLI,RI,RO,0,-H/2,0,90
VATT,3,3,3,11
CM,COIL_V,VOLU
VSEL,NONE    ! PLATE
BLOCK,,A/2,,A/2,-GAP/2,-GAP/2-T
VATT,2,2,2
CM,PLATE_V,VOLU
ALLSEL,ALL    ! PREPARE FOR BOOLEAN
CM,KEEP_V,VOLU
VSEL,NONE    ! ENCLOSURE
BLOCK,,A/2+D_DMN,,A/2+D_DMN,0,-GAP/2-T-D_DMN
CM,SCRAP_V,VOLU
ALLSEL,ALL    ! BOOLEAN
CMSEL,ALL
VSBV,SCRAP_V,KEEP_V,,DELE,KEEP
```

```
CMSEL,U,KEEP_V
VATT,1,1,1
CM,AIR_V,VOLU
CMSEL,ALL
CMDELE,KEEP_V
CMPLOT

C*** DEFINE ATTRIBUTES AND MESH
ET,1,SOLID236   ! AIR (AZ)
MP,MURX,1,1
ET,2,SOLID236,1   ! PLATE (AZ,VOLT)
MP,MURX,2,1
MP,RSVX,2,RSV_PLATE
ET,3,SOLID236,2   ! STRANDED COIL (AZ,VOLT,EMF)
MP,MURX,3,1
R,3,CARE,TURNS,VOLU,0,1,0
RMORE,R_COIL,8
VSEL,S,MAT,,2,3   ! MESH COIL AND PLATE
ALLSEL,BELOW,VOLU
ESIZE,ESZ1
KESIZE,ALL,ESZ1
MSHAPE,1,3D
VMESH,ALL
VSEL,S,MAT,,1
ESIZE,ESZ2
VMESH,ALL
ALLSEL,ALL
EPLOT

C*** ELECTRICAL BCS
VSEL,S,MAT,,3
ALLSEL,BELOW,VOLU
CP,1,VOLT,ALL
CP,2,EMF,ALL
N_COIL=NDNEXT(0)
ALLSEL,ALL
D,N_COIL,VOLT,V         ! VOLTAGE LOAD
ASEL,S,LOC,X             ! CURRENT NORMAL @X=0 & Y=0 PLANES OF PLATE
ASEL,A,LOC,Y
VSEL,S,MAT,,2
ASLV,R
DA,ALL,VOLT
ALLSEL,ALL
C*** MAGNETIC BCS
ASEL,S,LOC,X             ! X SYMMETRY PLANE: FLUX PARALLEL
DA,ALL,AZ
ASEL,S,LOC,Y             ! Y SYMMETRY PLANE: FLUX PARALLEL
DA,ALL,AZ
ALLSEL,ALL              ! ALL OTHER BOUNDARIES FLUX PARALLEL
ASEL,S,EXT
ASEL,U,LOC,X
ASEL,U,LOC,Y
ASEL,U,LOC,Z
DA,ALL,AZ
EPLOT
FINISH

C*** SOLVE
/COM,  COIL BETWEEN 2 CONDUCTIVE PLATES
/SOLU
ANTYPE,TRANS
TIME,T_FINAL
KBC,1
NSBS=50
NSUBST,NSBS
AUTOTS,OFF
OUTRES,ALL,ALL
KUSE,1
ALLSEL,ALL
SOLVE
FINISH
```

```
C*** POST PROCESS
/POST1
SET,FIRST
PLVE,B,,,,VECT,,ON
VSEL,S,MAT,,2
ALLS,BELO,VOLU
/OUT
PLVE,JT,,,,VECT,,ON
VSEL,S,MAT,,3
ALLS,BELO,VOLU
PLVE,JT,,,,VECT,,ON
FINI
/OUT,SCRATCH
/POST26
*DIM,VALUE,,2,3
*DIM,VALUE4,,2,3
*DIM,VALUE7,,2,3
*DIM,LABEL,CHAR,2  ! PARAMETERS FOR POSTPROCESSING
LABEL(1) = 'C_PLATE'
LABEL(2) = 'C_FREE'
RFORCE,2,N_COIL,AMPS,,IC_PLATE
VGET,IC,2    ! SAVE RESULTS TO ARRAY
VGET,VALUE(1,2),2,1E-2
VGET,VALUE4(1,2),2,4E-2
VGET,VALUE7(1,2),2,7E-2
FINISH

C*** CONVERT MODEL: COIL IN AIR
/COM, COIL IN AIR
/PREP7    ! CONVERT PLATE ELEMENTS => AIR
ALLSEL,ALL
ET,2,236
DADELE,ALL,VOLT
FINISH
/SOLU     ! SOLVE
ALLSEL,ALL
SOLVE
FINISH

C*** POST PROCESS
/POST26
RFORCE,2,N_COIL,AMPS,,IC_AIR
VPUT,IC,3,,,IC_PLATE     ! MOVE RESULTS FROM AN ARRAY
VGET,VALUE(2,2),2,1E-2
VGET,VALUE4(2,2),2,4E-2
VGET,VALUE7(2,2),2,7E-2
VALUE(1,1)=1.16   ! ORIGINAL RESULTS
VALUE(2,1)=0.97
VALUE4(1,1)=1.51
VALUE4(2,1)=1.57
VALUE7(1,1)=1.58
VALUE7(2,1)=1.61
VALUE(1,3)=VALUE(1,2)/VALUE(1,1)
VALUE(2,3)=VALUE(2,2)/VALUE(2,1)
VALUE4(1,3)=VALUE4(1,2)/VALUE4(1,1)
VALUE4(2,3)=VALUE4(2,2)/VALUE4(2,1)
VALUE7(1,3)=VALUE7(1,2)/VALUE7(1,1)
VALUE7(2,3)=VALUE7(2,2)/VALUE7(2,1)
/OUT
*VLEN,2
/OUT,VM121_1,vrt
/COM
/COM,----------- VM121 RESULTS COMPARISON at Time=1e-2 Sec -------------
/COM,
/COM,          |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'    ',F7.3,'     ',F10.3,'       ',1F15.3)
/COM,----------------------------------------------------------------
/OUT,VM121_4,vrt
/COM
/COM,----------- VM121 RESULTS COMPARISON at Time=4e-2 Sec -------------
```

```
/COM,
/COM,          |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE4(1,1),VALUE4(1,2),VALUE4(1,3)
(1X,A8,'    ',F7.3,'     ',F10.3,'       ',1F15.3)
/COM,-------------------------------------------------------------
/OUT,VM121_7,vrt
/COM
/COM,----------- VM121 RESULTS COMPARISON at Time=7e-2 Sec -------------
/COM,
/COM,          |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE7(1,1),VALUE7(1,2),VALUE7(1,3)
(1X,A8,'    ',F7.3,'     ',F10.3,'       ',1F15.3)
/COM,-------------------------------------------------------------
/OUT
/AXL,X,TIME (S)
/AXL,Y,COIL CURRENT (A)
PLVAR,2,3
PRVAR,2,3
*LIST,VM121_1,vrt
*LIST,VM121_4,vrt
*LIST,VM121_7,vrt
FINISH
```

VM122 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM122
/PREP7
/TITLE, VM122, PRESSURE DROP IN A FLOWING FLUID
C***    FLUID MECHANICS, BINDER, 3RD. ED., PAGE 118, ART. 8-6
ET,1,FLUID116,2             ! Use only pressure degrees of freedom
keyo,1,7,1
R,1,6                       ! DIAMETER
MP,DENS,1,8.411E-5          ! BENZENE MASS DENSITY
MP,MU,1,.016                ! FRICTION FACTOR
N,1
N,2,2400
E,1,2
D,2,PRES,0                  ! OUTLET REFERENCE PRESSURE
F,1,FLOW,121.3/386.4        ! INLET MASS FLOWRATE
OUTPR,BASIC,1
OUTPR,NLOAD,1
FINISH
/SOLU
SOLVE
*GET,DELTAP,NODE,1,PRES
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'DELTA P'
LABEL(1,2) = ',(PSI)'
*VFILL,VALUE(1,1),DATA,4.69
*VFILL,VALUE(1,2),DATA,DELTAP
*VFILL,VALUE(1,3),DATA,ABS(DELTAP/4.69)
/OUT,vm122,vrt
/COM
/COM,------------------- VM122 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F12.3,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm122,vrt
```

VM123 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM123
/PREP7
/TITLE, VM123, LAMINAR FLOW IN A PIPING SYSTEM
C***    FLOW OF FLUIDS, CRANE TECH. PAPER NO. 410, PAGE 4-5, EX. 4-9
ET,1,FLUID116,2      ! THERMAL-FLOW PIPE
R,1,.4206            ! PIPE DIAMETER
rmore
rmore,,53            ! LOSS LENGTH
MP,DENS,1,1.7546     ! MASS DENSITY OF OIL
MP,MU,1,.05          ! INITIAL FRICTION FACTOR
MP,VISC,1,.010032    ! OIL VISCOSITY
N,1
N,2,300
E,1,2
D,2,PRES,0           ! OUTLET REFERENCE PRESSURE
F,1,FLOW,75.53/32.2 ! INLET MASS FLOW
OUTPR,BASIC,1
OUTPR,NLOAD,1
FINISH
/SOLU
SOLVE
FINISH
/POST1
ETABLE,RE,NMISC,2
ESORT,RE
*GET,REY,SORT,,MAX
*GET,DELTAP,NODE,1,PRES
*status,parm
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'DELTA P ','Re'
LABEL(1,2) = 'lb/ft/ft '
*VFILL,VALUE(1,1),DATA,6160,708
*VFILL,VALUE(1,2),DATA,DELTAP,REY
*VFILL,VALUE(1,3),DATA,ABS(DELTAP/6160),ABS(REY/708)
/OUT,vm123,vrt
/COM
/COM,------------------- VM123 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F12.0,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm123,vrt
```

VM124 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM124
/PREP7
/TITLE, VM124, DISCHARGE OF WATER FROM A RESERVOIR
C***    ELEMENTARY THEORETICAL FLUID MECHANICS, BRENKERT, PAGE 224, PROB. 4
ET,1,FLUID116,2       ! FLOW PIPE WITH LOSS COEFFICIENTS
KEYO,1,7,3
KEYO,1,8,1
DENS = 1.94
MP,DENS,1,DENS
MP,MU,1,.025
MP,VISC,1,2.36E-5
```

```
TB,FCON              ! NON-LINEAR FRICTION FACTOR TABLE
TBPT,,1e5,0.028
TBPT,,3e5,0.028
TBPT,,5e5,0.028
TBPT,,7e5,0.028
TBPT,,9e5,0.028
TBPT,,1e6,0.028
ACELY = 32.2
R,1,.25
RMORE
RMORE,10*ACELY*DENS  ! INCLUDE PUMP HEAD
R,2,.25
RMORE
RMORE,,.5            ! INCLUDE SHARP-EDGE LOSS
R,3,.25
RMORE
RMORE,,.9            ! INCLUDE ELBOW LOSS
R,4,.25
RMORE
RMORE,,.9            ! INCLUDE ELBOW LOSS
N,1,-.01,10
N,2,    ,10
N,3,20,  10
N,4,20
N,5,90
E,1,2
EGEN,4,1,-1,,,,,1    ! INCREMENT REAL CONSTANTS
ACEL,,ACELY          ! GRAVITY LOAD
D,1,PRES,,,5,4       ! WATER SURFACE AND PIPE OUTLET AT ZERO PRESSURE
CNVTOL,FLOW,1,.0001  ! SET CONVERGENCE VALUE FOR FLUID FLOW WITH
                     !  TOLERANCE LIMIT
OUTPR,,1             ! PRINT BASIC SOLUTION QUANTITIES OF SUBSTEP 1
FINISH
/SOLU
SOLVE
FINISH
/POST1
ETABLE,R,NMISC,2
ESORT,R
*GET,RE,SORT,,MAX
ETABLE,FL,NMISC,3
ESORT,FL
*GET,FLOW,SORT,,MAX
*status,parm
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'FLOW RT. ','Re'
LABEL(1,2) = 'lb/sec '
*VFILL,VALUE(1,1),DATA,0.898,1.94E5
*VFILL,VALUE(1,2),DATA,FLOW,RE
*VFILL,VALUE(1,3),DATA,ABS(FLOW/0.898),ABS(RE/1.94E5)
/OUT,vm124,vrt
/COM
/COM,------------------- VM124 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,' ',F12.3,F17.3,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm124,vrt
```

VM125 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM125
```

```
/PREP7
/TITLE, VM125, RADIATION HEAT TRANSFER BETWEEN CONCENTRIC CYLINDERS
C*** PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND PRINTING, PAGE 260
ANTYPE,STATIC
ET,1,LINK33,,,,,,,1    ! HEAT CONDUCTING BAR; SUPPRESS SOLUTION OUTPUT
R,1,1                  ! UNIT CROSS-SECTIONAL AREA (ARBITRARY)
MP,KXX,1,1             ! ARBITRARY CONDUCTIVITY DEFINED FOR
MP,KXX,2,1             !       INNER AND OUTER CYLINDERS
K,1
K,2,0,0,-1
K,3,-5
K,4,0,0,1
CIRCLE,1,1,2,3,,18     ! INNER CIRCLE; GENERATED CLOCKWISE
MAT,1
ESIZE,,1
LMESH,ALL
CIRCLE,1,2,4,3,,18     ! OUTER CIRCLE; GENERATED ANTI-CLOCKWISE
MAT,2
LMESH,19,36
FINISH
/AUX12
EMIS,1,.7
EMIS,2,.5
VTYPE,0                ! HIDDEN PROCEDURE FOR VIEW FACTORS
GEOM,1                 ! GEOMETRY SPECIFICATION 2-D
WRITE,VM125            ! WRITE RADIATION MATRIX TO FILE VM125.SUB
FINISH
/PREP7
DOF,TEMP
ET,2,MATRIX50,1,,,,,1  ! SUPERELEMENT (RADIATION MATRIX)
TYPE,2
SE,VM125
TOFFST,460.0           ! TEMPERATURE OFFSET FOR ABSOLUTE SCALE
LSEL,S,LINE,,1,18
NSLL,S,1               ! SELECT INNER CYLINDER NODES
D,ALL,TEMP,540         ! T1 = 540 + 460 = 1000 DEG. R.
LSEL,S,LINE,,19,36
NSLL,S,1               ! SELECT OUTER CYLINDER NODES
D,ALL,TEMP,0.0         ! T2 = 460 DEG. R.
NSEL,ALL
LSEL,ALL
FINISH
/SOLU
SOLVE
FINISH
/POST1
ESEL,S,ELEM,,1,18      ! SELECT INNER ELEMENTS
NSLE                   ! AND ASSOCIATED NODES
PRRSOL                 ! PRINT HEAT FLOW FROM INNER TO OUTER CYLINDER
NSEL,INVE
PRRSOL                 ! PRINT HEAT FLOW FROM OUTER TO INNER CYLINDER
ESEL,ALL
FSUM,HEAT
*GET,Q,FSUM,0,ITEM,HEAT
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'Q(BTU/hr'
LABEL(1,2) = '-in)'
*VFILL,VALUE(1,1),DATA,37
*VFILL,VALUE(1,2),DATA,Q
*VFILL,VALUE(1,3),DATA,ABS(Q/37)
/COM
/OUT,vm125,vrt
/COM,------------------- VM125 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F12.1,'   ',1F15.3)
/COM,-----------------------------------------------------------
/COM,
/OUT
```

```
FINISH
/DELETE,VM125,sub
*LIST,vm125,vrt
```

VM126 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM126
/PREP7
/TITLE, VM126, HEAT TRANSFERRED TO A FLOWING FLUID
C***    HEAT, MASS AND MOMENTUM TRANS, ROHSENOW AND CHOI, PAGE 168, EX 7.5
ET,1,FLUID116,1,4,,1                    ! THERMAL-FLOW PIPE ELEMENT
ET,2,FLUID116,1
R,1,(1/12),.00545415                    ! DIAMETER
RMORE,,,1.63,.08,.7,.35                 ! FLOW DEPENDENT FILM COEFF.
MP,KXX,1,.017    ! BTU/hr-ft-F
MP,DENS,1,1.4377E-10   ! lbf-hr**2/ft**4
MP,C,1,1.002e8    ! BTU-ft/lbf-hr**2-F
MP,VISC,1,1.17418E-10   ! lbf-hr/ft**2
N,1
N,19,,,.46875                           ! NODE JUST BEYOND
FILL,1,19,8,3,2                         ! NODES ALONG PIPE AXIS
N,2
N,18
FILL,2,18,7,4,2                         ! CONVECTION NODES (ARBITRARY LOCATION)
TYPE,1
E,1,3,2,4
EGEN,8,2,1
type,2
E,17,19                                 ! EXTENSION ELEMENT
D,1,TEMP,100                            ! INLET AIR TEMPERATURE
D,2,TEMP,200,,18,2                      ! WALL TEMPERATURE
SFE,ALL,,HFLUX,,1.1321e-8               ! FLOW RATE INPUT  lbf-hr/ft
OUTPR,,LAST                             ! PRINT FINAL CONVERGED ITERATION
OUTPR,NLOAD,1
FINISH
/SOLU
EQSLV,JCG
SOLVE
FINISH
/POST1
ETABLE,HEAT,NMISC,5                     ! STORE HEAT TRANSPORT RATE
PRETAB,HEAT                             ! PRINT HEAT TRANSPORT RATES PER ELEMENT
NSEL,S,NODE,,1,19,2                     ! SELECT PIPE NODES
PRNSOL,TEMP                             ! PRINT TEMPERATURES ALONG PIPE LENGTH
*GET,TO,NODE,17,TEMP
ETABLE,HEAT,NMISC,5
ESORT,HEAT
*GET,QOUT,SORT,,MAX
*GET,QIN,SORT,,MIN
*status,parm
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'To ','Q(in)','Q(out)'
LABEL(1,2) = 'F ','BTU/hr','BTU/hr'
*VFILL,VALUE(1,1),DATA,123,113.28,139.33
*VFILL,VALUE(1,2),DATA,TO,QIN,QOUT
*VFILL,VALUE(1,3),DATA,ABS(TO/123),ABS(QIN/113.28),ABS(QOUT/139.33)
/COM
/OUT,vm126,vrt
/COM,------------------- VM126 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F12.2,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
```

```
FINISH
*LIST,vm126,vrt
```

VM127 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM127
/PREP7
MP,PRXY,,0.3
/TITLE, VM127, BUCKLING OF A BAR WITH HINGED SOLVES (LINE ELEMENTS)
C***    STR. OF MATL., TIMOSHENKO, PART 2, 3RD ED., PAGE 148
ET,1,BEAM188              ! BEAM ELEMENT
KEYOPT,1,3,3
SECT,1,BEAM,RECT
SECD,0.5,0.5
MP,EX,1,30E6
N,1
N,11,,100
FILL
E,1,2
EGEN,10,1,1
D,ALL,UZ,,,,,ROTX,ROTY
SAVE,,DB
FINISH

/COM
/COM,***BUCKLING ANALYSIS USING PSTRES COMMAND******
/SOLUTION
ANTYPE,STATIC                   ! STATIC ANALYSIS
PSTRES,ON                       ! CALCULATE PRESTRESS EFFECTS
D,1,ALL                         ! FIX SYMMETRY END
F,11,FY,-1                      ! UNIT LOAD AT FREE END
SOLVE
FINISH

/SOLU
ANTYPE,BUCKLE                   ! BUCKLING ANALYSIS
BUCOPT,LANB,1                   ! USE BLOCK LANCZOS EIGENVALUE EXTRACTION METHOD
MXPAND,1
SOLVE
*GET,FCR1,MODE,1,FREQ
*status,parm
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'Fcr '
LABEL(1,2) = 'lb '
*VFILL,VALUE(1,1),DATA,38.553
*VFILL,VALUE(1,2),DATA,FCR1
*VFILL,VALUE(1,3),DATA,ABS(FCR1/38.553)
SAVE,TABLE_1
FINISH
/CLEAR,NOSTART

/COM,
/COM, ****USING LINEAR PERTURBATION METHOD*************
/COM,
/PREP7
RESUME,,DB                      ! RESUME THE DATABASE
FINISH

/SOLU
ANTYPE,STATIC                   ! STATIC ANALYSIS
RESCONTROL,LINEAR,ALL,1         ! RESTART FILES FOR SUBSEQUENT LINEAR PERTURBATION
D,1,ALL                         ! FIX SYMMETRY END
F,11,FY,-1                      ! UNIT LOAD AT FREE END
SOLVE
FINISH
/SOLU
```

```
ANTYPE,STATIC,RESTART,,,PERTURB ! PERFORM A PERTURBATION ANALYSIS
PERTURB,BUCKLE,,,ALLKEEP        ! PERTURBED BUCKLING SOLVE
SOLVE,ELFORM                    ! REFORM ELEMENT MATRICES
BUCOPT,LANB,1,,,RANGE           ! USE BLOCK LANCZOS EIGENVALUE EXTRACTION METHOD, EXTRACT 1 MODE
MXPAND,1                        ! EXPAND 1 MODE SHAPE
SOLVE
*GET,FCR2,MODE,1,FREQ
*status,parm
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'Fcr '
LABEL(1,2) = 'lb '
*VFILL,VALUE(1,1),DATA,38.553
*VFILL,VALUE(1,2),DATA,FCR2
*VFILL,VALUE(1,3),DATA,ABS(FCR2/38.553)
SAVE,TABLE_2
FINI
/CLEAR,NOSTART

/NOPR
/COM
/OUT,vm127,vrt
/COM,------------------- VM127 RESULTS COMPARISON -------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,
RESUME,TABLE_1
/COM,USING PSTRES COMMAND
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F12.3,'   ',1F15.3)
/COM,
/COM,
RESUME,TABLE_2
/COM,USING LINEAR PERTURBATION METHOD
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F12.3,'   ',1F15.3)
/COM,
/COM,----------------------------------------------------------
/OUT
*LIST,vm127,vrt
FINISH
```

VM128 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM128
/PREP7
MP,PRXY,,0.3
/TITLE, VM128, BUCKLING OF A BAR WITH HINGED SOLVES (AREA ELEMENTS)
C***    STR. OF MATL., TIMOSHENKO, PART 2, 3RD ED., PAGE 148
ET,1,PLANE182,2,,3               ! 2-D SOLID
R,1,.5                           ! THICKNESS (SQUARE CROSS-SECTION)
MP,EX,1,30E6
MP,PRXY,1,0.3
N,1
N,11,,100
FILL
NGEN,2,11,1,11,,.5
E,12,13,2,1
EGEN,10,1,1
FINISH
/SOLU
ANTYPE,STATIC
RESCONTROL,LINEAR,ALL,1         ! RESTART FILES FOR SUBSEQUENT LINEAR PERTURBATION
D,1,ALL,,,12,11                 ! FIX SYMMETRY SOLVE
```

```
F,11,FY,-.5,,22,11                ! UNIT LOAD AT FREE END DIVIDED BETWEEN NODES
OUTPR,,1
/OUT,SCRATCH
SOLVE
FINISH
/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB ! PERFORM A PERTURBATION ANALYSIS
PERTURB,BUCKLE,,,ALLKEEP        ! PERTURBED BUCKLING SOLVE
SOLVE,ELFORM                    ! REFORM ELEMENT MATRICES

BUCOPT,SUBSPACE,1               ! USE SUBSPACE EXTRACTION METHOD, EXTRACT 1 MODE
MXPAND,1                        ! EXPAND 1 MODE SHAPE
SOLVE
/OUT,
*GET,FCR,MODE,1,FREQ
*STATUS,PARM
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'Fcr '
LABEL(1,2) = 'lb '
*VFILL,VALUE(1,1),DATA,38.553
*VFILL,VALUE(1,2),DATA,FCR
*VFILL,VALUE(1,3),DATA,ABS(FCR/38.553)
/OUT,vm128,vrt
/COM,--------------------- vm128 RESULTS COMPARSION ---------------
/COM,
/COM, BLOCK LANCZOS SOLUTION
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F10.3,'   ',1F5.3)
/COM,
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vm128,vrt
```

VM129 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM129
/TITLE, VM129, NUMERICAL DIFFERENTIATION AND INTEGRATION USING APDL COMMAND
C***    REFERENCE - ANY BASIC CALCULUS BOOK
*DIM,A,,145                 ! DEFINE ARRAYS WITH DIMENSION
*DIM,B,,145
*DIM,C,,145
*DIM,D,,145
*DIM,E,,145
*DIM,F,,145
*DIM,G,,145
*DIM,H,,145
*VFILL,A(1),RAMP,0,1        ! ARRAY A(N) : TIME IN SECOND
*VFACT,0.043633             ! MULTIPLYING FACTOR : FREQUENCY = (PI/72)
*VFUN,B(1),COPY,A(1)        ! RESULT ARRAY B(N)=FREQUENCY*A(N)
*VFUN,C(1),SIN,B(1)         ! ARRAY C(N) : SIN(B(N))
*VFACT,1.2732               ! MULTIPLYING FACTOR : AMPLITUDE A
*VFUN,D(1),COPY,C(1)        ! ARRAY D(N) : A*C(N)
*VOPER,E(1),D(1),DER1,A(1) ! ARRAY E(N) : FIRST DERIVATIVE OF D WRT TIME
*VOPER,F(1),D(1),INT1,A(1) ! ARRAY F(N) : SINGLE INTEGRAL (I1) OF D WRT TIME
*VOPER,G(1),D(1),DER2,A(1) ! ARRAY G(N) : SECOND DERIVATIVE OF D WRT TIME
*VOPER,H(1),D(1),INT2,A(1) ! ARRAY H(N) : DOUBLE INTEGRAL (I2) OF D WRT TIME
*VSCFUN,DERIV1,MAX,E(1)     ! MAXIMUM VALUE OF FIRST DERIVATIVE
*VSCFUN,DERIV2,MAX,G(1)     ! MAXIMUM VALUE OF SECOND DERIVATIVE
*status,parm                   ! LIST SCALAR PARAMETERS
*STATUS,F,37,37             ! LIST VALUE OF F(N) AT UPPER LIMIT (INTEGRAL I1)
*STATUS,H,37,37             ! LIST VALUE OF H(N) AT UPPER LIMIT (INTEGRAL I2)
*SET,INTER1,F(37,1,1)
*SET,INTER2,H(37,1,1)
```

```
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = '1ST DER ','2ND DER','1ST INT','2ND INT'
LABEL(1,2) = 'MAX','MAX','T(0-36)','T(0-36)'
*VFILL,VALUE(1,1),DATA,5.555E-2,2.424E-3,29.18,381.7
*VFILL,VALUE(1,2),DATA,DERIV1,DERIV2,INTER1,INTER2
DRV1=ABS(DERIV1/5.555E-2)
DRV2=ABS(DERIV2/2.424E-3)
INT1=ABS(INTER1/29.18)
INT2=ABS(INTER2/381.7)
*VFILL,VALUE(1,3),DATA,DRV1,DRV2,INT1,INT2
/COM
/OUT,vm129,vrt
/COM,------------------- VM129 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.6,'  ',F15.6,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm129,vrt
```

VM130 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM130
/TITLE, VM130, FOURIER SERIES GENERATION FOR A SAW TOOTH WAVE
/COM    VIBRATION PROBS. IN ENGR., TIMOSHENKO, 3RD. ED., PAGE 102, PROB. 2
*DIM,COEFF,,24
*DIM,MODE,TABLE,24
*DIM,ISYM,TABLE,24
*DIM,THETA,TABLE,121
*DIM,CURVEI,TABLE,121                 ! CURVE INPUT TO PROGRAM
*DIM,CURVEO,TABLE,121                 ! CURVE WHICH WILL BE DEVELOPED
!                                       FROM GENERATED COEFFICIENTS
*VFILL,MODE(2),RAMP,1,2               ! ODD MODE NUMBERS
*VFILL,ISYM(2),RAMP,-1,0              ! ISYM = -1 (SINE)
*VFILL,THETA(1),RAMP,0,3              ! THETA VALUES INCREMENT 3 DEGREES
*VFILL,CURVEI(1),RAMP,0,1/30          ! WAVE DATA:  0 TO 90 DEG
*VFILL,CURVEI(31),RAMP,1,-1/30        !             90 TO 270 DEG
*VFILL,CURVEI(91),RAMP,-1,1/30        !             270 TO 360 DEG
!     CALCULATE FOURIER COEFFICIENT
*MFOURI,FIT, COEFF(1),MODE(1),ISYM(1),THETA(1),CURVEI(1)
!     EVALUATE SERIES BASED ON COEFFICIENTS
*MFOURI,EVAL,COEFF(1),MODE(1),ISYM(1),THETA(1),CURVEO(1)

*VWRITE                               ! WRITE OUTPUT IN TABULAR FORMAT
(///T14,'MODE',T24,'COEFF',T34,'ISYM',/)
*VWRITE,  MODE(1),COEFF(1),ISYM(1)
(T10,F10.4,T20,F10.4,T30,F10.4,T40,F10.4)

*VWRITE
(///T14,'THETA',T23,'CURVE IN',T34,'CURVE OUT',/)
*VWRITE, THETA(1),CURVEI(1),CURVEO(1)
(T10,F10.4,T20,F10.4,T30,F10.4)
/GFILE,500
JPEG,QUAL,100
/TRIAD,OFF
/PLOPTS,LOGO,0
/PLOPTS,INFO,2
/PLOPTS,WP,0
/RGB,INDEX,100,100,100,0
/RGB,INDEX,80,80,80,13
/RGB,INDEX,60,60,60,14
/RGB,INDEX,0,0,0,15
/YRANGE,-1.25,1.25,ALL
```

```
*VPLOT,THETA(1),CURVEI(1)            ! PLOT INPUT CURVE VERSUS THETA
/USER
/NOERASE
/COM OVERLAY THE OUTPUT CURVE ON THE INPUT CURVE
*VPLOT,THETA(1),CURVEO(1)    ! PLOT OUTPUT CURVE VERSUS THETA
*SET,M1,COEFF(2,1,1)
*SET,M3,COEFF(3,1,1)
*SET,M5,COEFF(4,1,1)
*SET,M7,COEFF(5,1,1)
*status,parm
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'M1 ','M2 ','M3 ','M4 '
LABEL(1,2) = 'COEF','COEF','COEF','COEF'
*VFILL,VALUE(1,1),DATA,.811,-.901E-1,.324E-1,-.165E-1
*VFILL,VALUE(1,2),DATA,M1,M3,M5,M7
*VFILL,VALUE(1,3),DATA,ABS(M1/.811),ABS(M3/(-.901E-1)),ABS(M5/(.324E-1)),ABS(M7/(-.165E-1))
/COM
/OUT,vm130,vrt
/COM,------------------- VM130 RESULTS COMPARISON -------------
/COM,
/COM,                   |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F12.4,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm130,vrt
```

VM131 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM131
/PREP7
/TITLE, VM131, ACCELERATION OF A ROTATING CRANE BOOM
C***    VECTOR MECHANICS FOR ENGINEERS, BEER & JOHNSTON, P 616, PROB. 15.13
ANTYPE,STATIC
ET,1,MASS21,,,2       ! GENERALIZED MASS WITHOUT ROTARY INERTIA
R,1,1                 ! UNIT MASS
N,1,34.64,20
E,1
OMEGA,,,.5            ! ANGULAR VELOCITY OF RISING BOOM WRT GLOBAL
CGOMGA,,.3            ! ANGULAR VELOCITY OF CAB WRT REFERENCE SYSTEM
D,1,ALL
OUTRES,,1
OUTPR,RSOL,1
OUTPR,NLOAD,1
FINISH
/out,scratch
/SOLU
SOLVE
NSEL,S,NODE,,1,1
FINI
/out
/POST1
FSUM
*GET,AX,FSUM,,ITEM,FX
*GET,AY,FSUM,,ITEM,FY
*GET,AZ,FSUM,,ITEM,FZ
*status,parm
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'AX ','AY ','AZ '
LABEL(1,2) = 'ft/s/s','ft/s/s','ft/s/s'
*VFILL,VALUE(1,1),DATA,-11.78,-5,6
*VFILL,VALUE(1,2),DATA,(-1)*(AX),(-1)*(AY),(-1)*(AZ)
*VFILL,VALUE(1,3),DATA,ABS((-1)*AX/11.78),ABS((-1)*AY/5),ABS((-1)*AZ/6)
```

```
/COM
/OUT,vm131,vrt
/COM,------------------- VM131 RESULTS COMPARISON -------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F12.2,'   ',1F15.2)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm131,vrt
```

VM132 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM132
/PREP7
/TITLE, VM132, STRESS RELAXATION OF A BOLT DUE TO CREEP
C***    STR. OF MATL., TIMOSHENKO, PART 2, 3RD ED., PAGE 531
ANTYPE,STATIC
ET,1,LINK180             ! SPAR ELEMENT
SECTYPE,1,LINK
SECDATA,1
MP,EX,1,30E6
TB,CREEP,1,1,1,1         ! IMPLICIT CREEP WITH STRAIN HARDENING
TBDATA,1,4.8E-30,7       ! CREEP PROPERTIES
N,1
N,2,10
E,1,2
INIS,SET,DTYP,EPEL       ! APPLY INITIAL STRAIN
INIS,DEFI,1,ALL,ALL,ALL,1/30000
BFUNIF,TEMP,900        ! UNIFORM TEMPERATURE
TIME,1000
KBC,1
D,ALL,ALL              ! FIX ALL DOFS
FINISH
/SOLU
SOLCONTROL,0
NSUBST,100
RATE,ON,ON
OUTPR,BASIC,10         ! PRINT BASIC SOLUTION FOR EVERY 10TH SUBSTEP
OUTRES,ESOL,1          ! STORE ELEMENT SOLUTION FOR EVERY SUBSTEP
/OUT,SCRATCH
SOLVE
FINISH
/POST26
ESOL,2,1,,LS,1,SIG     ! STORE AXIAL STRESS
/OUT,
PRVAR,2                ! PRINT AXIAL STRESS VS TIME
*GET,T190,VARI,2,RTIME,190
*GET,T420,VARI,2,RTIME,420
*GET,T690,VARI,2,RTIME,690
*GET,T880,VARI,2,RTIME,880
*GET,T950,VARI,2,RTIME,950
*status,parm
*DIM,LABEL,CHAR,5,2
*DIM,VALUE,,5,3
LABEL(1,1) = 'SIG @ ','SIG @ ','SIG @ ','SIG @ ','SIG @ '
LABEL(1,2) = '190 hr','420 hr','690 hr','880 hr','950 hr'
*VFILL,VALUE(1,1),DATA,975,950,925,910,905
*VFILL,VALUE(1,2),DATA,T190,T420,T690,T880,T950
V1 = ABS(T190/975)
V2 = ABS(T420/950)
V3 = ABS(T690/925)
V4 = ABS(T880/910)
V5 = ABS(T950/905)
*VFILL,VALUE(1,3),DATA,V1,V2,V3,V4,V5
```

```
/COM
/OUT,vm132,vrt
/COM,------------------- VM132 RESULTS COMPARISON -------------
/COM,
/COM,                   |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F12.0,'   ',1F15.2)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm132,vrt
```

VM133 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM133
/PREP7
MP,PRXY,,0.3
/TITLE, VM133, MOTION OF A ROD DUE TO IRRADIATION INDUCED CREEP
C***    REFERENCE - ANY BASIC CALCULUS BOOK
ANTYPE,STATIC
ET,1,BEAM188
SECT,1,BEAM,RECT
SECD,0.5,0.5
MP,EX,1,300
TB,CREEP,1,,,3
TBDATA,1,0.5e-2,1,0,0,1
N,1
N,2,1
E,1,2
D,1,ALL                 ! FIX ONE END
F,2,FX,0.25             ! FORCE INDUCING CONSTANT STRESS
FINISH
/SOLU
RATE,OFF
BFE,1,TEMP,1,1000,1000,1000,1000 ! APPLY CONSTANT TEMPERATURE
TIME,1E-8               ! NEAR ZERO TIME FOR FIRST LOAD STEP
OUTPR,BASIC,1           ! PRINT BASIC ELEMENT SOLUTION
OUTRES,EPCR,1           ! STORE CREEP STRAIN RESULTS FOR EVERY SUBSTEP
CNVTOL,F,,,,1E-6        ! NEAR ZERO VALUE FOR MINREF FIELD
CNVTOL,M,-1             ! CONVERGENCE CRITERION BASED UPON MOMENTS IS
                        !  REMOVED AS IT IS NOT NEEDED FOR THIS TEST
/OUT,SCRATCH
SOLVE                   ! LOAD STEP 1
NSUBST,50,500,50
TIME,5
OUTPR,BASIC,5
RATE,ON
SOLVE                   ! LOAD STEP 2
FINISH
/POST26
ESOL,2,1,,LEPCR,1,EPCR ! STORE CREEP STRAIN
/OUT,
PRVAR,2                 ! PRINT STRAIN VARIATION WITH TIME
*GET,T1,VARI,2,RTIME,0
*GET,T2,VARI,2,RTIME,.5
*GET,T3,VARI,2,RTIME,1
*GET,T4,VARI,2,RTIME,5
*status,parm
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'CRP STR @','CRP STR @','CRP STR @','CRP STR @'
LABEL(1,2) = '0 hr','.5 hr','1 hr','5 hr'
*VFILL,VALUE(1,1),DATA,0,.00197,.00316,.00497
*VFILL,VALUE(1,2),DATA,T1,T2,T3,T4
*VFILL,VALUE(1,3),DATA,000,ABS(T2/.00197),ABS(T3/.00316),ABS(T4/.00497)
/COM
```

```
/OUT,vm133,vrt
/COM,------------------- VM133 RESULTS COMPARISON -------------
/COM,
/COM,                   |   TARGET   |   Mechanical APDL    |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F12.5,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm133,vrt
```

VM134 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM134
/PREP7
/TITLE, VM134, PLASTIC BENDING OF A CLAMPED I-BEAM
C***    THE ANALYSIS OF STRUCTURES, N.J. HOFF, 1964, P. 388
ET,1,BEAM188,,,3
MP,EX  ,1,29E6
MP,PRXY,1,0.3
TB,BKIN,1,1                  ! BILINEAR KINEMATIC HARDENING BEHAVIOR
TBTEMP,0.0
TBDATA,1,38000,5.8E6         ! YIELD STRESSES AND TANGENT MODULUS
SECTYPE,1,BEAM,I
SECDATA,95.95,95.95,10.6,0.1,0.1,0.0001
SECCONTROL,1E15              ! OVERRIDE THE PROGRAM-CALCULATED TRANSVERSE SHEAR STIFFNESS
N,1
N,10,72
FILL
N,100,,,1
E,1,2,100
*REPEAT,9,1,1
D,1,ALL                      ! FIX ONE END
D,10,ROTY,,,,,UY,ROTX,ROTZ   ! SYMMETRIC MID-SPAN B.C.
FINISH
/SOLU
SFBEAM,1,1,PRES,2190         ! LOAD STEP 1: W1
*REPEAT,9,1
OUTPR,BASIC,LAST             ! PRINT BASIC SOLUTION FOR LAST SUBSTEP
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
*GET,DEF1,NODE,10,UZ
FINISH
/POST26
RFORCE,2,10,M,Y
RFORCE,3,1,M,Y
PLVAR,2,3
*GET,MID1,VARI,2,EXTREM,VMAX
*GET,END1,VARI,3,EXTREM,VMAX
FINISH
/SOLU
SFBEAM,1,1,PRES,3771         ! LOAD STEP 2: W2
*REPEAT,9,1
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
*GET,DEF2,NODE,10,UZ
FINISH
/POST26
RFORCE,2,10,M,Y
RFORCE,3,1,M,Y
```

```
PLVAR,2,3
*GET,MID2,VARI,2,EXTREM,VMAX
*GET,END2,VARI,3,EXTREM,VMAX
FINISH
/SOLU
SFBEAM,1,1,PRES,9039          ! LOAD STEP 3: W3; PLASTIC YIELDING
*REPEAT,9,1
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
*GET,DEF3,NODE,10,UZ
FINISH
/POST26
RFORCE,2,10,M,Y
RFORCE,3,1,M,Y
PLVAR,2,3
*GET,MID3,VARI,2,EXTREM,VMAX
*GET,END3,VARI,3,EXTREM,VMAX
ESEL,S,ELEM,,1,1
FINISH
/POST1
ETABLE,ESA1,LEPEL,1
ESORT,ESA1,,,1
*GET,EPELA,SORT,,MAX
ETABLE,ESB1,LEPPL,1
ESORT,ESB1,,,1
*GET,EPPLA,SORT,,MAX
FINISH
/POST26
ESEL,S,ELEM,,9,9
FINISH
/POST1
ETABLE,ESA2,LEPEL,1
ESORT,ESA2,,,1
*GET,EPELB,SORT,,MAX
ETABLE,ESB2,LEPPL,1
ESORT,ESB2,,,1
*GET,EPPLB,SORT,,MAX
*SET,ENDST,ABS(EPPLA+EPELA)
*SET,MIDST,ABS(EPELB+EPPLB)
*status,parm
FINISH
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'MID DEFL  ','MOM END ','MID MOM '
LABEL(1,2) = ' in ','in-lb','in-lb'
*VFILL,VALUE(1,1),DATA,-.160,-3.784E6,-1.892E6
*VFILL,VALUE(1,2),DATA,DEF1,END1,MID1
*VFILL,VALUE(1,3),DATA,ABS(DEF1/(-.160)),ABS(END1/(-3.784E6)),ABS(MID1/(-1.892E6))
/COM
/OUT,vm134,vrt
/COM,------------------- VM134 RESULTS COMPARISON ------------------
/COM,
/COM,   W1=2190 lb/in  |      TARGET   |      Mechanical APDL   | RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F13.3,'  ',F22.3,'   ',1F16.2)
/COM,-----------------------------------------------------------
/OUT
/NOPR
LABEL(1,1) = 'MID DEFL  ','MOM END ','MID MOM '
LABEL(1,2) = ' in ','in/lb','in/lb'
*VFILL,VALUE(1,1),DATA,-.357,-5.98E6,-3.78E6
*VFILL,VALUE(1,2),DATA,DEF2,END2,MID2
*VFILL,VALUE(1,3),DATA,ABS(DEF2/(-.357)),ABS(END2/(-5.98E6)),ABS(MID2/(-3.78E6))
/GOPR
/COM
/OUT,vm134,vrt,,APPEND
/COM,------------------- VM134 RESULTS COMPARISON ------------------
/COM,
```

```
/COM,   W2=3771 lb/in  |      TARGET   |      Mechanical APDL   | RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F13.3,'  ',F22.3,'   ',1F16.2)
/COM,---------------------------------------------------------------
/OUT
/NOPR
*DIM,LABEL1,CHAR,5,2
*DIM,VALUE1,,5,3
LABEL1(1,1) = 'MID DEFL  ','MOM END ','MID MOM ','TTL END ','TTL MID '
LABEL1(1,2) = ' in ','in-lb','in-lb','STRAIN','STRAIN'
*VFILL,VALUE1(1,1),DATA,-2.09,-1.51E7,-8.36E6,.02,.0089
*VFILL,VALUE1(1,2),DATA,DEF3,END3,MID3,ENDST,MIDST
V1 = ABS(DEF3/(-2.09))
V2 = ABS(END3/(-1.51E7))
V3 = ABS(MID3/(-8.36E6))
V4 = ABS(ENDST/.02)
V5 = ABS(MIDST/.0089)
*VFILL,VALUE1(1,3),DATA,V1,V2,V3,V4,V5
/GOPR
/COM
/OUT,vm134,vrt,,APPEND
/COM,------------------- VM134 RESULTS COMPARISON ------------------
/COM,
/COM,   W3=9039 lb/in  |        TARGET   |        Mechanical APDL   | RATIO
/COM,
*VWRITE,LABEL1(1,1),LABEL1(1,2),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A8,A8,'   ',F15.4,'  ',F22.4,'   ',1F16.2)
/COM,---------------------------------------------------------------
/OUT
/OUT,vm134,vrt,,APPEND
/COM,---------------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM134 NOT CONTAINED IN
/COM,THIS TABLE
/COM,---------------------------------------------------------------
/OUT
FINISH
*LIST,vm134,vrt
```

VM135 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM135
/TITLE, VM135, BENDING OF A BEAM ON AN ELASTIC FOUNDATION
C***    STR. OF MATL., TIMOSHENKO, PART 2, 3RD ED., PAGE 12
/PREP7
ET,1,BEAM189             ! BEAM
SECTYPE,1,BEAM,RECT
SECDATA,5,4.224
MP,EX  ,1,30E6
MP,PRXY,1,0.3
ET,2,153                 ! SURFACE EFFECT ELEMENT
R,2,,,,1515.15           ! FUNDATION STIFFNESS
TYPE,1
N,1
N,27,286
FILL
*DO,i,1,25,2
 E,i,i+2,i+1
*ENDDO
TYPE,2
REAL,2
*DO,i,1,25,2
 E,i,i+2,i+1
*ENDDO
F,1,FY,-1000             ! APPLY DOWNWARD FORCE
F,1,MZ,10000             ! APPLY END MOMENT
D,1,UX
```

```
DSYM,SYMM,Z
OUTPR,,1
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
/OUT,
*GET,UY,NODE,1,U,Y
*status,parm
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'END DISP  '
LABEL(1,2) = ' in '
*VFILL,VALUE(1,1),DATA,-.03762
*VFILL,VALUE(1,2),DATA,UY
*VFILL,VALUE(1,3),DATA,ABS(UY/.03762)
/COM
/OUT,vm135,vrt
/COM,------------------- VM135 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F12.5,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT

FINISH
*LIST,vm135,vrt
```

VM136 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM136
/PREP7
MP,PRXY,,0.3
/TITLE, VM136, LARGE DEFLECTIONS OF A BUCKLED BAR (THE ELASTICA)
C***    THEORY OF ELASTIC STABILITY, TIMOSHENKO AND GERE, 2ND ED., PAGE 78
ANTYPE,STATIC
NLGEOM,ON                 ! ACTIVATE LARGE DEFLECTION PROCESS
ET,1,BEAM188
KEYOPT,1,3,3
SECT,1,BEAM,RECT
SECD,0.5,0.5
MP,EX,1,3E7
N,1
N,11,,100
FILL
E,1,2
EGEN,10,1,1
D,ALL,UZ,,,,,ROTX,ROTY
FINISH
/SOLU
SOLCONTROL,0
NEQIT,150                 ! PERFORM MAXIMUM 150 EQUILIBRIUM ITERATIONS
OUTPR,BASIC,LAST          ! PRINT BASIC SOLUTION AT THE END OF EACH LOAD STEP
D,1,ALL
FCR=-38.553               ! SET CRITICAL LOAD PARAMETER
PI=3.14159265359
F,11,FY,FCR*1.015         ! VERTICAL LOAD
F,11,FX,.5                ! SMALL HORIZONTAL LOAD
/OUT,SCRATCH
SOLVE                     ! LOAD STEP 1
FDEL,11,FX                ! REMOVE PERTURBING HORIZONTAL LOAD
F,11,FY,FCR*1.063
SOLVE                     ! LOAD STEP 2
F,11,FY,FCR*1.152
SOLVE                     ! LOAD STEP 3
```

```
F,11,FY,FCR*1.293
SOLVE                    ! LOAD STEP 4
F,11,FY,FCR*1.518
SOLVE                    ! LOAD STEP 5
F,11,FY,FCR*1.884
SOLVE                    ! LOAD STEP 6
FINISH
/POST1
/USER
/FOCUS,,50,50            ! USER FOCUS TO CENTER ALL DISPLAYS
/DIST,,55                ! SELECT DISTANCE FOR MAGNIFICATION
/DSCALE,,1               ! SCALE TRUE TO GEOMETRY
/OUT,
SET,1,0
PLDISP,1
/NOERASE                 ! OVERLAY DISPLAYS ON SAME FRAME
SET,2,0
PLDISP
SET,3,0
PLDISP
*GET,UX3,NODE,11,U,X
*GET,UY3,NODE,11,U,Y
*GET,ROT3A,NODE,11,ROT,Z
SET,4,0
PLDISP
*GET,UX4,NODE,11,U,X
*GET,UY4,NODE,11,U,Y
*GET,ROT4A,NODE,11,ROT,Z
SET,5,0
PLDISP
*GET,UX5,NODE,11,U,X
*GET,UY5,NODE,11,U,Y
*GET,ROT5A,NODE,11,ROT,Z
SET,6,0
PLDISP
*GET,UX6,NODE,11,U,X
*GET,UY6,NODE,11,U,Y
*GET,ROT6A,NODE,11,ROT,Z
*status,parm
*SET,ROT6,(180*ROT6A/PI)
*SET,ROT5,(180*ROT5A/PI)
*SET,ROT4,(180*ROT4A/PI)
*SET,ROT3,(180*ROT3A/PI)
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'ROT Z ','UX','UY'
LABEL(1,2) = ' DEG',' in',' in'
*VFILL,VALUE(1,1),DATA,-60,59.3,-25.9
*VFILL,VALUE(1,2),DATA,ROT3,UX3,UY3
*VFILL,VALUE(1,3),DATA,ABS(ROT3/60),ABS(UX3/59.3),ABS(UY3/25.9)
/COM
/OUT,vm136,vrt
/COM,------------------- VM136 RESULTS COMPARISON -------------
/COM,
/COM,    F=44.413 lb  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F12.1,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
/NOPR
*VFILL,VALUE(1,1),DATA,-80,71.9,-44
*VFILL,VALUE(1,2),DATA,ROT4,UX4,UY4
*VFILL,VALUE(1,3),DATA,ABS(ROT4/80),ABS(UX4/71.9),ABS(UY4/44)
/GOPR
/COM
/OUT,vm136,vrt,,APPEND
/COM,------------------- VM136 RESULTS COMPARISON -------------
/COM,
/COM,    F=49.849 lb  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
```

```
(1X,A8,A8,'   ',F10.1,'  ',F12.1,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
/NOPR
*VFILL,VALUE(1,1),DATA,-100,79.2,-65.1
*VFILL,VALUE(1,2),DATA,ROT5,UX5,UY5
*VFILL,VALUE(1,3),DATA,ABS(ROT5/100),ABS(UX5/79.2),ABS(UY5/65.1)
/GOPR
/COM
/OUT,vm136,vrt,,APPEND
/COM,------------------- VM136 RESULTS COMPARISON -------------
/COM,
/COM,    F=58.523 lb  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F12.1,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
/NOPR
*VFILL,VALUE(1,1),DATA,-120,80.3,-87.7
*VFILL,VALUE(1,2),DATA,ROT6,UX6,UY6
*VFILL,VALUE(1,3),DATA,ABS(ROT6/120),ABS(UX6/80.3),ABS(UY6/87.7)
/GOPR
/COM
/OUT,vm136,vrt,,APPEND
/COM,------------------- VM136 RESULTS COMPARISON -------------
/COM,
/COM,    F=72.634 lb  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F12.1,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm136,vrt
```

VM137 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM137
/PREP7
/TITLE, VM137, LARGE DEFLECTION OF A CIRCULAR MEMBRANE
C***     THEORY OF PLATES AND SHELLS, TIMOSHENKO, P. 404, EQ. 236
ET,1,SHELL208,,,2
SECTYPE,1,SHELL
SECDATA,0.0001
SECNUM,1
MP,EX,1,30E6
MP,NUXY,1,.25
MP,ALPX,1,1E-5
N,1
N,11,10
FILL
E,1,2
EGEN,10,1,1
FINISH
/SOLU
ANTYPE,STATIC
NLGEOM,ON            ! LARGE DEFLECTION OPTION
CNVTOL,F,,,,1        ! USE FORCE CONVERGENCE ONLY, MINIMUM REFERENCE VALUE OF 1
OUTPR,,LAST
TUNIF,-50            ! THERMAL PRESTRESS TO START
NSEL,S,LOC,X,0
DSYM,SYMM,X          ! SYMMETRY B.C. AT X=0
NSEL,ALL
D,11,ALL
/OUT,SCRATCH
SOLVE
```

```
KBC,1              ! STEP B.C.
SF,ALL,PRES,.1     ! APPLY PRESSURE LOAD
SOLVE
TUNIF,0            ! REMOVE THERMAL PRESSURES
SOLVE
/POST1
/OUT,
SET,3
SHELL,MID
*GET,UY,NODE,1,U,Y
ESEL,S,ELEM,,1,1
ETABLE,CENT,S,X
ESORT,CENT
*GET,PRSCNT,SORT,,MAX
ESEL,S,ELEM,,10,10
ETABLE,CEN,S,X
ESORT,CEN
*GET,PRSOUT,SORT,,MAX
*STATUS,PARM
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'Y DISP ','PRES CENT ','PRES RIM'
LABEL(1,2) = ' in',' psi',' psi'
*VFILL,VALUE(1,1),DATA,-.459,61010,47310
*VFILL,VALUE(1,2),DATA,UY,PRSCNT,PRSOUT
*VFILL,VALUE(1,3),DATA,ABS(UY/.459),ABS(PRSCNT/61010),ABS(PRSOUT/47310)
/COM
/OUT,vm137,vrt
/COM,------------------- VM137 RESULTS COMPARISON --------------
/COM,
/COM,   LOAD STEP 3   |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F12.3,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm137,vrt
```

VM138 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM138
/PREP7
/TITLE, VM138, LARGE DEFLECTION BENDING OF A CIRCULAR PLATE
C***    THEORY OF PLATES AND SHELLS, TIMOSHENKO, P. 401, EQ. 232
ANTYPE,STATIC
NLGEOM,ON                ! LARGE DEFLECTION OPTION
ET,1,SHELL208,,,2
SECTYPE,1,SHELL
SECDATA,0.0025
SECNUM,1
MP,EX,1,2E11
MP,NUXY,1,0.3
N,1
N,11,.25
FILL
E,1,2
EGEN,10,1,1
OUTPR,,LAST
NSEL,S,LOC,X,0
DSYM,SYMM,X              ! SYMMETRY B.C. AT X=0
NSEL,ALL
D,11,ALL                 ! FIX RIM
SFE,1,1,PRES,,6585.175   ! ELEMENT PRESSURE LOAD
*REPEAT,10,1
FINISH
/SOLU
```

```
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
*GET,UY,NODE,1,U,Y
*STATUS,PARM
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'Y DISP '
LABEL(1,2) = ' m'
*VFILL,VALUE(1,1),DATA,-.00125
*VFILL,VALUE(1,2),DATA,UY
*VFILL,VALUE(1,3),DATA,ABS(UY/.00125)
/COM
/OUT,vm138,vrt
/COM,------------------- VM138 RESULTS COMPARISON -------------
/COM,
/COM,    LOAD STEP 3    |    TARGET    |    Mechanical APDL    |    RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'    ',F10.5,'  ',F12.5,'    ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm138,vrt
```

VM139 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM139
/PREP7
/TITLE, VM139, BENDING OF A LONG UNIFORMLY LOADED RECTANGULAR PLATE
C***            STR. OF MATL., TIMOSHENKO, PART 2, 3RD ED., PAGE 80
C***            USING SHELL181 ELEMENTS
ANTYPE,STATIC
ET,1,SHELL181,,,2
KEYOPT,1,8,2
SECTYPE,1,SHELL
SECDATA,0.375,1,0,3

MP,EX,1,30E6
MP,NUXY,1,0.3

RECT,0,22.5,0,9
LSEL,S,LINE,,1,3,2
LESIZE,ALL,,,8
LSEL,ALL
LSEL,S,LINE,,2,4,2
LESIZE,ALL,,,1
LSEL,ALL
AMESH,1
D,1,UX,,,,,UY,UZ
D,11,UX,,,,,UZ
D,ALL,ROTZ
NSEL,S,LOC,X,22.5
DSYM,SYMM,X,0,22.5        ! SYMMETRY B.C.'S AT CENTERLINE
NSEL,ALL
FINISH
/SOLU
SFE,ALL,2,PRES,0,10
OUTPR,BASIC,LAST
/OUT,SCRATCH
SOLVE                     ! ANALYSIS 1 : SMALL DEFLECTION SOLUTION
FINISH
/POST1
/OUT,
SET,1                     ! ANALYSIS 1 : SMALL DEFLECTION SOLUTION
```

```
NSEL,S,LOC,Y,0
SHELL,BOT                ! BOTTOM STRESSES ALONG LENGTH
PRNSOL,S,COMP
*GET,S2,NODE,2,S,X
PRNSOL,S,PRIN
NSEL,ALL
FINISH
/SOLU
NLGEOM,ON                ! LARGE DEFLECTION OPTION
/OUT,SCRATCH
SOLVE                    ! ANALYSIS 2 : LARGE DEFLECTION SOLUTION
FINISH
/POST1
/OUT,
SET,1                    ! ANALYSIS 2 : CONVERGED LARGE DEFLECTION SOLUTION
NSEL,S,LOC,Y,0
SHELL,MID                ! MIDDLE STRESSES ALONG LENGTH
PRNSOL,S,COMP
*GET,S3,NODE,1,S,X
PRNSOL,S,PRIN
SHELL,BOT                ! BOTTOM STRESSES ALONG LENGTH
PRNSOL,S,COMP
*GET,S4,NODE,2,S,X
PRNSOL,S,PRIN
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'BOT PRS '
LABEL(1,2) = 'psi'
*VFILL,VALUE(1,1),DATA,108000
*VFILL,VALUE(1,2),DATA,S2
*VFILL,VALUE(1,3),DATA,ABS(S2/108000)
SAVE,TABLE1
*DIM,LABEL1,CHAR,2,2
*DIM,VALUE1,,2,3
LABEL1(1,1) = 'MID PRS ','BOT PRS '
LABEL1(1,2) = 'psi ','psi '
*VFILL,VALUE1(1,1),DATA,11240,25280
*VFILL,VALUE1(1,2),DATA,S3,S4
*VFILL,VALUE1(1,3),DATA,ABS(S3/11240),ABS(S4/25280)
FINISH
SAVE,TABLE2

/CLEAR, NOSTART          ! CLEAR DATABASE FOR SECOND SOLUTION
/PREP7
/TITLE, VM139, BENDING OF A LONG UNIFORMLY LOADED RECTANGULAR PLATE
C***           USING SOLSH190 ELEMENTS
ANTYPE,STATIC
ET,1,SOLSH190,,0
MP,EX,1,30E6
MP,NUXY,1,0.3
BLOCK,0,22.5,0,9,0,-0.375
LSEL,S,LINE,,9,12,1
LESIZE,ALL, , ,2
LSEL,INVE
LESIZE,ALL, , ,10
LSEL,ALL
VMESH,1
NSEL,S,LOC,Z,-0.375/2
NSEL,R,LOC,X,0
D,ALL,UX
D,ALL,UZ
NSEL,R,LOC,Y,0
D,ALL,UY
ALLSEL,ALL
NSEL,S,LOC,X,22.5
DSYM,SYMM,X,0,22.5       ! SYMMETRY B.C.'S AT CENTERLINE
NSEL,ALL
FINISH
/SOLU
NSEL,S,LOC,Z,-0.375
ESLN,S
SFE,ALL,6,PRES,0,10
```

```
ALLSEL,ALL
/OUT,SCRATCH
SOLVE                    ! ANALYSIS 1 : SMALL DEFLECTION SOLUTION
FINISH
/POST1
/OUT,
SET,1                    ! ANALYSIS 1 : SMALL DEFLECTION SOLUTION
NSEL,S,LOC,Z,-0.375/2    ! MID STRESSES ALONG LENGTH
NSEL,R,LOC,Y,0
NSEL,R,LOC,X,22.5
*GET,ND1,NODE,0,NUM,MAX  ! NODE AT SHELL-MID   X = 0.0, Y = 0.0, Z = -0.375/2
NSEL,S,LOC,Z,-0.375
NSEL,R,LOC,Y,0
NSEL,R,LOC,X,22.5
*GET,ND2,NODE,0,NUM,MAX  ! NODE AT SHELL-BOT   X = 22.5, Y = 0.0, Z = -0.375
NSEL,S,LOC,Z,-0.375      ! BOTTOM STRESSES ALONG LENGTH
NSEL,R,LOC,Y,0
PRNSOL,S,COMP
*GET,S2,NODE,ND2,S,X
PRNSOL,S,PRIN
NSEL,ALL
FINISH
/SOLU
NLGEOM,ON                ! LARGE DEFLECTION OPTION
/OUT,SCRATCH
SOLVE                    ! ANALYSIS 2 : LARGE DEFLECTION SOLUTION
FINISH
/POST1
/OUT,
SET,1                    ! ANALYSIS 2 : CONVERGED LARGE DEFLECTION SOLUTION
NSEL,S,LOC,Z,-0.375/2    ! MIDDLE STRESSES ALONG LENGTH
NSEL,R,LOC,Y,0
PRNSOL,S,COMP
*GET,S3,NODE,ND1,S,X
PRNSOL,S,PRIN
NSEL,S,LOC,Z,-0.375      ! BOTTOM STRESSES ALONG LENGTH
NSEL,S,LOC,Y,0
PRNSOL,S,COMP
*GET,S4,NODE,ND2,S,X
PRNSOL,S,PRIN
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'BOT PRS '
LABEL(1,2) = 'PSI'
*VFILL,VALUE(1,1),DATA,108000
*VFILL,VALUE(1,2),DATA,S2
*VFILL,VALUE(1,3),DATA,ABS(S2/108000)
SAVE,TABLE3
*DIM,LABEL1,CHAR,2,2
*DIM,VALUE1,,2,3
LABEL1(1,1) = 'MID PRS ','BOT PRS '
LABEL1(1,2) = 'PSI ','PSI '
*VFILL,VALUE1(1,1),DATA,11240,25280
*VFILL,VALUE1(1,2),DATA,S3,S4
*VFILL,VALUE1(1,3),DATA,ABS(S3/11240),ABS(S4/25280)
SAVE,TABLE4
RESUME,TABLE1
/OUT,vm139,vrt
/COM,------------------- VM139 RESULTS COMPARISON --------------
/COM,
/COM,                |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,SMALL DEFLECTION SOLUTION USING SHELL181:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F12.0,'   ',1F15.3)
/NOPR
RESUME,TABLE2
/GOPR
/COM,
/COM,LARGE DEFLECTION SOLUTION USING SHELL181:
/COM,
```

```
*VWRITE,LABEL1(1,1),LABEL1(1,2),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F12.0,'   ',1F15.3)
/NOPR
RESUME,TABLE3
/GOPR
/COM,
/COM,SMALL DEFLECTION SOLUTION USING SOLSH190:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F12.0,'   ',1F15.3)
/NOPR
RESUME,TABLE4
/GOPR
/COM,
/COM,LARGE DEFLECTION SOLUTION USING SOLSH190:
/COM,
*VWRITE,LABEL1(1,1),LABEL1(1,2),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F12.0,'   ',1F15.3)
/COM,----------------------------------------------------------
/COM,
/COM,----------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM139  NOT CONTAINED IN
/COM,THIS TABLE
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm139,vrt
```

VM140 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM140
/PREP7
/TITLE, VM140, STRETCHING, TWISTING AND BENDING OF A LONG SOLID SHAFT
C***    STR. OF MATL., TIMOSHENKO, PART 1, 3RD ED., PAGE 296
ET,1,PLANE83,,,,2,,1
MP,EX,1,30E6
MP,NUXY,1,0                ! ZERO POISSONS RATIO
N,1
N,25,,24
FILL
NGEN,3,25,1,25,1,.25
E,51,53,3,1,52,28,2,26
EGEN,12,2,1
MODE,0,1                   ! AXIAL + TORSION MODE
D,1,ALL,,,51,25            ! FIX SUPPORT
D,2,UZ,,,25                ! CENTERLINE CONSTRAINTS AGAINST TORSION
F,75,FY,100                ! APPLY AXIAL FORCE
F,75,FZ,400                ! APPLY TORSION
FINISH
/SOLU
OUTPR,BASIC,LAST           ! PRINTOUT SOLUTION
/OUT,SCRATCH
SOLVE
MODE,1,1                   ! BENDING MODE
DDELE,2,UZ,25              ! DELETE PREVIOUS UZ CONSTRAINTS
FDEL,75,ALL                ! DELETE PREVIOUS FORCES
D,2,UY,,,25                ! CENTERLINE CONSTRAINTS AGAINST BENDING
F,75,FX,-50                ! APPLY VERTICAL FORCE
SOLVE
FINISH
/POST1
/OUT,
SET,1,1,,,,0.0             ! GET LOAD STEP 1 AT 0.0 DEGREES
LCWRITE,1                  ! WRITE OUT AS LOAD CASE 1
SET,2,1,,,,0.0             ! GET LOAD STEP 2 AT 0.0 DEGREES
LCOPER,ADD,1               ! ADD LOAD CASE 1 TO LOAD CASE 2
ESEL,S,ELEM,,1             ! SELECT ELEMENT 1
```

```
NSLE
PRNSOL,S,COMP
PRNSOL,S,PRIN              ! PRINT PRINCIPLE STRESSES
*GET,TOR,NODE,51,S,YZ
*GET,AXBND,NODE,51,S,Y
*GET,COMB,NODE,51,S,1
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'TORSION ','AXIAL+BEND ','COMBINED '
LABEL(1,2) = ' psi',' psi',' psi'
*VFILL,VALUE(1,1),DATA,1018.6,6238.9,6401
*VFILL,VALUE(1,2),DATA,TOR,AXBND,COMB
*VFILL,VALUE(1,3),DATA,ABS(TOR/1018.6),ABS(AXBND/6238.9),ABS(COMB/6401)
/COM
/OUT,vm140,vrt
/COM,------------------- VM140 RESULTS COMPARISON -------------
/COM,
/COM,   LOAD STEP 3   |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F12.1,'   ',1F15.3)
/COM,-----------------------------------------------------------
*status,parm
/OUT
FINISH
*LIST,vm140,vrt
```

VM141 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM141
/SHOW
/PREP7
smrt,off
/DEVICE,VECTOR,ON
/TITLE, VM141, DIAMETRAL COMPRESSION OF A DISK
/COM,            THEORY OF ELASTICITY, TIMOSHENKO AND GOODIER, 2ND ED., PG 107
/COM,            PLANE STRESS ELEMENTS (PLANE82 AND PLANE183)
C***  USING PLANE183, PLANE82 ELEMENTS
ANTYPE,STATIC             ! STATIC ANALYSIS
ET,1,PLANE183,,,3,,,,1      ! THICKNESS INPUT, SUPPRESS SOLUTION PRINTOUT
ET,2,PLANE82,,,3,,,,1
ET,3,PLANE82,,,3,,2       ! NODAL STRESS PRINTOUT SELECTED
R,1,.2                    ! THICKNESS
MP,EX,1,30E6
MP,NUXY,1,0.3
CSYS,1                    ! CYLINDRICAL COORDINATES
K,1,1,90
K,2,.5,90
K,4,1
K,5,1,50
L,1,5
LESIZE,1,,,7,5
L,5,4
LESIZE,2,,,4,2
CSYS,0                    ! CARTESIAN COORDINATES
K,3
L,3,4
LESIZE,3,,,5
L,2,3
LESIZE,4,,,4,2
L,2,5
LESIZE,5,,,5
L,1,2
LESIZE,6,,,7,5
A,1,2,5,5
A,2,3,4,5
TYPE,2
```

```
MSHK,1                    ! MAPPED AREA MESH
MSHA,0,2D                 ! USING QUADS
AMESH,2                   ! QUADRILATERAL MESHING
EPLOT
TYPE,1
MSHK,0                    ! FREE AREA MESH
MSHA,1,2D                 ! USING TRIS
AMESH,1                   ! TRIANGLE MESHING
EPLOT
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0
ESLN
TYPE,3
EMODIF,ALL                ! MODIFY ALL SELECTED ELEMENTS
SAVE,VM141,DB
NSEL,S,LOC,Y,0
DSYM,SYMM,Y               ! SYMMETRY ALONG X AXIS
NSEL,S,LOC,X,0
DSYM,SYMM,X               ! SYMMETRY ALONG Y AXIS
NSEL,ALL
ESEL,ALL
OUTPR,NSOL,NONE           ! NODAL DISPL. & REACTION FORCES PRINTOUT CONTROL
OUTPR,ESOL,ALL            ! ELEMENTAL  PRINTOUT CONTROL
FK,1,FY,-1000             ! APPLY HALF OF FORCE (SYMMETRY)
FINISH
*CREATE,SOLVIT,MAC
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
NSEL,S,LOC,X,0            ! SELECT ONLY THE NODES OF INTEREST
NSEL,A,LOC,X,0.1
NSEL,R,LOC,Y,0
PRNSOL,S,COMP             ! PRINT COMPONENT NODAL STRESSES
NSEL,R,LOC,X,0
NSEL,A,LOC,X,0.2
NSEL,R,LOC,Y,0
*GET,SNOD,NODE,,NUM,MIN   ! GET STARTING NODE FOR PATH (X=0)
*GET,FNOD,NODE,,NUM,MAX   ! GET END NODE FOR PATH (X=0.2)
NSEL,ALL
ESEL,ALL
PATH,STRESS1,2,,48         ! DEFINE PATH WITH NAME = "STRESS1"
PPATH,1,SNOD              ! DEFINE PATH POINTS BY NODE
PPATH,2,FNOD
PDEF,SY,S,Y               ! INTERPOLATE SY STRESS ON PATH
PRANGE,24                 ! PRINT EVERY 24TH POINT
PRPATH,SY                 ! PRINT SY STRESS ALONG THE PATH
*GET,S1,PATH,0,MIN,SY
NSEL,R,LOC,X,0
NSEL,A,LOC,X,0.1
NSEL,R,LOC,Y,0
*GET,FNOD,NODE,,NUM,MAX
PATH,STRESS2,2,,48        ! DEFINE PATH WITH NAME = "STRESS2"
PPATH,1,SNOD
PPATH,2,FNOD
PDEF,SY,S,Y               ! INTERPOLATE SY STRESS ON PATH
PRANGE,24                 ! PRINT EVERY 24TH POINT
PRPATH,SY                 ! PRINT SY STRESS ALONG THE PATH
*GET,S2,PATH,0,MAX,SY
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'P (psi)','P (psi)'
LABEL(1,2) = ' X=0 ',' X=.1'
*VFILL,VALUE(1,1),DATA,-9549,-9298
*VFILL,VALUE(1,2),DATA,S1,S2
*VFILL,VALUE(1,3),DATA,ABS(S1/9549),ABS(S2/9298)
FINISH
*END
SOLVIT
SAVE,TABLE_1
```

```
/CLEAR, NOSTART
C***  USING SHELL281 ELEMENTS
/FILNAM,GEN
/PREP7
smrt,off
!              S.E. GENERATION PASS  (SHELL ELEMENTS ,SHELL281)
RESUME,VM141,DB
ANTYPE,SUBST               ! SUBSTRUCTURE GENERATION PASS
SEOPT,GEN
! NOTE: SINCE PLANE183 AND SHELL281 HAVE DIFFERENT NODE ORDER, DELETE OLD MESH
ACLEAR,1,2                 ! DELETE NODES AND ELEMENTS
ETDELE,1,3                 ! DELETE PREVIOUS ELEMENT TYPES
ET,1,SHELL281    ! SHELL 281 ELEMENT
ET,2,SHELL281
ET,3,SHELL281
SECTYPE,1,SHELL
SECDATA,0.2,1,0,5
/OUTPUT,SCRATCH
NUMCMP,NODE                ! COMPRESS NODE NUMBER TO ZERO
/OUTPUT
TYPE,2
MSHK,1                     ! MAPPED AREA MESH
MSHA,0,2D                  ! USING QUADS
AMESH,2                    ! MESH AREA 2 WITH QUADRILATERALS
EPLOT
TYPE,1
MSHK,0                     ! FREE AREA MESH
MSHA,1,2D                  ! USING TRIS
AMESH,1                    ! MESH AREA 1 WITH TRIANGLES
EPLOT
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0
ESLN
TYPE,3
EMODIF,ALL
NSEL,S,LOC,Y,0
DSYM,SYMM,Y                ! SYMMETRY ALONG X AXIS
NSEL,S,LOC,X,0
DSYM,SYMM,X                ! SYMMETRY ALONG Y AXIS
NSEL,ALL
ESEL,ALL
D,ALL,UZ,,,,,ROTX,ROTY     ! CONSTRAIN UNNEEDED DOF'S
NSEL,S,LOC,X
NSEL,R,LOC,Y,1
*GET,NDOF,NODE,,NUM,MAX    ! GET NODE NUMBER FOR MASTER DOF
M,NDOF,UY                  ! SELECT MASTER DOF AT LOAD APPLICATION POINT
NSEL,ALL
FINISH
/SOLU
EQSLV,SPARSE
/OUT,SCRATCH
SOLVE
/OUT,
SAVE                       ! SAVE SUBSTRUCTURE DATA BASE FOR EXPANSION PASS
PARSAV,SCALAR,GEN,PARM
FINISH
/CLEAR, NOSTART
/FILNAM,USE
PARRES,,GEN,PARM
/PREP7
smrt,off
/TITLE, VM141, DIAMETRAL COMPRESSION OF A DISK  (S.E. USE PASS)
ET,1,MATRIX50
SE,GEN
F,NDOF,FY,-1000
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
/OUT,
FINISH
/CLEAR, NOSTART
```



```
/FILNAM,GEN
RESUME
/SOLU
EXPASS,ON,YES             ! EXPANSION PASS WITH ELEMENT SOLUTION
SEEXP,GEN,USE
/TITLE, VM141, DIAMETRAL COMPRESSION OF A DISK  (S.E. EXPANSION PASS)
OUTPR,NSOL,NONE           ! DISPLACEMENT PRINTOUT CONTROL
OUTPR,ESOL,ALL
EXPSOL,1,1
/OUT,SCRATCH
SOLVE
/OUT,
FINISH
/POST1
NSEL,R,LOC,X,0
NSEL,A,LOC,X,0.2
NSEL,R,LOC,Y,0
*GET,SNOD,NODE,,NUM,MIN   ! GET STARTING NODE FOR PATH (X=0)
*GET,FNOD,NODE,,NUM,MAX   ! GET END NODE FOR PATH (X=0.2)
NSEL,ALL
ESEL,ALL
PATH,STRESS3,2,,48         ! DEFINE PATH WITH NAME = "STRESS3"
PPATH,1,SNOD
PPATH,2,FNOD
PDEF,SY,S,Y               ! INTERPOLATE SY STRESS ON PATH
PRANGE,24                 ! PRINT EVERY 24TH POINT
PRPATH,SY                 ! PRINT SY STRESS ALONG THE PATH
*GET,S1,PATH,0,MIN,SY
NSEL,R,LOC,X,0
NSEL,A,LOC,X,0.1
NSEL,R,LOC,Y,0
*GET,FNOD,NODE,,NUM,MAX
NSEL,ALL
ESEL,ALL
PATH,STRESS4,2,,48         ! DEFINE PATH WITH NAME = "STRESS4"
PPATH,1,SNOD
PPATH,2,FNOD
PDEF,SY,S,Y               ! INTERPOLATE SY STRESS ON PATH
PRANGE,24                 ! PRINT EVERY 24TH POINT
PRPATH,SY                 ! PRINT SY STRESS ALONG THE PATH
*GET,S2,PATH,0,LAST,SY
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'P (psi)','P (psi)'
LABEL(1,2) = ' X=0 ',' X=.1'
*VFILL,VALUE(1,1),DATA,-9549,-9298
*VFILL,VALUE(1,2),DATA,S1,S2
*VFILL,VALUE(1,3),DATA,ABS(S1/9549),ABS(S2/9298)
SAVE,TABLE_2
FINISH
/CLEAR, NOSTART
/TITLE, VM141, DIAMETRAL COMPRESSION OF A DISK
C***  USING SHELL181 ELEMENTS
/PREP7
smrt,off
ET,1,SHELL181
SECTYPE,1,SHELL
SECDATA,0.2,1,0,5         ! THICKNESS
MP,EX,1,30E6              ! DEFINE MATERIAL PROPERTIES
MP,NUXY,1,0.3
PCIRC,,1,0,90             ! CREATE MODEL GEOMETRY
ESIZE,,10
AMESH,ALL                 ! MESH ALL AREAS
EPLOT
FINISH
/SOLU
NSEL,S,LOC,Y,0            ! APPLY BOUNDARY CONDITIONS
DSYM,SYMM,Y               ! SYMMETRY ALONG X AXIS
NSEL,S,LOC,X,0
DSYM,SYMM,X               ! SYMMETRY ALONG Y AXIS
NSEL,ALL
ESEL,ALL
```

```
F,NODE(0,1,0),FY,-1000     ! APPLY HALF OF FORCE (SYMMETRY)
D,ALL,UZ,,,,,ROTX,ROTY     ! CONSTRAIN UNNEEDED DOF'S
/OUT,SCRATCH
SOLVE
/OUT,
FINISH
/POST1
*GET,S1,NODE,12,S,Y
*GET,S2,NODE,22,S,Y
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'P (psi)','P (psi)'
LABEL(1,2) = ' X=0 ',' X=.1'
*VFILL,VALUE(1,1),DATA,-9549,-9298
*VFILL,VALUE(1,2),DATA,S1,S2
*VFILL,VALUE(1,3),DATA,ABS(S1/9549),ABS(S2/9298)
FINISH
SAVE,TABLE_3
/CLEAR,NOSTART
/TITLE, VM141, DIAMETRAL COMPRESSION OF A DISK
C***  USING SHELL281 ELEMENTS
/PREP7
smrt,off
/DEVICE,VECTOR,ON
ANTYPE,STATIC              ! STATIC ANALYSIS
ET,1,SHELL281
ET,2,SHELL281
ET,3,SHELL281
SECTYPE,1,SHELL
SECDATA,0.2,1,0,5
MP,EX,1,30E6
MP,NUXY,1,0.3
CSYS,1                     ! CYLINDRICAL COORDINATES
K,1,1,90
K,2,.5,90
K,4,1
K,5,1,50
L,1,5
LESIZE,1,,,7,5
L,5,4
LESIZE,2,,,4,2
CSYS,0                     ! CARTESIAN COORDINATES
K,3
L,3,4
LESIZE,3,,,5
L,2,3
LESIZE,4,,,4,2
L,2,5
LESIZE,5,,,5
L,1,2
LESIZE,6,,,7,5
A,1,2,5,5
A,2,3,4,5
TYPE,2
MSHK,1                     ! MAPPED AREA MESH
MSHA,0,2D                  ! USING QUADS
AMESH,2                    ! QUADRILATERAL MESHING (PLANE82)
EPLOT
TYPE,1
MSHK,0                     ! FREE AREA MESH
MSHA,1,2D                  ! USING TRIS
AMESH,1                    ! TRIANGLE MESHING (PLANE183)
EPLOT
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0
ESLN
TYPE,3
EMODIF,ALL                 ! MODIFY ALL SELECTED ELEMENTS
NSEL,S,LOC,Y,0
DSYM,SYMM,Y                ! SYMMETRY ALONG X AXIS
NSEL,S,LOC,X,0
DSYM,SYMM,X                ! SYMMETRY ALONG Y AXIS
```

```
NSEL,ALL
ESEL,ALL
OUTPR,NSOL,NONE            ! NODAL DISPL. & REACTION FORCES PRINTOUT CONTROL
FK,1,FY,-1000              ! APPLY HALF OF FORCE (SYMMETRY)
D,ALL,UZ,,,,,ROTX,ROTY     ! CONSTRAIN UNNEEDED DOF'S
FINISH
SOLVIT
SAVE,TABLE_4
/NOPR
RESUME,TABLE_1
/COM
/OUT,vm141,vrt
/COM,------------------- VM141 RESULTS COMPARISON ------------
/COM,
/COM,                      TARGET   |    Mechanical APDL   |    RATIO
/COM,
/COM, PLANE82 AND PLANE183
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.0,'  ',F13.0,'   ',1F16.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM, SHELL281-SUBSTRUCTURE
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.0,'  ',F13.0,'   ',1F16.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM, SHELL181
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.0,'  ',F13.0,'   ',1F16.3)
/NOPR
RESUME,TABLE_4
/GOPR
/COM,
/COM, SHELL281
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.0,'  ',F13.0,'   ',1F16.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm141,vrt
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
/DELETE,TABLE_4
/DELETE,GEN,PARM
/DELETE,GEN,db
/DELETE,GEN,emat
/DELETE,GEN,esav
/DELETE,GEN,rst
/DELETE,GEN,seld
/DELETE,GEN,sub
/DELETE,USE,dsub
/DELETE,USE,emat
/DELETE,USE,esav
/DELETE,USE,rst
/DELETE,USE,sord
/DELETE,VM141,DB
/DELETE,SOLVIT,MAC
```

VM142 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM142
/FILNAM,vm142          ! DEFINE JOBNAME FOR THE COARSE MODEL
/GRAPH,POWER
/PREP7
smrt,off
/TITLE, VM142, STRESS CONCENTRATION AT A HOLE IN A PLATE
C*** ROARK 4TH EDITION, PAGE 384.
/NOPR
ANTYPE,STATIC          ! STATIC ANALYSIS
ET,1,PLANE183
MP,EX,1,30E6
MP,NUXY,1,0.3
K,1,6                  ! KEYPOINTS
K,2,6,6
K,3,,6
K,4,,.5
K,5,.5
K,6
L,1,2                  ! LINE SEGMENTS
L,2,3
L,3,4
LESIZE,3,,,4,.25       ! DEFINE NO. OF DIVISONS AND SPACING FOR LINE 3
LARC,4,5,6,0.5
LESIZE,4,,,6           ! DEFINE NO. OF DIVISONS FOR LINE 4
L,5,1
LESIZE,5,,,4,4         ! DEFINE NO. OF DIVISONS AND SPACING FOR LINE 5
AL,1,2,3,4,5           ! AREA DEFINED BY 5 BOUNDING LINES
ESIZE,,4               ! 4 DIVISIONS PER LINE
MSHAPE,1,2D
MSHKEY,0
AMESH,ALL
LSEL,S,LINE,,3,5,2
DL,ALL,,SYMM
LSEL,S,LINE,,1
NSLL,,1
SF,ALL,PRES,-1000.     ! APPLY TENSION ON PLATE
LSEL,ALL
NSEL,ALL
CSYS,1
FINISH
/SOLU
SOLVE
FINISH
SAVE                   ! SAVE FILE AS VM142.DB
/POST1
SET,1,1
NSORT,S,X,,,3          ! SORT BASED ON SX, RETAIN ONLY THE HIGHEST 3
PRNSOL,S,COMP
PLESOL,S,X
*GET,CRSESTR,NODE,18,S,X
*status,parm
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'MX STR '
LABEL(1,2) = 'CRS MODEL'
*VFILL,VALUE(1,1),DATA,3018
*VFILL,VALUE(1,2),DATA,CRSESTR
*VFILL,VALUE(1,3),DATA,ABS(CRSESTR/3018)
SAVE,TABLE_1
FINISH
/CLEAR, NOSTART ! CLEAR THE DATABASE
/FILNAM,SUBMODEL       ! DEFINE JOBNAME FOR THE SUBMODEL
/PREP7
smrt,off
/NOPR
/TITLE, VM142, STRESS CONCENTRATION AT A HOLE IN A PLATE
```

```
C*** BOUNDARY INTERPOLATION, MODIFIED SECTION
ANTYPE,STATIC
ET,1,PLANE182,2
MP,EX,1,30E6
MP,NUXY,1,0.3
CSYS,1
K,10,.5,45            ! DEFINE KEYPOINTS FOR SUBMODEL
K,11,.5,90
K,12,1.5,45
K,13,1.5,90
A,10,12,13,11
ESIZE,,8              ! 8 DIVISIONS
MSHK,1                    ! MAPPED AREA MESH
MSHA,0,2D                 ! USING QUADS
AMESH,1
LSEL,S,LINE,,1,2
NSLL,,1               ! SELECT NODES OF CUT BOUNDARY
NWRITE                ! WRITE GEOMETRY TO SUBMODEL.NODE
LSEL,ALL
NSEL,ALL
FINISH
SAVE                  ! SAVE SUBMODEL DATA IN FILE SUBMODEL.DB
/POST1
RESUME,vm142,db       ! RESUME FROM FILE VM142.DB
FILE,vm142,rst        ! DEFINE RESULTS FILE NAME
CBDOF,,,,,,,0,,0      ! ACTIVATE CUT BOUNDARY INTERPOLATION
FINISH
/PREP7
smrt,off
RESUME                ! RESUME SUBMODEL FROM FILE SUBMODEL.DB
/NOPR
/INPUT,,cbdo,,:cb1    ! READ IN INTERPOLATED B.C.'S FROM SUBMODEL.CBDO
/GOPR
LSEL,S,LINE,,3        ! APPLY REMAINING BOUNDARY CONDITIONS
DL,ALL,,SYMM
FINISH
/SOLU
SOLVE
FINISH
/POST1
SET,1,1
NSORT,S,X,,,3
PRNSOL,S,COMP
PLESOL,S,X
*GET,SUBSTR,NODE,18,S,X
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'MAX STRS'
LABEL(1,2) = ' SUBMOD'
*VFILL,VALUE(1,1),DATA,3018
*VFILL,VALUE(1,2),DATA,SUBSTR
*VFILL,VALUE(1,3),DATA,ABS(SUBSTR/3018 )
SAVE,TABLE_2
FINISH
/CLEAR,NOSTART
RESUME,TABLE_1
/OUT,vm142,vrt
/COM,-------------------(VM142)RESULTS COMPARISON---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,PLANE183
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F12.0,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,PLANE182
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F12.0,'   ',1F15.3)
/COM,-----------------------------------------------------------
```

```
/COM,
/OUT
FINISH
/DEL,TABLE_1
/DEL,TABLE_2
*LIST,vm142,vrt
```

VM143 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM143
*CREATE,FRACT,MAC
!  MACRO TO CREATE 3D SOLID95 CRACK TIP ELEMENTS FROM 3D SOLID45 ELEMENTS
!     MAKE A COMPONENT CONTAINING THE CRACK TIP NODES (CRACKTIP)
!     THE CRACK TIP IS BETWEEN NODES K AND O
!     SET ELEMENT TYPE TO POINT TO SOLID95
!     SET ARG1 TO  N  (THE TYPE OF THE ELEMENTS AROUND THE CRACK TIP)
!
/NOPR
NSEL,ALL
*GET,N,NODE,,NUM,MAX                  ! CURRENT MAXIMUM NODE NUMBER
CMSEL,S,CRACKTIP                      ! SELECT THE TIP NODES
ESLN                                  ! ANY ELEMENTS ATTACHED
*GET,ELMAX,ELEM,,NUM,MAX              ! CURRENT MAXIMUM ELEMENT NUMBER
*DO,IEL,1,ELMAX                       ! LOOP ON MAX ELEMENT
   ELMI=IEL
   *IF,ELMI,LE,0,EXIT                 ! NO MORE SELECTED
   *GET,ELTYPE,ELEM,ELMI,ATTR,TYPE    ! GET ELEMENT TYPE
   *IF,ELTYPE,NE,ARG1,CYCLE           ! CHECK FOR SELECTED ELEMENT
   N3 = NELEM(ELMI,3)                 ! GET NODE 3 (K)
   *IF,NSEL(N3),LE,0,CYCLE            ! IT MUST BE SELECTED
   N7 = NELEM(ELMI,7)                 ! GET NODE 7 (L)
   *IF,NSEL(N7),LE,0,CYCLE            ! IT MUST ALSO BE SELECTED
   N1 = NELEM(ELMI,1)                 ! GET NODE 1 (I)
   N2 = NELEM(ELMI,2)                 ! GET NODE 2 (J)
   N5 = NELEM(ELMI,5)                 ! GET NODE 5 (M)
   N6 = NELEM(ELMI,6)                 ! GET NODE 6 (N)

   X3 = 0.75*NX(N3)                   ! WEIGHTED POSITION OF N3
   Y3 = 0.75*NY(N3)
   Z3 = 0.75*NZ(N3)
   X  = 0.25*NX(N2) + X3              ! QUARTER POINT LOCATION ( NODE (R) )
   Y  = 0.25*NY(N2) + Y3
   Z  = 0.25*NZ(N2) + Z3
   N  = N + 1                         ! NEXT NODE
   N10 = N
   N,N10,X,Y,Z                        ! MIDSIDE NODE LOCATION
   X  = 0.25*NX(N1) + X3
   Y  = 0.25*NY(N1) + Y3
   Z  = 0.25*NZ(N1) + Z3
   N  = N + 1
   N12= N
   N,N12,X,Y,Z
   X7 = 0.75*NX(N7)
   Y7 = 0.75*NY(N7)
   Z7 = 0.75*NZ(N7)
   X  = 0.25*NX(N6) + X7
   Y  = 0.25*NY(N6) + Y7
   Z  = 0.25*NZ(N6) + Z7
   N  = N + 1
   N14 = N
   N,N14,X,Y,Z
   X  = 0.25*NX(N5) + X7
   Y  = 0.25*NY(N5) + Y7
   Z  = 0.25*NZ(N5) + Z7
   N  = N + 1
   N16 = N
   N,N16,X,Y,Z
```

```
   N4=N3
   N8=N7
   NSEL,ALL
   TYPE,3
   EN,ELMI,N1,N2,N3,N4,N5,N6,N7,N8   ! REDEFINE THE ELEMENT
   EMORE,0,N10,0,N12,0,N14,0,N16
   EMORE,
*ENDDO
CMSEL,U,CRACKTIP                     ! UNSELECT THE TIP NODES
NUMMRG,NODE                          ! MERGE MIDSIDE NODES
NSEL,ALL                             ! SELECT ALL ELEMENTS
ESEL,ALL                             ! SELECT ALL ELEMENTS
/GOPR
*END

/PREP7
SMRT,OFF
/TITLE, VM143, FRACTURE MECHANICS STRESS INTENSITY  - CRACK IN A FINITE WIDTH PLATE
C***    BROWN AND SRAWLEY, ASTM SPECIAL TECHNICAL PUBLICATION NO. 410.
/COM,     ****** CRACK IN 3-DIMENSIONS USING SOLID45 AND SOLID95
ANTYPE,STATIC                ! STATIC ANALYSIS
ET,1,SOLID45
ET,2,SOLID45                 ! ELEMENTS AROUND THE CRACK TIP
ET,3,SOLID95                 ! CRACK TIP ELEMENTS CREATED USING MACRO FRACT
MP,EX,1,3E7
MP,NUXY,1,.3
CSYS,1                       ! CYLINDRICAL COORDINATE SYSTEM
N,1
NGEN,9,20,1
N,11,.8
N,171,.8,180
FILL,11,171,7,31,20
CSYS,0                       ! CARTESIAN COORDINATE SYSTEM
FILL,1,11,9,2,1,9,20,3
N,15,4
N,75,4,5
FILL,15,75,2,35,20
N,155,-1,5
FILL,75,155,3,95,20
N,172,-1
FILL,155,172,5,177,-1,,,.15
FILL,11,15,3,,,7,20,3
NGEN,2,200,1,177,,,,.25
E,2,22,1,1,202,222,201,201
EGEN,8,20,-1
E,2,3,23,22,202,203,223,222
EGEN,8,20,-1
EGEN,9,1,-8
EGEN,5,1,73,78
E,171,151,173,172,371,351,373,372
E,151,131,174,173,351,331,374,373
E,131,132,175,174,331,332,375,374
EGEN,3,1,-1
E,134,135,155,177,334,335,355,377
TYPE,2
EMODIF,1                    ! MODIFY ELEMENTS 1 TO 8 FROM TYPE,1 TO TYPE,2
*REPEAT,8,1
NUMMRG,NODE                 ! MERGE COINCIDENT NODES
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0
CM,CRACKTIP,NODE
/NERR,0                     ! TEMPORARILY NO WARNINGS OR ERRORS PRINTOUT
                            ! (IN ORDER TO AVOID WARNING MESSAGES DUE TO
                            !  MIDSIDE NODES LOCATION)
FRACT,2                     ! CONVERSION MACRO, TYPE 2 IS SOLID45
                            ! ELEMENTS AROUND THE CRACK TIP
/NERR,DEFA                  ! TURN ON THE WARNINGS OR ERRORS PRINTOUT
/OUTPUT
OUTPR,,ALL
OUTPR,VENG,ALL              ! STORE STRAIN ENERGY FOR J-INTEGRAL EVALUATION
NSEL,S,LOC,X,-1
DSYM,SYMM,X                 ! SYMMETRIC B.C.'S AT X = -1
```

```
NSEL,S,LOC,X,0,4
NSEL,R,LOC,Y,0
DSYM,SYMM,Y                  ! SYMMETRIC B.C.'S AT Y = 0 EXCEPT CRACK NODES
NSEL,ALL
D,ALL,UZ                     ! Z CONSTRAINTS FOR PLANE STRAIN PROBLEM
NSEL,S,LOC,Y,5
SF,ALL,PRES,-.5641895
NSEL,ALL
ESEL,ALL
FINISH
/OUTPUT,SCRATCH
/SOLU
SOLVE
FINISH
/OUTPUT
/POST1
ETABLE,SENE,SENE              ! RETRIEVE STRAIN ENERGY PER ELEMENT
ETABLE,VOLU,VOLU              ! RETRIEVE VOLUME PER ELEMENT
C*** IN POST1 DETERMINE KI (STRESS INTENSITY FACTOR) USING KCALC !**
PATH,KI1,3,,48                 ! DEFINE PATH WITH NAME = "KI1"
PPATH,1,1                     ! DEFINE PATH POINTS BY NODE
PPATH,2,406
PPATH,3,162
KCALC,,,1                     ! COMPUTE KI FOR A HALF-MODEL WITH SYMM. B.C.
*GET,KI1,KCALC,,K,1           ! GET KI AS PARAMETER KI1
!*******************************************************************************
!*************************  J-INTEGRAL USER FILE  ****************************
!******************************************************************************
! ****NOTE:- IN GENERAL USAGE, THE USER FILE WOULD BE AVAILABLE IN THE
!             LOCAL DIRECTORY RATHER THAN BEING CREATED IN THE INPUT
!******************************************************************************
*CREATE,JIN1
STINFC                         ! DATA BLOCK NAME
SEXP,W,SENE,VOLU,1,-1          ! CALCULATE STRAIN ENERGY DENSITY
PATH,JINT,4,50,48              ! DEFINE PATH WITH NAME = "JINT"
PPATH,1,ARG1                   ! DEFINE PATH POINTS BY NODE
PPATH,2,ARG2
PPATH,3,ARG3
PPATH,4,ARG4
PDEF,W,ETAB,W                  ! PUT STRAIN ENERGY DENSITY ON THE PATH
PCALC,INTG,J,W,YG              ! INTEGRATE ENERGY W.R.T. GLOBAL Y
*GET,JA,PATH,,LAST,J           ! GET FINAL VALUE OF INTEGRAL FOR 1ST TERM OF J
PDEF,CLEAR                     ! CLEAR OLD PATH VARIABLES
PVECT,NORM,NX,NY,NZ            ! DEFINE THE PATH UNIT NORMAL VECTOR
PDEF,INTR,SX,SX                ! PUT STRESS SX ON THE PATH
PDEF,INTR,SY,SY                ! PUT STRESS SY ON THE PATH
PDEF,INTR,SXY,SXY              ! PUT STRESS SXY ON THE PATH
PCALC,MULT,TX,SX,NX            ! CALCULATE TRACTION TX
PCALC,MULT,C1,SXY,NY           !   TX = SX*NX + SXY*NY
PCALC,ADD,TX,TX,C1
PCALC,MULT,TY,SXY,NX           ! CALCULATE TRACTION TY
PCALC,MULT,C1,SY,NY            !   TY = SXY*NX + SY*NY
PCALC,ADD,TY,TY,C1
*GET,DX,PATH,,LAST,S           ! DEFINE PATH SHIFT AS 1% OF PATH LENGTH
DX=DX/100
PCALC,ADD,XG,XG,,,,-DX/2       ! SHIFT PATH FROM X TO X-DX/2 (GLOBAL X DIR.)
PDEF,INTR,UX1,UX               ! DEFINE UX AT X-DX
PDEF,INTR,UY1,UY               ! DEFINE UY AT X-DX
PCALC,ADD,XG,XG,,,,DX          ! SHIFT PATH FROM X-DX/2 TO X+DX/2
PDEF,INTR,UX2,UX               ! DEFINE UX AT X+DX
PDEF,INTR,UY2,UY               ! DEFINE UY AT X+DX
PCALC,ADD,XG,XG,,,,-DX/2       ! SHIFT PATH BACK TO ORIGINAL POSITION
C=(1/DX)
PCALC,ADD,C1,UX2,UX1,C,-C      ! CALCULATE DERIVATIVE DUX/DX
PCALC,ADD,C2,UY2,UY1,C,-C      ! CALCULATE DERIVATIVE DUY/DX
PCALC,MULT,C1,TX,C1            ! DEFINE INTEGRAND
PCALC,MULT,C2,TY,C2            !   = TX*DUX/DX + TY*DUY/DX
PCALC,ADD,C1,C1,C2
PCALC,INTG,J,C1,S              ! FORM SECOND INTEGRAL (W.R.T. PATH LENGTH S)
*GET,JB,PATH,,LAST,J           ! GET FINAL VALUE OF INTEGRAL FOR 2ND TERM OF J
JINT=2*(JA-JB)                 ! ADD BOTH TERMS AND DOUBLE FOR HALF MODELS
PDEF,CLEAR                     ! CLEAR PATH VARIABLES
```

```
*END
C**************** IN POST1 DETERMINE KI FROM J-INTEGRAL !***********************
CON1=30E6/(1-(0.3*0.3))       ! J-TO-KI CONVERSION FACTOR
*ULIB,JIN1                    ! ASSIGN LOCAL FILE JIN1 AS USER FILE
*USE,STINFC,4,45,125,164      ! USE DATA BLOCK STINFC AND GIVE PATH NODES
KI2=SQRT(CON1*JINT)           ! CALCULATE KI FROM J
*STATUS,KI1                   ! VIEW RESULTS
*STATUS,KI2
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'BY DISP ','BY J-'
LABEL(1,2) = 'EXTRP ','INT'
*VFILL,VALUE(1,1),DATA,1.0249,1.0249
*VFILL,VALUE(1,2),DATA,KI1,KI2
*VFILL,VALUE(1,3),DATA,ABS(KI1/1.0249),ABS(KI2/1.0249)
SAVE,TABLE_1
FINISH

/CLEAR, NOSTART ! CLEAR DATABASE FOR 2ND SOLUTION
/PREP7
SMRT,OFF
/TITLE, VM143, FRACTURE MECHANIC STRESS INTENSITY - CRACK IN A FINITE WIDTH PLATE
/COM,   ****** CRACK IN 2-DIMENSIONS USING 2-D PLANE183 ******
ET,1,PLANE183,,,2              ! PLANE183 (PLANE STRAIN)
MP,EX,1,30E6
MP,NUXY,1,0.3
K,1                           ! DEFINE KEYPOINTS AND LINE SEGMENTS
K,2,4
K,3,4,5
K,4,-1,5
K,5,-1
L,1,2
L,2,3
LESIZE,2,,,4
L,3,4
LESIZE,3,,,4
L,4,5,
LESIZE,4,,,6,.2
L,5,1
ESIZE,,5
KSCON,1,.15,1,8               ! DEFINE CRACK TIP ELEMENT SIZE
AL,1,2,3,4,5
DL,1,1,SYMM                   ! APPLY SOLID MODEL BOUNDARY CONDITIONS
DL,4,1,SYMM
SFL,3,PRES,-.5641895
AMESH,1
OUTPR,ALL
FINISH
/COM
/OUTPUT,SCRATCH
/SOLU
SOLVE
FINISH
/OUTPUT
/POST1
ETABLE,SENE,SENE              ! RETRIEVE STRAIN ENERGY PER ELEMENT
ETABLE,VOLU,VOLU              ! RETRIEVE VOLUME PER ELEMENT
C*** IN POST1 DETERMINE KI (STRESS INTENSITY FACTOR) USING KCALC !**
NSEL,S,LOC,Y,0                ! SELECT NODES FOR LPATH COMMAND
NSEL,R,LOC,X,0
*GET,NOD1,NODE,,NUM,MIN
NSEL,A,LOC,Y
NSEL,R,LOC,X,-.005,-.145
*GET,NOD2,NODE,,NUM,MIN
NSEL,A,LOC,Y
NSEL,R,LOC,X,-.145,-.155
*GET,NOD3,NODE,,NUM,MIN
NSEL,ALL
PATH,KI2,3,,48                 ! DEFINE PATH WITH NAME = "KI2"
PPATH,1,NOD1                   ! DEFINE PATH POINTS BY NODE
PPATH,2,NOD2
PPATH,3,NOD3
```

```
KCALC,,,1                         ! COMPUTE KI FOR A HALF-MODEL WITH SYMM. B.C.
*GET,KI1,KCALC,,K,1               ! GET KI AS A PARAMETER KI1
C**************** IN POST1 DETERMINE KI FROM J-INTEGRAL !***********************
CSYS,1
NSEL,S,LOC,X,.5,.8                ! SELECT NODES FOR LPATH COMMAND IN STINFC
NSEL,R,LOC,Y,-1,1
*GET,NOD4,NODE,,NUM,MAX
NSEL,S,LOC,X,.5,.8
NSEL,R,LOC,Y,35,55
*GET,NOD5,NODE,,NUM,MAX
NSEL,S,LOC,X,.5,.8
NSEL,R,LOC,Y,120,145
*GET,NOD6,NODE,,NUM,MAX
NSEL,S,LOC,X,.5,.8
NSEL,R,LOC,Y,179,181
*GET,NOD7,NODE,,NUM,MIN
NSEL,ALL
CSYS,0
*USE,STINFC,NOD4,NOD5,NOD6,NOD7 ! USE DATA BLOCK STINFC AND GIVE PATH NODES
CON1=30E6/(1-(0.3*0.3))          ! J-TO-KI CONVERSION FACTOR
KI2=SQRT(CON1*JINT)              ! CALCULATE KI FROM J
*STATUS,KI1                      ! VIEW RESULTS
*STATUS,KI2
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'BY DISP ','BY J-'
LABEL(1,2) = 'EXTRP ','INT'
*VFILL,VALUE(1,1),DATA,1.0249,1.0249
*VFILL,VALUE(1,2),DATA,KI1,KI2
*VFILL,VALUE(1,3),DATA,ABS(KI1/1.0249),ABS(KI2/1.0249)
SAVE,TABLE_2
FINISH

/CLEAR, NOSTART ! CLEAR DATABASE FOR 3ND SOLUTION
/PREP7
SMRT,OFF
/TITLE, VM143, FRACTURE MECHANICS STRESS INTENSITY  - CRACK IN A FINITE WIDTH PLATE
/COM,     ****** CRACK IN 3-DIMENSIONS USING SOLID185 AND SOLID186
ET,1,SOLID185
ET,2,SOLID185                  ! ELEMENTS AROUND THE CRACK TIP
ET,3,SOLID186                  ! CRACK TIP ELEMENTS CREATED USING MACRO FRACT
MP,EX,1,3E7
MP,NUXY,1,.3
CSYS,1                        ! CYLINDRICAL COORDINATE SYSTEM
N,1
NGEN,9,20,1
N,11,.8
N,171,.8,180
FILL,11,171,7,31,20
CSYS,0                        ! CARTESIAN COORDINATE SYSTEM
FILL,1,11,9,2,1,9,20,3
N,15,4
N,75,4,5
FILL,15,75,2,35,20
N,155,-1,5
FILL,75,155,3,95,20
N,172,-1
FILL,155,172,5,177,-1,,,.15
FILL,11,15,3,,,7,20,3
NGEN,2,200,1,177,,,,,.25
E,2,22,1,1,202,222,201,201
EGEN,8,20,-1
E,2,3,23,22,202,203,223,222
EGEN,8,20,-1
EGEN,9,1,-8
EGEN,5,1,73,78
E,171,151,173,172,371,351,373,372
E,151,131,174,173,351,331,374,373
E,131,132,175,174,331,332,375,374
EGEN,3,1,-1
E,134,135,155,177,334,335,355,377
TYPE,2
```

```
EMODIF,1                    ! MODIFY ELEMENTS 1 TO 8 FROM TYPE,1 TO TYPE,2
*REPEAT,8,1
NUMMRG,NODE                 ! MERGE COINCIDENT NODES
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0
CM,CRACKTIP,NODE
/NERR,0                     ! TEMPORARILY NO WARNINGS OR ERRORS PRINTOUT
                            ! (IN ORDER TO AVOID WARNING MESSAGES DUE TO
                            !  MIDSIDE NODES LOCATION)
FRACT,2                     ! CONVERSION MACRO, TYPE 2 IS SOLID185
                            ! ELEMENTS AROUND THE CRACK TIP
/NERR,DEFA                  ! TURN ON THE WARNINGS OR ERRORS PRINTOUT
/OUTPUT
OUTPR,,ALL
OUTPR,VENG,ALL              ! STORE STRAIN ENERGY FOR J-INTEGRAL EVALUATION
NSEL,S,LOC,X,-1
DSYM,SYMM,X                 ! SYMMETRIC B.C.'S AT X = -1
NSEL,S,LOC,X,0,4
NSEL,R,LOC,Y,0
DSYM,SYMM,Y                 ! SYMMETRIC B.C.'S AT Y = 0 EXCEPT CRACK NODES
NSEL,ALL
D,ALL,UZ                    ! Z CONSTRAINTS FOR PLANE STRAIN PROBLEM
NSEL,S,LOC,Y,5
SF,ALL,PRES,-.5641895
NSEL,ALL
ESEL,ALL
FINISH
/OUTPUT,SCRATCH
/SOLU
SOLVE
FINISH
/OUTPUT
/POST1
ETABLE,SENE,SENE             ! RETRIEVE STRAIN ENERGY PER ELEMENT
ETABLE,VOLU,VOLU             ! RETRIEVE VOLUME PER ELEMENT
C*** IN POST1 DETERMINE KI (STRESS INTENSITY FACTOR) USING KCALC !**
PATH,KI1,3,,48                ! DEFINE PATH WITH NAME = "KI1"
PPATH,1,1                    ! DEFINE PATH POINTS BY NODE
PPATH,2,406
PPATH,3,162
KCALC,,,1                    ! COMPUTE KI FOR A HALF-MODEL WITH SYMM. B.C.
*GET,KI1,KCALC,,K,1          ! GET KI AS PARAMETER KI1
C*************** IN POST1 DETERMINE KI FROM J-INTEGRAL !***********************
CON1=30E6/(1-(0.3*0.3))       ! J-TO-KI CONVERSION FACTOR
*ULIB,JIN1                    ! ASSIGN LOCAL FILE JIN1 AS USER FILE
*USE,STINFC,4,45,125,164      ! USE DATA BLOCK STINFC AND GIVE PATH NODES
KI2=SQRT(CON1*JINT)           ! CALCULATE KI FROM J
*STATUS,KI1                   ! VIEW RESULTS
*STATUS,KI2
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'BY DISP ','BY J-'
LABEL(1,2) = 'EXTRP ','INT'
*VFILL,VALUE(1,1),DATA,1.0249,1.0249
*VFILL,VALUE(1,2),DATA,KI1,KI2
*VFILL,VALUE(1,3),DATA,ABS(KI1/1.0249),ABS(KI2/1.0249)
SAVE,TABLE_3
FINISH
RESUME,TABLE_1
/COM
/OUT,vm143,vrt
/COM,------------------- VM143 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,USING SOLID95 AND SOLID45 (3-D ANALYSIS)
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F12.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
```

```
/COM,USING PLANE183 (2-D ANALYSIS)
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F12.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM,USING SOLID186 AND SOLID185 (3-D ANALYSIS)
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F12.4,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm143,vrt

/DELETE,FRACT,MAC
```

VM144 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM144
/PREP7
/TITLE, VM144, BENDING OF A COMPOSITE BEAM
C***    FORMULAS FOR STRESS AND STRAIN, ROARK, 5TH ED.
C***    USING LAYERED SOLID ELEMENTS (SOLID185)
ANTYPE,STATIC
ET,1,SOLID185               ! LAYERED SOLID ELEMENT
KEYOPT,1,2,2                ! ENHANCED STRAIN FORMULATION
KEYOPT,1,3,1                ! LAYERED SOLID
KEYOPT,1,8,1                ! WRITE LAYER RESULTS
SECTYPE,1,SHELL
SECDATA,0.2,1               ! LAYER 1: 0.2 THK
SECDATA,0.1,2               ! LAYER 2: 0.1 THK
MP,EX,1,1.2E6               ! MATERIAL 1 PROPERTIES
MP,NUXY,1,0
MP,ALPX,1,1.8E-4
MP,ALPY,1,0.0
MP,ALPZ,1,0.0
MP,EX,2,0.4E6               ! MATERIAL 2 PROPERTIES
MP,NUXY,2,0
MP,ALPX,2,0.6E-4
MP,ALPY,2,0.0
MP,ALPZ,2,0.0
N,1
N,9,8
FILL
NGEN,2,10,1,9,1,,.5
NGEN,2,20,1,19,1,,,.3
E,1,2,12,11,21,22,32,31
EGEN,8,1,-1                 ! 8 ELEMENTS ALONG LENGTH
D,1,ALL,,,31,10             ! FIXED END
F,9,FX,-(50/3),,19,10       ! APPLY NODAL FORCES TO GENERATE MOMENT
F,29,FX,(50/3),,39,10
BFUNIF,TEMP,100             ! ELEVATED TEMPERATURE LOAD
FINISH
/SOLU
SOLVE
FINISH
/POST1
NSEL,S,LOC,X,8
PRNSOL,U,Z                  ! PRINT FREE END DISPLACEMENTS
*GET,U3,NODE,9,U,Z
NSEL,S,LOC,Z,0.3
PRNSOL,S,COMP               ! PRINT STRESSES ALONG TOP SURFACE
*GET,ST3,NODE,21,S,X
NSEL,S,LOC,Z
PRNSOL,S,COMP               ! PRINT STRESSES ALONG BOTTOM SURFACE
*GET,SB3,NODE,1,S,X
```

```
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'DISP ','PRS TP ','PRS BTM '
LABEL(1,2) = 'in','psi','psi'
*VFILL,VALUE(1,1),DATA,.832,2258,1731
*VFILL,VALUE(1,2),DATA,U3,ST3,SB3
*VFILL,VALUE(1,3),DATA,ABS(U3/.832),ABS(ST3/2258),ABS(SB3/1731)
SAVE, TABLE_1
FINISH
/CLEAR,NOSTART
/PREP7
C***    USING LAYERED SOLID ELEMENTS (SOLID186)
ANTYPE,STATIC
ET,1,SOLID186               ! LAYERED SOLID ELEMENT
KEYOPT,1,3,1                ! LAYERED SOLID
KEYOPT,1,8,1                ! WRITE LAYER RESULTS
SECTYPE,1,SHELL
SECDATA,0.2,1               ! LAYER 1: 0.2 THK
SECDATA,0.1,2               ! LAYER 2: 0.1 THK
MP,EX,1,1.2E6               ! MATERIAL 1 PROPERTIES
MP,NUXY,1,0
MP,ALPX,1,1.8E-4
MP,ALPY,1,0.0
MP,ALPZ,1,0.0
MP,EX,2,0.4E6               ! MATERIAL 2 PROPERTIES
MP,NUXY,2,0
MP,ALPX,2,0.6E-4
MP,ALPY,2,0.0
MP,ALPZ,2,0.0
N,1
N,9,8
FILL
NGEN,2,10,1,9,1,,.5
NGEN,2,20,1,19,1,,,.3
E,1,2,12,11,21,22,32,31
EGEN,8,1,-1                 ! 8 ELEMENTS ALONG LENGTH
EMID
NSEL,S,LOC,X
D,ALL,ALL,                  ! FIXED END
NSEL,ALL
NLIST,ALL
SFE,8,3,PRES,,4000/3,4000/3,-4000/3,-4000/3  ! TAPERED PRESSURE TO APPLY MOMENT ON FACE
BFUNIF,TEMP,100             ! ELEVATED TEMPERATURE LOAD
FINISH
/SOLU
OUTPR,NSOL,1
OUTPR,RSOL,1
SOLVE
FINISH
/POST1
NSEL,S,LOC,X,8
PRNSOL,U,Z                  ! PRINT FREE END DISPLACEMENTS
*GET,U3,NODE,9,U,Z
NSEL,S,LOC,Z,0.3
PRNSOL,S,COMP               ! PRINT STRESSES ALONG TOP SURFACE
*GET,ST3,NODE,21,S,X
NSEL,S,LOC,Z
PRNSOL,S,COMP               ! PRINT STRESSES ALONG BOTTOM SURFACE
*GET,SB3,NODE,1,S,X
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'DISP ','PRS TP ','PRS BTM '
LABEL(1,2) = 'in','psi','psi'
*VFILL,VALUE(1,1),DATA,.832,2258,1731
*VFILL,VALUE(1,2),DATA,U3,ST3,SB3
*VFILL,VALUE(1,3),DATA,ABS(U3/.832),ABS(ST3/2258),ABS(SB3/1731)
SAVE, TABLE_2
FINISH
/CLEAR,NOSTART
/PREP7
C***    USING LAYERED SOLID ELEMENTS (SOLSH190)
ANTYPE,STATIC
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```
ET,1,SOLSH190                 ! LAYERED SOLID-SHELL ELEMENT
KEYOPT,1,8,1                  ! WRITE LAYER RESULTS
SECTYPE,1,SHELL
SECDATA,0.2,1                 ! LAYER 1: 0.2 THK
SECDATA,0.1,2                 ! LAYER 2: 0.1 THK
MP,EX,1,1.2E6                 ! MATERIAL 1 PROPERTIES
MP,NUXY,1,0
MP,ALPX,1,1.8E-4
MP,ALPY,1,0.0
MP,ALPZ,1,0.0
MP,EX,2,0.4E6                 ! MATERIAL 2 PROPERTIES
MP,NUXY,2,0
MP,ALPX,2,0.6E-4
MP,ALPY,2,0.0
MP,ALPZ,2,0.0
N,1
N,9,8
FILL
NGEN,2,10,1,9,1,,.5
NGEN,2,20,1,19,1,,,.3
E,1,2,12,11,21,22,32,31
EGEN,8,1,-1                   ! 8 ELEMENTS ALONG LENGTH
D,1,ALL,,,31,10               ! FIXED END
F,9,FX,-(50/3),,19,10         ! APPLY NODAL FORCES TO GENERATE MOMENT
F,29,FX,(50/3),,39,10
BFUNIF,TEMP,100               ! ELEVATED TEMPERATURE LOAD
FINISH
/SOLU
SOLVE
FINISH
/POST1
NSEL,S,LOC,X,8
PRNSOL,U,Z                    ! PRINT FREE END DISPLACEMENTS
*GET,U3,NODE,9,U,Z
NSEL,S,LOC,Z,0.3
PRNSOL,S,COMP                 ! PRINT STRESSES ALONG TOP SURFACE
*GET,ST3,NODE,21,S,X
NSEL,S,LOC,Z
PRNSOL,S,COMP                 ! PRINT STRESSES ALONG BOTTOM SURFACE
*GET,SB3,NODE,1,S,X
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'DISP ','PRS TP ','PRS BTM '
LABEL(1,2) = 'in','psi','psi'
*VFILL,VALUE(1,1),DATA,.832,2258,1731
*VFILL,VALUE(1,2),DATA,U3,ST3,SB3
*VFILL,VALUE(1,3),DATA,ABS(U3/.832),ABS(ST3/2258),ABS(SB3/1731)
SAVE, TABLE_3
FINISH
/CLEAR,NOSTART
/PREP7
C***    USING LAYERED SHELL ELEMENTS (SHELL281)
ANTYPE,STATIC
ET,1,SHELL281                 ! 8 NODE LAYERED SHELL ELEMENT
KEYOPT,1,8,1                  ! WRITE LAYER RESULTS
SECTYPE,1,SHELL
SECDATA,0.2,1                 ! LAYER 1: 0.2 THK
SECDATA,0.1,2                 ! LAYER 2: 0.1 THK
MP,EX,1,1.2E6                 ! MATERIAL 1 PROPERTIES
MP,NUXY,1,0
MP,ALPX,1,18E-5
MP,ALPY,1,0.0
MP,EX,2,0.4E6                 ! MATERIAL 2 PROPERTIES
MP,NUXY,2,0
MP,ALPX,2,6E-5
MP,ALPY,2,0
N,1
N,9,8
FILL
NGEN,3,10,1,9,,,.25
E,1,3,23,21,2,13,22,11
EGEN,4,2,-1                   ! 4 ELEMENTS ALONG BEAM LENGTH
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```
CP,1,ROTY,9,19,29            ! COUPLE FREE END NODES FOR ROTATION
D,1,ALL,,,21,10              ! FIXED END
F,19,MY,10                   ! APPLY BENDING MOMENT AT FREE EDGE
BFUNIF,TEMP,100              ! ELEVATED TEMPERATURE LOAD
FINISH
/SOLU
SOLVE
FINISH
/POST1
NSEL,S,LOC,X,8               ! SELECT FREE EDGE
PRNSOL,U,Z                   ! PRINT DISPLACEMENTS
*GET,U1,NODE,9,U,Z
NSEL,S,LOC,Y                 ! SELECT NODES ALONG LENGTH
SHELL,TOP
PRNSOL,S,COMP                ! PRINT TOP STRESSES
*GET,ST1,NODE,1,S,X
SHELL,BOT
PRNSOL,S,COMP                ! PRINT BOTTOM STRESSES
*GET,SB1,NODE,1,S,X
ALLSEL
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'DISP ','PRS TP ','PRS BTM '
LABEL(1,2) = 'in','psi','psi'
*VFILL,VALUE(1,1),DATA,.832,2258,1731
*VFILL,VALUE(1,2),DATA,U1,ST1,SB1
*VFILL,VALUE(1,3),DATA,ABS(U1/.832),ABS(ST1/2258),ABS(SB1/1731)
SAVE,TABLE_4
RESUME,TABLE_1
/COM
/OUT,vm144,vrt
/COM,------------------- VM144 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS USING LAYERED SOLID 185
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F12.3,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING LAYERED SOLID186
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F12.3,'   ',1F15.3)
/NOPR
RESUME, TABLE_3
/GOPR
/COM,RESULTS USING LAYERED SOLSH190
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F12.3,'   ',1F15.3)
/NOPR
RESUME, TABLE_4
/GOPR
/COM,RESULTS USING LAYERED SHELL281
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F12.3,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm144,vrt
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VM145 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM145
/PREP7
/TITLE, VM145, STRETCHING OF AN ORTHOTROPIC SOLID
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C***    MECHANICS OF SOLIDS, CRANDALL AND DAHL, 1959, PAGE 225
ANTYPE,STATIC               ! STATIC ANALYSIS
ET,1,SOLID185               ! ANISOTROPIC SOLID
MP,EX,2,10E6                ! LABELED MATERIAL PROPERTY INPUT
MP,EY,2,20E6
MP,EZ,2,40E6
MP,NUXY,2,.1
MP,NUYZ,2,.2
MP,NUXZ,2,.3
MP,GXY,2,10E6
MP,GYZ,2,10E6
MP,GXZ,2,10E6
TB,ANEL,1,,,1
TBDATA,1,.1E-6,-.5E-8,-.75E-8     ! UNINVERTED MATERIAL PROPERTY MATRIX INPUT
TBDATA,7,.5E-7,-.5E-8,,,,.25E-7
TBDATA,16,.1E-6,,,.1E-6,,.1E-6
N,1
N,2,1
NGEN,2,2,1,2,,,,1
NGEN,4,4,1,4,,,1
E,1,2,6,5,3,4,8,7
MAT,2
E,9,10,14,13,11,12,16,15
OUTPR,,1
D,1,ALL,,,9,8
D,3,UX,,,7,2
D,11,UX,,,15,2
D,2,UY,,,4
D,10,UY,,,12
D,2,UZ,,,14,4
D,5,UZ,,,13,8
F,2,FX,25,,16,2
F,5,FY,50,,8
F,13,FY,50,,16
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
/POST1
/OUT,
*GET,UX,NODE,8,U,X
*GET,UY,NODE,8,U,Y
*GET,UZ,NODE,8,U,Z
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'X DISP ','Y DISP ','Z DISP '
LABEL(1,2) = ' in',' in',' in'
*VFILL,VALUE(1,1),DATA,.9E-5,.95E-5,-.175E-5
*VFILL,VALUE(1,2),DATA,UX,UY,UZ
*VFILL,VALUE(1,3),DATA,ABS(UX/(.9E-5)),ABS(UY/(.95E-5)),ABS(UZ/(-.175E-5))
/COM
/OUT,vm145,vrt
/COM,------------------- VM145 RESULTS COMPARISON ---------------
/COM,
/COM,                 |     TARGET   |     Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F12.8,'  ',F17.8,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm145,vrt
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VM146 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM146
/PREP7
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/TITLE, VM146, BENDING OF A REINFORCED CONCRETE BEAM
C***   STR. OF MATL., TIMOSHENKO, PART 1, 3RD ED., PAGE 221

ANTYPE,STATIC
ET,1,SOLID65,,,,,2            ! REINFORCED CONCRETE SOLID ELEMENT
ET,2,LINK180                  ! STEEL RODS
ET,3,PIPE288       ! DUMMY ELEMENTS FOR CONSTRAINT EQUATIONS
KEYOPT,3,3,3             ! CUBIC SHAPE FUNCTION
KEYOPT,3,4,2       ! THICK PIPE THEORY
R,1
SECTYPE,2,LINK
SECDATA,0.15             ! HALF AREA OF ROD
SECTYPE,3,PIPE
SECDATA,1,0.5,8
MP,EX,1,2E6                   ! CONCRETE PROPERTIES
MP,NUXY,1,0
TB,CONCR,1
TBDATA,3,0.0,-1               ! ZERO TENSILE CRACKING STRENGTH
                              ! REMOVE CRUSHING CAPABILITY
MP,EX,2,30E6                  ! STEEL PROPERTIES
MP,NUXY,2,0.3
N,1
N,2,1.5
NGEN,5,2,1,2,1,,1.5
NGEN,2,10,1,10,1,,,5
E,7,8,10,9,17,18,20,19
TYPE,3                        ! DEFINE DUMMY ELEMENTS FOR ROTZ DOF
SECNUM,3
E,10,8
E,20,18
EGEN,4,-2,1,3

TYPE,2
MAT,2                         ! REINFORCING RODS AT THE BOTTOM SURFACE
SECNUM,2
E,1,2
E,11,12
CE,1,, 2,UX,-1, 6,UX,1, 6,ROTZ,3         ! CONSTRAINT EQUATION TO ENSURE
CE,2,,12,UX,-1,16,UX,1,16,ROTZ,3         !  PLANE SECTION REMAINS PLANE
CE,3,, 4,UX,-1, 6,UX,1, 6,ROTZ,1.5
CE,4,,14,UX,-1,16,UX,1,16,ROTZ,1.5
CE,5,, 8,UX,-1, 6,UX,1, 6,ROTZ,-1.5
CE,6,,18,UX,-1,16,UX,1,16,ROTZ,-1.5
CE,7,,10,UX,-1, 6,UX,1, 6,ROTZ,-3
CE,8,,20,UX,-1,16,UX,1,16,ROTZ,-3
NSEL,S,LOC,X
D,ALL,ALL                                ! FIX NODES IN Y-Z PLANE
NSEL,ALL
D,ALL,ROTY                               ! CONSTRAIN UNNEEDED PIPE ROTATIONS
F,6,MZ,300,,16,10                        ! APPLY BENDING MOMENT
FINISH
/SOLU
AUTOTS,ON
NSUBST,5
OUTPR,,LAST
/OUT,SCRATCH
SOLVE
/POST1
/OUT,
ESEL,S,ELEM,,1,1
*GET,SCON,NODE,9,S,X
ESEL,S,ELEM,,13,13
ETAB,ST,LS,1
ESORT,ST
*GET,STL,SORT,,MAX
*status,parm
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'TSTR STL ','TSTR CON'
LABEL(1,2) = ' psi',' psi'
*VFILL,VALUE(1,1),DATA,387.28,-18.54
*VFILL,VALUE(1,2),DATA,STL,SCON
```

```
*VFILL,VALUE(1,3),DATA,ABS(STL/387.28),ABS(SCON/18.54)
SAVE,TABLE_1
FINI
/CLEAR,NOSTART

/NOPR
/COM
/OUT,vm146,vrt
/COM,------------------- VM146 RESULTS COMPARISON --------------
/COM,
/COM,                  |     TARGET   |     Mechanical APDL    |   RATIO
/COM,
RESUME,TABLE_1
/COM,
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F12.2,'  ',F14.2,'   ',1F15.3)
/COM,
/COM,
/COM,-----------------------------------------------------------


/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM146 NOT CONTAINED IN
/COM,THIS TABLE
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm146,vrt
```

VM147 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM147
/PREP7
/TITLE, VM147, GRAY-BODY RADIATION WITHIN A FRUSTRUM OF A CONE
!       REF:  SIEGEL, R., HOWELL J.R., "THERMAL RADIATION HEAT TRANSFER"
!             2ND EDITION, HEMISPHERE PUBLISHING CORPORATION, 1981.
ET,1,LINK33           ! HEAT CONDUCTING BAR
N,1
N,2,0.075
N,3,0.075
N,4,0.05,0.075
N,5,0.05,0.075
N,6,0,0.075
MAT,1                 ! SURFACE 1 (LOWER SURFACE)
E,1,2
MAT,2                 ! SURFACE 2 (INSULATED OUTSIDE SURFACE)
E,3,4
MAT,3                 ! SURFACE 3 (TOP SURFACE)
E,5,6
FINISH
/AUX12
EMIS,1,0.6
EMIS,2,0.8
EMIS,3,0.5
VTYPE,1               ! NON-HIDDEN (FAST) METHOD
GEOM,1,50             ! 2-D AXISYMMETRIC GEOM WITH 50 FACETS
MPRINT,1
STEF,5.6696E-8        ! STEFAN-BOLTZMANN CONSTANT IN MKS UNITS
WRITE,CONE,SUB        ! WRITE RADIATION SUBSTRUCTURE MATRIX
FINISH
/CLEAR,NOSTART        ! CLEAR DATABASE; DO NOT READ START.ANS FILE
/PREP7
ET,1,SURF151,,,1,1    ! 2-D AXISYMMETRIC THERMAL SURFACE EFFECT ELEMENT
KEYOPT,1,8,1          !  WITH HEAT FLUX LOADS
ET,2,MATRIX50,1       ! RADIATION SUBSTRUCTURE MATRIX (SUPERELEMENT)
N,1
N,2,0.075
```

```
E,2,1                  ! LOWER SURFACE FOR HEAT FLUX
TYPE,2
SE,CONE,SUB            ! READ IN RADIATION SUPERELEMENT
FINISH
/SOLU
ANTYPE,STATIC          ! STEADY-STATE THERMAL ANALYSIS
SFE,1,1,HFLUX,,6000    ! APPLY HEAT FLUX LOAD ON SURFACE EFFECT ELEMENT
D,5,TEMP,550,,6
TUNIF,500              ! STARTING UNIFORM TEMPERATURE FOR NONLINEAR SOLUTION
SOLVE
FINISH
/POST1
NSEL,S,NODE,,1,2       ! SELECT LOWER SURFACE NODES
PRNSOL,TEMP            ! LIST TEMPERATURES
*GET,T1,NODE,1,TEMP
*status,parm
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'TEMP '
LABEL(1,2) = ' K'
*VFILL,VALUE(1,1),DATA,904
*VFILL,VALUE(1,2),DATA,T1
*VFILL,VALUE(1,3),DATA,ABS(T1/904)
/COM
/OUT,vm147,vrt
/COM,------------------- VM147 RESULTS COMPARISON --------------
/COM,
/COM,                  |     TARGET   |     Mechanical APDL    |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F12.0,'  ',F14.0,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm147,vrt
```

VM148 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM148
/PREP7
/TITLE, VM148, BENDING OF A PARABOLIC BEAM
C***    STR. OF MATL., TIMOSHENKO, PART 1, 3RD ED., PAGE 210
C***    USING 3-D SOLID95
ANTYPE,STATIC
ET,1,SOLID95                    ! 20 NODE SOLID ELEMENT
MP,EX,1,30E6
MP,EY,1,30E6
MP,EZ,1,30E6
MP,GXY,1,1.5E8
MP,GYZ,1,1.5E8
MP,GXZ,1,1.5E8
MP,NUXY,1,0
MP,NUYZ,1,0
MP,NUXZ,1,0
N,1,.05,SQRT(.05/4)             ! NODE CLOSE TO TIP
*DO,I,2,9
 N,I,(I-1)/2,SQRT((I-1)/8)      ! NEXT EIGHT NODES
*ENDDO
N,11
N,19,4
FILL                            ! NODES ALONG THE AXIS
NSYMM,Y,20,1,9                  ! REFLECT NODES IN Y DIRECTION
NGEN,3,30,1,29,1,,,-.1          ! GENERATE NODES ALONG THICKNESS
E,1,3,23,21,61,63,83,81
EMORE,2,13,22,11,62,73,82,71
EMORE,31,33,53,51
EGEN,4,2,1
```

```
F,11,FY,-500,,71,60            ! APPLY END LOAD AT TIP NODES
NSEL,S,LOC,X,4
D,ALL,ALL                      ! FIX NODES AT SUPPORTED END
NSEL,ALL
OUTPR,,1
SAVE
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
*CREATE,RES3D,MAC              ! CREATE MACRO TO RETRIEVE RESULTS
/POST1
/OUT,
*GET,UY,NODE,11,U,Y
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'Y DELF '
LABEL(1,2) = ' in'
*VFILL,VALUE(1,1),DATA,-.01067
*VFILL,VALUE(1,2),DATA,UY
*VFILL,VALUE(1,3),DATA,ABS(UY/.01067)
FINISH
*END
RES3D                                   !EXECUTE MACRO TO RETRIEVE RESULTS
SAVE,TABLE_1

/CLEAR, NOSTART                         !CLEAR DATABASE FOR SECOND SOLUTION
/TITLE, VM148, BENDING OF A PARABOLIC BEAM
C***    USING 3-D SOLID186
/PREP7
RESUME                                  ! RESUME DATABASE
ET,1,SOLID186                           ! ANALYZE AGAIN USING 3-D SOLID186
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
/OUT,
FINISH
RES3D                                   !EXECUTE MACRO TO RETRIEVE RESULTS
SAVE,TABLE_2

/NOPR
RESUME,TABLE_1
/GOPR
/COM
/OUT,vm148,vrt
/COM,------------------- VM148 RESULTS COMPARISON --------------
/COM,
/COM,                 |     TARGET   |     Mechanical APDL   |   RATIO
/COM,
/COM, SOLID95
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F12.5,'  ',F14.5,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM, SOLID186
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F12.5,'  ',F14.5,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm148,vrt
```

VM149 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm149
/title,vm149,Residual Vector in Mode Superposition Harmonic Analysis
/com,
/com, Verification manual to verify the effect of residual
/com, vector to improve the solution accuracy in modal
/com, response analysis
/com,
/com, Reference: J.M.Dickens,J.M.Nakagawa,M.J.Wittbrodt
/com, "A critique of mode acceleration and modal truncation
/com,  augmentation methods for modal response analysis"
/com, computers & structures,Vol.62,No.6,pp 985-998,1997
/com,

/com, ********************************
/com, CASE1: EXTRACTING ALL THE MODES
/com, ********************************


/filename,case1

/prep7
et,1,combin14,,,2            ! 2D Spring-damper element
et,2,mass21,,,4              ! 2D Mass without rotary inertia
et,3,mass21,,,4              ! 2D Mass without rotary inertia

r,1,10000                    ! Stiffness for spring element
r,2,1                        ! Mass
r,3,0.5                      ! Mass

n,1
n,2,1
n,3,2
n,4,3
n,5,4
n,6,5

e,1,2                        ! Spring 1
e,2,3                        ! Spring 2
e,3,4                        ! Spring 3
e,4,5                        ! Spring 4
e,5,6                        ! Spring 5

type,2
real,2

e,2                          ! Mass 1
e,3                          ! Mass 2
e,4                          ! Mass 3

type,3
real,3
e,5                          ! Mass 4

d,1,all
d,6,all

nsel,s,,,2,5
d,all,uy
nsel,all
finish

/solution
antype,modal
modopt,lanb,4                ! Extracting all modes
mxpand,all,,,yes
f,4,fx,1                     ! Generate load vector for harmonic analysis
```

```
solve
fini

/solution
antype,harmic,new
hropt,msup,4,,              ! Mode superposition harmonic analysis
outres,all,all
fdele,all
lvscale,1                   ! Scaling the load vector
harfrq,3,70                 ! Frequency range
dmprat,0.02                 ! Damping
nsubst,500
kbc,1
save
solve
fini

/solution
expass,on
outres,all,all
numexp,all,,,yes
solve
finish


/post26
file,case1,rst
numvar,20
/com, ******************************************************
/com,  Computing the 1st peak displacement and spring force
/com, ********************************************************
nsol,2,4,u,x,4ux
realvar,4,2,,,UXR           ! Real value of UX
imagin,5,2,,,UXI            ! Imaginary value of UX
prod,6,4,4,,UXR_2
prod,7,5,5,,UXI_2
add,8,6,7,,UXR_2+UXI_2
sqrt,9,8,,,ampl_disp,,,1    ! Amplitude


esol,10,4,4,smisc,1
realvar,11,10,,,ForceR       ! Real value of Spring force
imagin,12,10,,,ForceI        ! Imaginary value of Spring force
prod,13,11,11,,ForceR_2
prod,14,12,12,,ForceI_2
add,15,13,14,,ForceR_2+ForceI_2
sqrt,16,15,,,ampl_force,,,1     ! Amplitude

/out,scratch
/grid,1
/gropt,logy,1
/xrange,3,70
/axlab,y,amplitude_disp_force
plvar,9,16
prvar,9,16

*get,ux_max_all,vari,9,extrem,vmax
*get,force_max_all,vari,16,extrem,vmax
*get,freq_ux_all,vari,9,extrem,tmax
*get,freq_force_all,vari,16,extrem,tmax

/out,
/com, ******************************************************
/com,  Computing the 2nd peak spring force
/com, ******************************************************
timerange,11,70             ! Listing values between 11hz to 70Hz
store,new                   ! Store new set of data

esol,10,4,4,smisc,1
realvar,11,10,,,ForceR       ! Real value of Spring force
imagin,12,10,,,ForceI        ! Imaginary value of Spring force
prod,13,11,11,,ForceR_2
```

```
prod,14,12,12,,ForceI_2
add,15,13,14,,ForceR_2+ForceI_2
sqrt,16,15,,,ampl_force,,,1     ! Amplitude

/out,scratch
/grid,1
/gropt,logy,1
/xrange,3,70
/axlab,y,amplitude_disp_force
plvar,16
prvar,16

*get,force_max_all2,vari,16,extrem,vmax


*dim,label,char,5,1
*dim,value,,5,3

label(1,1)='UX_MAX'
label(2,1)='F_MAX'
label(3,1)='FREQ_UX'
label(4,1)='FREQ_F'
label(5,1)='F_MAX2'

*vfill,value(1,1),data,2.500e-03
*vfill,value(1,2),data,ux_max_all
*vfill,value(1,3),data,abs(2.500e-03/ux_max_all)

*vfill,value(2,1),data,10.000
*vfill,value(2,2),data,force_max_all
*vfill,value(2,3),data,abs(10.000/force_max_all)

*vfill,value(3,1),data,10.100
*vfill,value(3,2),data,freq_ux_all
*vfill,value(3,3),data,abs(10.100/freq_ux_all)

*vfill,value(4,1),data,10.100
*vfill,value(4,2),data,freq_force_all
*vfill,value(4,3),data,abs(10.100/freq_force_all)

*vfill,value(5,1),data,4.5
*vfill,value(5,2),data,force_max_all2
*vfill,value(5,3),data,abs(4.5/force_max_all2)

save,table_1
fini
/clear,nostart

/out,
/com, *******************************************
/com, CASE2: EXTRACTING 1 MODE + RESIDUAL VECTOR
/com, ********************************************

/title,vm149,Residual Vector in Mode Superposition Harmonic Analysis
/filename,case2

/prep7
et,1,combin14,,,2           ! 2D Spring-damper element
et,2,mass21,,,4             ! 2D Mass without rotary inertia
et,3,mass21,,,4             ! 2D Mass without rotary inertia

r,1,10000                   ! Stiffness for spring element
r,2,1                       ! Mass
r,3,0.5                     ! Mass

n,1
n,2,1
n,3,2
n,4,3
n,5,4
n,6,5
```

```
e,1,2                        ! Spring 1
e,2,3                        ! Spring 2
e,3,4                        ! Spring 3
e,4,5                        ! Spring 4
e,5,6                        ! Spring 5

type,2
real,2

e,2                          ! Mass 1
e,3                          ! Mass 2
e,4                          ! Mass 3

type,3
real,3
e,5                          ! Mass 4

d,1,all
d,6,all

nsel,s,,,2,5
d,all,uy
nsel,all
finish

/solution
antype,modal
modopt,lanb,1            ! Extract 1 mode
mxpand,1,,,yes
resvec,on                ! Compute residual vector
f,4,fx,1                 ! Generate load vector
solve
fini

/post1
set,1,2
*get,residual_vector,active,0,set,freq
finish

/solution
antype,harmic,
resvec,on                ! Include residual vector
hropt,msup,1,,
fdele,all
lvscale,1                ! Scale load vector
harfrq,3,70              ! Excitation frequency range
dmprat,0.02              ! Damping
nsubst,500
kbc,1
save
solve
fini

/solution
expass,on
outres,all,all
numexp,all,,,yes
solve
finish

/post26
file,case2,rst
numvar,20
/com, ******************************************************
/com,  Computing the 1st peak displacement and spring force
/com, ********************************************************
nsol,2,4,u,x,4ux
realvar,4,2,,,UXR            ! Real value of UX
imagin,5,2,,,UXI             ! Imaginary value of UX
prod,6,4,4,,UXR_2
prod,7,5,5,,UXI_2
add,8,6,7,,UXR_2+UXI_2
```

```
sqrt,9,8,,,ampl_disp,,,1


esol,10,4,4,smisc,1
realvar,11,10,,,ForceR     ! Real value of Spring force
imagin,12,10,,,ForceI      ! Imaginary value of Spring force
prod,13,11,11,,ForceR_2
prod,14,12,12,,ForceI_2
add,15,13,14,,ForceR_2+ForceI_2
sqrt,16,15,,,ampl_force,,,1

/out,scratch
/grid,1
/gropt,logy,1
/xrange,3,70
/axlab,y,amplitude_disp_force
plvar,9,16
prvar,9,16


*get,ux_max_residual,vari,9,extrem,vmax
*get,force_max_residual,vari,16,extrem,vmax
*get,freq_ux_residual,vari,9,extrem,tmax
*get,freq_force_residual,vari,16,extrem,tmax

/out,
/com, *********************************************************
/com,  Computing the 2nd peak spring force
/com, *********************************************************
timerange,11,70
store,new

esol,10,4,4,smisc,1
realvar,11,10,,,ForceR       ! Real value of Spring force
imagin,12,10,,,ForceI        ! Imaginary value of Spring force
prod,13,11,11,,ForceR_2
prod,14,12,12,,ForceI_2
add,15,13,14,,ForceR_2+ForceI_2
sqrt,16,15,,,ampl_force,,,1     ! Amplitude

/out,scratch
/grid,1
/gropt,logy,1
/xrange,3,70
/axlab,y,amplitude_disp_force
plvar,16
prvar,16

*get,force_max_resvec2,vari,16,extrem,vmax


*dim,label,char,6,1
*dim,value,,6,3

label(1,1)='RES_MODE'
label(2,1)='UX_MAX'
label(3,1)='F_MAX'
label(4,1)='FREQ_UX'
label(5,1)='FREQ_F'
label(6,1)='F_MAX2'

*vfill,value(1,1),data,21.865
*vfill,value(1,2),data,residual_vector
*vfill,value(1,3),data,abs(21.865/residual_vector)

*vfill,value(2,1),data,2.500e-03
*vfill,value(2,2),data,ux_max_residual
*vfill,value(2,3),data,abs(2.500e-03/ux_max_residual)

*vfill,value(3,1),data,10.000
*vfill,value(3,2),data,force_max_residual
*vfill,value(3,3),data,abs(10.000/force_max_residual)
```

```
*vfill,value(4,1),data,10.100
*vfill,value(4,2),data,freq_ux_residual
*vfill,value(4,3),data,abs(10.100/freq_ux_residual)

*vfill,value(5,1),data,10.100
*vfill,value(5,2),data,freq_force_residual
*vfill,value(5,3),data,abs(10.100/freq_force_residual)

*vfill,value(6,1),data,4.5
*vfill,value(6,2),data,force_max_resvec2
*vfill,value(6,3),data,abs(4.5/force_max_resvec2)



save,table_2
finish
resume,table_1
/com,
/out,vm149,vrt
/com,
/com, ------------------------------VM149 RESULTS COMPARISON----------------------
/com,
/com,                      | TARGET |  Mechanical APDL | RATIO
/com,
/com,
/com, Extracting all modes
/com, --------------------
/com,
/com,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A14,'   ',F12.5,'    ',F12.5,'    ',F12.3)
/com,
/com,
/NOPR,
resume,table_2
/GOPR
/com,
/com, Extracting 1 mode + residual vector
/com, -----------------------------------
/com,
/com,
/com,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A14,'   ',F12.5,'    ',F12.5,'    ',F12.3)
/com,
/com,
/NOPR,
/com,
/com,
/com, --------------------------------------------------------------------------------
/out,
*list,vm149,vrt
finish
```

VM150 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm150
/title,vm150,Diffusion in a Plane Sheet
/com,
/com,
/com, Reference: Crank,J. The Mathematics of Diffusion.
/com, 2nd printing, Bristol: Oxford University Press
/com, 1975, pg 47-48
/com,
```

```
/NOPR

! DEFINED PARAMETERS
L=2E-3   ! SHEET THICKNESS, M
H=50E-3   ! PLANE HEIGHT, M
W=50E-3   ! PLANE WIDTH, M
D=1E-12   ! DIFFUSIVITY, M^2/S
CONC0=0.01  ! INITIAL CONCENTRATION, KG/M^3
CONC1=0.2  ! APPLIED CONCENTRATION, KG/M^3
MSAT=CONC1*2*L*W*H ! MOISTURE WEIGHT GAIN AT SATURATION, KG
T=1600*3600  ! TIME AT END OF LOAD STEP, S
PI=4*ATAN(1) ! VALUE OF PI COMPUTED
SUB=50   ! NUMBER OF SUBSTEPS
ITER=5   ! NUMBER OF ITERATIONS FOR CRANK EQUATION
XLOC=L/2  ! LOCATION WITHIN PLATE FOR POSTPROCESSING

/PREP7
ET,1,SOLID239  ! DIFFUSION SOLID
MP,DXX,1,D
BLOCK,-L,L,0,H,0,W
LESIZE,5,L/2
LESIZE,3,2*L
LESIZE,10,2*L
VMESH,ALL
ALLS

NSEL,S,LOC,X,-L
NSEL,A,LOC,X,L
D,ALL,CONC,CONC1 ! APPLY CONC1 AT X=-L AND X=L
NSEL,INVE
IC,ALL,CONC,CONC0 ! SET INITIAL CONCENTRATION CONC0
ALLS
FINISH

/SOLU
ANTYPE,TRANS
OUTRES,ALL,ALL
KBC,1
NSUB,SUB
TIME,T
SOLVE
FINISH

/POST1
*DIM,CONCENTRATION_,TABLE,SUB,2
*DIM,MASS_,TABLE,SUB,2
*DO,II,1,SUB
  SET,1,II
  *GET,II_TIME,ACTIVE,,SET,TIME
  CONCENTRATION_(II,0)=II_TIME
  MASS_(II,0)=II_TIME

  NSEL,S,LOC,X,XLOC
  *GET,ND,NODE,,NUM,MIN
  *GET,ND_CONC,NODE,ND,CONC
  CONCENTRATION_(II,1)=ND_CONC
  ALLS

  ETABLE,CONC,CONC
  ETABLE,VOLU,VOLU
  SMULT,WATR,CONC,VOLU
  SSUM
  *GET,MOISTURE,SSUM,,ITEM,WATR
  MASS_(II,1)=MOISTURE

  C=CONC1
  M=MSAT
  *DO,JJ,0,ITER
    C=C-(((CONC1-CONC0)*4*((-1)**(JJ))*EXP((-D*II_TIME*((2*JJ+1)**2)*(PI**2))/(4*L**2))*COS(((2*JJ+1)*PI*XLOC)/(2*L)))/
    M=M-((MSAT*8*EXP((-D*II_TIME*((2*JJ+1)**2)*(PI**2))/(4*L**2)))/((PI*(2*JJ+1))**2))
  *ENDDO
  CONCENTRATION_(II,2)=C
```

```
  MASS_(II,2)=M
*ENDDO

/AXLAB,X,TIME (S)
/AXLAB,Y,CONCENTRATION (KG/M^3)
/GCOL,1,MAPDL
/GCOL,2,TARGET
*VPLOT,CONCENTRATION_(1,0),CONCENTRATION_(1,1),2
/AXLAB,Y,MOISTURE WEIGHT GAIN (KG)
*VPLOT,MASS_(1,0),MASS_(1,1),2

*DIM,CONC_RATIO,,SUB
*DIM,MASS_RATIO,,SUB
*VOPER,CONC_RATIO,CONCENTRATION_(1,1),DIV,CONCENTRATION_(1,2)
*VOPER,MASS_RATIO,MASS_(1,1),DIV,MASS_(1,2)
/OUT,vm150,vrt
/COM
/COM ----------------------- RESULTS COMPARISON ---------------------------
/COM
/COM
/COM   ***** CONCENTRATION (KG/M^3) AT LOCATION X = %XLOC% CM *****
/COM
/COM       TIME (S)     |      TARGET      |     MECHANICAL APDL     |     RATIO
/COM
*VLEN,1
*VWRITE,CONCENTRATION_(25,0),CONCENTRATION_(25,2),CONCENTRATION_(25,1),CONC_RATIO(25,1)
(,F15.0,'            ',F8.5,'             ',F8.5,'            ',F8.3)
/COM
/COM
/COM
/COM   ***** MOISTURE WEIGHT GAIN (KG) *****
/COM
/COM       TIME (S)     |       TARGET       |      MECHANICAL APDL      |     RATIO
/COM
*VLEN,1
*VWRITE,MASS_(25,0),MASS_(25,2),MASS_(25,1),MASS_RATIO(25,1)
(,F15.0,'         ',G14.5,'          ',G14.5,'          ',F8.3)
/COM
/COM ----------------------------------------------------------------------
/OUT,
*list,vm150,vrt
FINISH
```

VM151 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM151
/PREP7
MP,PRXY,,0.3
/TITLE, VM151, NONAXISYMMETRIC VIBRATION OF A CIRCULAR PLATE
C***         FORMULAS FOR NATURAL FREQUENCY AND MODE SHAPE, BLEVINS, PAGE 240
ET,1,SHELL61
R,1,.05             ! THICKNESS OF PLATE
MP,EX,1,30E6
MP,DENS,1,.00073
MP,PRXY,1,0.3
K,1
K,2,3
L,1,2
LESIZE,1,,,9
LMESH,1
NSEL,S,LOC,X,0
D,ALL,UX
NSEL,S,LOC,X,3      ! SELECT NODE AT R=3 AND CONSTRAIN
D,ALL,UX,,,,,UY
NSEL,ALL
D,ALL,UZ            ! CONSTRAIN TORSIONAL DOF'S
FINISH
```

```
/SOLU
ANTYPE,MODAL         ! MODE FREQUENCY ANALYSIS
MXPAND,3             ! EXPAND FIRST 3 MODE SHAPES
MODOPT,LANB,9
OUTPR,BASIC,ALL
MODE,0               ! ZERO HARMONIC MODE
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/WINDOW,1,LTOP
/OUT,
SET,1,1
PLDISP,1
/NOERASE
/WINDOW,1,OFF
*GET,F1,MODE,0,FREQ
FINISH
/SOLU
MODE,1               ! FIRST HARMONIC MODE
/OUT,SCRATCH
SOLVE
/OUT,
FINISH
/POST1
/WINDOW,2,RTOP
SET,1,1
PLDISP,1
/WINDOW,2,OFF
*GET,F2,MODE,1,FREQ
FINISH
/SOLU
MODE,2               ! SECOND HARMONIC MODE
/OUT,SCRATCH
SOLVE
/OUT,
FINISH
/POST1
/WINDOW,3,BOT
SET,1,1
PLDISP,1
*GET,F3,MODE,1,FREQ
*status,parm
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'F(0,1) ','F(1,1) ','F(1,2) '
LABEL(1,2) = 'Hz ','Hz ','Hz '
*VFILL,VALUE(1,1),DATA,269.96,756.13,1391.3
*VFILL,VALUE(1,2),DATA,F1,F2,F3
*VFILL,VALUE(1,3),DATA,ABS(F1/269.96),ABS(F2/756.13),ABS(F3/1391.3)
/COM
/OUT,vm151,vrt
/COM,------------------- VM151 RESULTS COMPARISON -------------
/COM,
/COM,                 |    TARGET   |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.2,'  ',F14.2,'   ',1F16.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm151,vrt
```

VM152 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM152
/PREP7
```

```
/TITLE, VM152, NONAXISYM. VIBR. OF A STRETCHED CIRCULAR MEMBRANE (HARMONIC ELS)
C***          VIBRATION PROBS. IN ENGR., TIMOSHENKO, 3RD. ED., ART. 69, PAGE 438
ET,1,SHELL61
R,1,.00005                ! PLATE THICKNESS
MP,EX,1,30E6
MP,ALPX,1,1E-5
MP,DENS,1,.00073
MP,NUXY,1,0
K,1                       ! DEFINE GEOMETRY
K,2,3
L,1,2
LESIZE,1,,,9
LMESH,1
NSEL,S,LOC,X,0
D,ALL,UX
NSEL,S,LOC,X,3
D,ALL,UX,,,,,UY
NSEL,ALL
D,ALL,UZ
TREF,0                    ! REFERENCE (STRESS-FREE) TEMPERATURE
BFUNIF,TEMP,-(20/3)       ! COOL MEMBRANE TO INVOKE PRESOLESS
FINISH
/SOLU
ANTYPE,STATIC
PSTRES,ON                 ! STATIC PRESTRESS ANALYSIS
OUTPR,BASIC,ALL
/OUT,SCRATCH
SOLVE
FINISH
/SOLU
ANTYPE,MODAL
PSTRES,ON                 ! PRESTRESSED MODAL ANALYSIS
MXPAND,3
MODOPT,LANB,3
MODE,0                    ! ZERO HARMONIC MODE
SOLVE
FINISH
/POST1
/WINDOW,1,LTOP
/OUT,
SET,1,1                   ! FOR WINDOW 1
PLDISP,1
/NOERASE
*GET,F11,MODE,0,FREQ
/WINDOW,1,OFF
/WINDOW,4,RBOT
SET,1,2                   ! FOR 4TH WINDOW
PLDISP,1
*GET,F12,MODE,2,FREQ
/WINDOW,4,OFF
FINISH
/SOLU
MODE,1                    ! FIRST HARMONIC MODE
/OUT,SCRATCH
SOLVE
/OUT,
FINISH
/POST1
/WINDOW,2,RTOP
SET,1,1
PLDISP,1
*GET,F21,MODE,0,FREQ
/WINDOW,2,OFF
FINISH
/SOLU
MODE,2                    ! SECOND HARMONIC MODE
/OUT,SCRATCH
SOLVE
/OUT,
FINISH
/POST1
/WINDOW,3,LBOT
```

```
SET,1,1
PLDISP,1
*GET,F31,MODE,0,FREQ
*status,parm
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'F(0,1) ','F(1,1) ','F(2,1) ','F(0,2) '
LABEL(1,2) = 'Hz ','Hz ','Hz ','Hz '
*VFILL,VALUE(1,1),DATA,211.1,336.5,450.9,484.7
*VFILL,VALUE(1,2),DATA,F11,F21,F31,F12
*VFILL,VALUE(1,3),DATA,ABS(F11/211.1),ABS(F21/336.5),ABS(F31/450.9),ABS(F12/484.7)
/COM
/OUT,vm152,vrt
/COM,------------------- VM152 RESULTS COMPARISON -------------
/COM,
/COM,                 |    TARGET   |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.1,'  ',F13.1,'   ',1F16.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm152,vrt
```

VM153 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM153
/FILNAM,PRSMEMB
/PREP7
/TITLE, VM153, NONAXISYM. VIBR. OF A STRETCHED CIRCULAR MEMBRANE (STATIC)
C***           VIBRATION PROBS. IN ENGR., TIMOSHENKO, PAGE 439, ARTICLE 69
C*** USING SHELL41 MEMBRANE SHELL
ANTYPE,STATIC            ! STATIC ANALYSIS
ET,1,SHELL41,,1
R,1,.00005               ! PLATE THICKNESS
MP,EX,1,30E6
MP,ALPX,1,1E-5
MP,DENS,1,.00073
MP,NUXY,1,0
CSYS,1
N,1,.001
N,10,3
FILL
NGEN,4,10,1,10,1,,10
NROTAT,ALL               ! ROTATE ALL NODES INTO CYLINDRICAL SYSTEM
E,1,2,12,11
EGEN,3,10,-1
EGEN,9,1,-3
NSEL,S,LOC,Y,0           ! DEFINE EDGE COMPONENTS FOR CYCLIC SYMM. MACRO
CM,RIGHT,NODE            ! RIGHT EDGE OF THE SECTOR MODEL
NSEL,S,LOC,Y,30
CM,LEFT,NODE             ! LEFT EDGE OF THE SECTOR MODEL
NSEL,ALL
/NOPR
CYCLIC
/GOPR
D,ALL,ALL,0              ! FIX ALL DISPLACEMENTS TO APPLY PRESTRESS
TREF,0                   ! REFERENCE TEMPERATURE
BFUNIF,TEMP,-6.66666     ! COOL DOWN TO INDUCE PRESTRESS
FINISH
*CREATE,SOLVIT,MAC
/SOLU                    ! SOLVE FOR STATIC SOLUTION
/OUTPUT,SCRATCH
ANTYPE,STATIC
PSTRES,ON                ! PRESTRESS KEY ON
CYCOPT,HINDX,0,0
SOLVE
```

```
FINISH
/PREP7
/TITLE, VM153, NONAXISYM. VIBR. OF A STRETCHED CIRCULAR MEMBRANE (MODAL)
CYCLIC,UNDOUBLE
DDEL,ALL,ALL              ! RELEASE ALL DISPLACEMENTS AND THEN
NSEL,S,LOC,Y,0            ! DEFINE BOUNDARY CONDITIONS
NSEL,A,LOC,Y,30
D,ALL,UX,,,,,UY
NSEL,S,LOC,X,3
D,ALL,ALL,0
NSEL,ALL
CYCLIC
FINISH
/SOLUTION
ANTYPE,MODAL              ! DEFINE MODAL ANALYSIS OPTIONS
MODOPT,LANB,4,1,1000      ! USE BLOCK LANCZOS ITER, EXTRACT 4 MODES IN 1 TO 1000 HZ
MXPAND,4                  ! EXPAND 4 MODES
PSTRES,ON
CYCOPT,HINDX,0,1          ! NODAL DIAMETER 0 TO 1, WITH 30 DEG. SECTORS
SOLVE
FINISH
/POST1
/OUTPUT
SET,1,1
*GET,F01_1,ACTIVE,,SET,FREQ   ! NATURAL FREQ. FOR 1ST MODE, 0 MODAL DIAM.
SET,1,2
*GET,F02_1,ACTIVE,,SET,FREQ   ! NATURAL FREQ. FOR 2ND MODE, 0 MODAL DIAM.
SET,2,1
*GET,F11_1,ACTIVE,,SET,FREQ   ! NATURAL FREQ. FOR 1ST MODE, 1 MODAL DIAM.
SET,2,2
*GET,F11_2,ACTIVE,,SET,FREQ   ! REPEATED FREQ. FOR 1ST MODE,1 MODAL DIAM.
SET,2,3
*GET,F12_1,ACTIVE,,SET,FREQ   ! NATURAL FREQ. FOR 2ND MODE, 1 MODAL DIAM.
SET,2,4
*GET,F12_2,ACTIVE,,SET,FREQ   ! REPEATED FREQ. FOR 2ND MODE,1 MODAL DIAM.
FINISH
/NOPR
/POST1
EXPAND,12                 ! EXPAND RESULTS FOR THE FULL 12 SECTOR MODEL
/VIEW,,1,1,1
/VUP,1,Z
/GLINE,,-1                ! NO ELEMENT OUTLINE
/TRIAD,OFF
SET,1,2
/TITLE, VM153, STRETCHED CIRCULAR MEMBRANE - NODAL DIAM 0, MODE 2
PLNSOL,U,Z
SET,2,2
/TITLE, VM153, STRETCHED CIRCULAR MEMBRANE - NODAL DIAM 1, MODE 2
PLNSOL,U,Z
FINISH
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'F(0,1) ','F(0,2) ','F(1,1) ','F(1,2) '
LABEL(1,2) = 'Hz ','Hz ','Hz ','Hz '
*VFILL,VALUE(1,1),DATA,211.1,484.7,336.5,616.1
*VFILL,VALUE(1,2),DATA,F01_1,F02_1,F11_1,F12_1
*VFILL,VALUE(1,3),DATA,ABS(F01_1/211.1),ABS(F02_1/484.7),ABS(F11_1/336.5),ABS(F12_1/616.1)
FINISH
*END
SOLVIT
SAVE,TABLE_1
/CLEAR,NOSTART
/TITLE, VM153, NONAXISYM. VIBR. OF A STRETCHED CIRCULAR MEMBRANE (STATIC)
C*** USING SHELL181 MEMBRANE SHELL OPTION
/FILNAM,PRSMEMB
/PREP7
ANTYPE,STATIC             ! STATIC ANALYSIS
ET,1,SHELL181,1           ! MEMBRANE STIFFNESS ONLY
SECT,1,SHELL
SECD,.00005,1             ! PLATE THICKNESS
MP,EX,1,30E6
MP,ALPX,1,1E-5
```

```
MP,DENS,1,.00073
MP,NUXY,1,0
CSYS,1
N,1,.001
N,10,3
FILL
NGEN,4,10,1,10,1,,10
NROTAT,ALL                ! ROTATE ALL NODES INTO CYLINDRICAL SYSTEM
E,1,2,12,11
EGEN,3,10,-1
EGEN,9,1,-3
NSEL,S,LOC,Y,0            ! DEFINE EDGE COMPONENTS FOR CYCLIC SYMM. MACRO
CM,RIGHT,NODE             ! RIGHT EDGE OF THE SECTOR MODEL
NSEL,S,LOC,Y,30
CM,LEFT,NODE              ! LEFT EDGE OF THE SECTOR MODEL
NSEL,ALL
/NOPR
CYCLIC
/GOPR
D,ALL,ALL,0               ! FIX ALL DISPLACEMENTS TO APPLY PRESTRESS
TREF,0                    ! REFERENCE TEMPERATURE
BFUNIF,TEMP,-6.66666      ! COOL DOWN TO INDUCE PRESTRESS
FINISH
SOLVIT
SAVE,TABLE_2
/NOPR
RESUME,TABLE_1
/COM
/OUT,vm153,vrt
/COM,------------------- VM153 RESULTS COMPARISON -------------
/COM,
/COM,                 |    TARGET   |    Mechanical APDL   |    RATIO
/COM,
/COM,
/COM, SHELL41
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.1,'  ',F16.1,'   ',1F16.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM, SHELL181
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.1,'  ',F16.1,'   ',1F16.3)
/NOPR
/COM,----------------------------------------------------------
/OUT
*LIST,vm153,vrt
```

VM154 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM154
/PREP7
/TITLE, VM154, VIBRATION OF A FLUID COUPLING
C***            FRITZ, ASME J. OF ENG. FOR INDUST., VOL. 94, 1972, PP 167-173.
C***            USING FLUID COUPLING ELEMENTS (FLUID38)
ANTYPE,MODAL           ! MODE-FREQUENCY ANALYSIS
ET,1,FLUID38
ET,2,COMBIN14,,1       ! ELEMENT WITH UX DEGREE OF FREEDOM
R,1,8,7,1              ! GEOMETRIC PROPERTIES OF FLUID38
R,2,10                 ! SPRING STIFFNESS
MP,DENS,1,934E-7
N,1
N,2
E,1,2
```

```
REAL,2
TYPE,2
E,1,2                 ! TYPE 2 ELEMENT WITH REAL CONSTANT 2
OUTPR,,1
D,1,UZ
D,2,ALL
FINISH
/SOLU
MODOPT,LANB,1
MXPAND,1
SOLVE
FINISH
/POST1
*GET,F1,MODE,1,FREQ
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'f FLD38 '
LABEL(1,2) = 'Hz'
*VFILL,VALUE(1,1),DATA,1.5293
*VFILL,VALUE(1,2),DATA,F1
*VFILL,VALUE(1,3),DATA,ABS(F1/1.5293)
SAVE,TABLE_1
FINISH
RESUME,TABLE_1
/COM
/OUT,vm154,vrt
/COM,------------------- VM154 RESULTS COMPARISON -------------
/COM,
/COM,                 |    TARGET   |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.4,'  ',F16.4,'   ',1F16.3)
/COM,
/COM,---------------------------------------------------------
FINISH
/DELETE,TABLE_1
/OUT
*LIST,vm154,vrt
FINISH
```

VM155 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM155
/TITLE,VM155,VERIFY CHABOCHE RATE-DEPENDENT PLASTICITY MATERIAL MODEL
/COM, REFERENCE:"R.C.Lin,ET AL.,MODELING OF FINITE STRAIN VISCOPLASTICITY BASED
/COM,            ON THE LOGARITHMIC COROTATIONAL DESCRIPTION
/COM,            ARCH APPL MECH, 2006(75),PG: 693-708
/COM,
/OUT,SCRATCH
/PREP7
ET,1,PLANE182                   ! 2D 8 NODE ELEMENT
KEYOPT,1,3,0                    ! PLANE STRESS

MP,EX,1,149650e6
MP,NUXY,1,0.33
TB,CHAB,1,,1                    ! DEFINE CHABOCHE MATERIAL DATA
TBDATA,1,1.53e8,62511e6,1.1/311e6*62511e6
TB,RATE,1,,6,CHABOCHE           ! DEFINE RATE DEPENDENT MATERIAL DATA
TBDATA,1,1.53e8,0,-1.53e8,317,1/7.7,1150e6

N, 1, 0.0, 0.0, 0.0
N, 2, 0.0, 1.0, 0.0
N, 3, 1.0, 0.0, 0.0
N, 4, 1.0, 1.0, 0.0
E,1,3,4,2

NSEL,S,LOC,X,0                   ! BOUNDARY CONDITIONS
```

```
D,ALL,UX,0
NSEL,S,LOC,Y,0
D,ALL,UY,0
ALLSEL
FINISH

/SOLU
OUTRES,ALL,NONE
NSUB,30,300,10
TIME,910/89
NSEL,S,LOC,X,1
D,ALL,UX,-0.01
NSEL,ALL
SOLVE

*DO,I,1,42
  NSEL,S,LOC,X,1
  D,ALL,UX,0.01
  NSEL,ALL
  TIME,910/89*(2*I+1)
  SOLVE

  TIME,910/89*(2*I+3)
  NSEL,S,LOC,X,1
  D,ALL,UX,-0.01
  NSEL,ALL
  SOLVE
*ENDDO

NSUB,30,300,30
OUTRES,ALL,LAST
NSEL,S,LOC,X,1
D,ALL,UX,0.01
NSEL,ALL
TIME,910
SOLVE
TIME,940
SOLVE

NSEL,S,LOC,X,1
D,ALL,UX,-0.01
NSEL,ALL
TIME,960
SOLVE
TIME,990
SOLVE

NSEL,S,LOC,X,1
D,ALL,UX,0
NSEL,ALL
TIME,1000
SOLVE
FINI

/POST1
*DIM,VALUE,,5,3
*DIM,LABEL,CHAR,1,5
LABEL(1,1)='910s'
LABEL(1,2)='940s'
LABEL(1,3)='960s'
LABEL(1,4)='990s'
LABEL(1,5)='1000s'
VALUE(1,1)=0.681E9
VALUE(2,1)=0.501E9
VALUE(3,1)=-0.692E9
VALUE(4,1)=-0.502E9
VALUE(5,1)=0.466E9
SET,FIRST
ETABLE,SXX,S,X
*GET,SS,ELEM,1,ETAB,SXX
VALUE(1,2)=SS
VALUE(1,3)=ABS(VALUE(1,1)/VALUE(1,2))
```

```
*DO,I,2,5
   SET,NEXT
   ETABLE,SXX,S,X
  *GET,SS,ELEM,1,ETAB,SXX
   VALUE(I,2)=SS
   VALUE(I,3)=ABS(VALUE(I,1)/VALUE(I,2))
*ENDDO

/COM
/OUT,vm155,vrt
/COM,----- VM155 RESULTS COMPARISON -------------------------
/COM,
/COM,  TIME   |  TARGET  |   Mechanical APDL   |  RATIO
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A5,' ',E10.4,'  ',E16.4,'   ',F15.3)
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A5,' ',E10.4,'  ',E16.4,'   ',F15.3)
*VWRITE,LABEL(1,3),VALUE(3,1),VALUE(3,2),VALUE(3,3)
(1X,A5,' ',E10.4,'  ',E16.4,'   ',F15.3)
*VWRITE,LABEL(1,4),VALUE(4,1),VALUE(4,2),VALUE(4,3)
(1X,A5,' ',E10.4,'  ',E16.4,'   ',F15.3)
*VWRITE,LABEL(1,5),VALUE(5,1),VALUE(5,2),VALUE(5,3)
(1X,A5,' ',E10.4,'  ',E16.4,'   ',F15.3)
/COM,-----------------------------------------------------------------------
/OUT
*LIST,vm155,vrt
FINISH
```

VM156 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM156
/PREP7
/TITLE, VM156, NATURAL FREQUENCY OF NONLINEAR SPRING-MASS SYSTEM
C***            VIBRATION PROBS. IN ENGR., TIMOSHENKO, 3RD. ED., PAGE 141
C***             USING NONLINEAR SPRING ELEMENT (COMBIN39)
ANTYPE,TRANS                  ! NONLINEAR TRANSIENT DYNAMIC ANALYSIS
ET,1,COMBIN39,,,2             ! ELEMENT WITH DISPLACEMENT ALONG NODAL Y-AXIS
ET,2,MASS21,,,4               ! MASS WITHOUT ROTARY INERTIA
R,1,0.0,0.0,.1,.204,.2,.432   ! SPRING DATA
RMORE,.3,.708,.4,1.056,.5,1.5
RMORE,.6,2.064,.7,2.772,.8,3.648
RMORE,.9,4.716,1.0,6.0
R,2,2588E-6                   ! MASS DATA
N,1
N,2
E,1,2
TYPE,2
REAL,2
E,2
D,1,ALL
D,2,UX
IC,2,UY,-1                    ! INITIAL DISPLACEMENT AND VELOCITY
KBC,1                         ! STEP LOADING
SAVE
FINISH
/SOLU
TRNOPT, , , , , ,HHT
SOLCONTROL,0
CNVTOL,F,1,1E-4               ! FORCE CONVERGENCE CRITERIA
OUTRES,NSOL,1
NSUBST,5
OUTPR,BASIC,NONE
TIME,.0002                    ! TIME TO ALLOW INITIAL CHANGE IN ACCELERATION
LSWRITE                       ! WRITE LOAD STEP FILE 1
NSUBST,40
OUTPR,BASIC,LAST
```

```
TIME,0.18                    ! TIME ARBITRARILY SELECTED
LSWRITE                      ! WRITE LOAD STEP FILE 2
/OUT,SCRATCH
LSSOLVE,1,2,1                ! READ IN 2 LOAD STEPS AND SOLVE
FINISH
/POST26
TIMERANGE,.003,.18
NSOL,2,2,U,Y,2UY
/OUT,
PRVAR,2               ! PRINT DISPLACEMENTS
*GET,PER,VARI,2,EXTREM,TMIN
*status,parm
FINISH
/POST1
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'PERIOD '
LABEL(1,2) = 'sec'
*VFILL,VALUE(1,1),DATA,.1447
*VFILL,VALUE(1,2),DATA,PER
*VFILL,VALUE(1,3),DATA,ABS(PER/.1447)
SAVE,TABLE_1
FINISH
/CLEAR,NOSTART
RESUME,TABLE_1
/OUT,vm156,vrt
/COM,------------------- VM156 RESULTS COMPARISON --------------
/COM,
/COM,     STIF39      |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F13.4,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
/COM,
FINISH
/DELETE,TABLE_1
FINISH
*LIST,vm156,vrt
```

VM157 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM157
/TITLE,VM157, MODAL ANALYSIS OF GAS WITH SUDDEN TEMPERATURE CHANGE
/COM, REFERENCE: OBERG, C.L., RYAN, N.W., BAER, A.D.
/COM, A STUDY OF T-BURNER BEHAVIOR, AIAA VOL. 6 NO. 6
/COM, PP 1131-1137 (1968)

MAT_COLD_DENS = 1.1E-7
MAT_COLD_SONC = 1100*12

DIM_FRACTION  = 0.31
DIM_RADIUS    = 1.5
DIM_LENGTH    = 9
DIM_COLD_LNGT = DIM_LENGTH*DIM_FRACTION
DIM_HOT_LNGT  = DIM_LENGTH-DIM_COLD_LNGT

TMP_OFFSET    = 460
TMP_COLD      = 900-TMP_OFFSET
TMP_HOT       = 4500-TMP_OFFSET
REF_PRESSURE  = 14.7

MAT_HOT_DENS  = MAT_COLD_DENS*(TMP_COLD+TMP_OFFSET)/(TMP_HOT+TMP_OFFSET)
MAT_HOT_SONC  = MAT_COLD_SONC*SQRT((TMP_HOT+TMP_OFFSET)/(TMP_COLD+TMP_OFFSET))

DIM_ELEM_SIZE = MAT_HOT_SONC/3000/50
```

```
/PREP7
ET,1,FLUID30,,1                  ! FLUID30,NO FSI (SYMMETRIC ELEMENT MATRIX)
! *** CORRECT
R,1,REF_PRESSURE
MP,DENS,1,MAT_COLD_DENS          ! DENSITY OF COLD GAS
MP,SONC,1,MAT_COLD_SONC          ! VELOCITY OF COLD GAS
MP,REFT,1,TMP_COLD               ! REFERENCE TEMPERATURE
TOFFST,TMP_OFFSET

CYLIND,,DIM_RADIUS,,DIM_COLD_LNGT,,90
CYLIND,,DIM_RADIUS,DIM_COLD_LNGT,DIM_COLD_LNGT+DIM_HOT_LNGT,,90
VGLUE,ALL

MSHAPE,0
ESIZE,DIM_ELEM_SIZE
VSEL,S,LOC,Z,0,DIM_COLD_LNGT
VMESH,ALL
VSEL,INVE
VMESH,ALL
ALLSEL,ALL
FINISH

/SOLU
ANTYPE,MODAL
MODOPT,LANB,5,,,,ON                  ! LANCZOS EIGENSOLVER
MXPAND,5
VSEL,S,VOLUME,,1,,,1
BFE,ALL,TEMP,,TMP_COLD
BF,ALL,CHRGD,REF_PRESSURE
ALLSEL,ALL
VSEL,S,VOLUME,,3,,,1
BFE,ALL,TEMP,,TMP_HOT
BF,ALL,CHRGD,REF_PRESSURE
ALLSEL,ALL
/OUT,SCRATCH
SOLVE
FINISH

/POST1
/OUT,
SET,1,2
ASEL,S,LOC,Z,DIM_COLD_LNGT+DIM_HOT_LNGT
NSLA,S,1
*GET,OUTPUT_PRES,NODE,NDNEXT(0),PRES
ALLSEL,ALL

*DIM,LABEL,CHAR,1,1
*DIM,VALUE,,1,3

LABEL(1,1) = 'AMPLITUDE'
*VFILL,VALUE(1,1),DATA,0.45
*VFILL,VALUE(1,2),DATA,ABS(OUTPUT_PRES)
*VFILL,VALUE(1,3),DATA,ABS(0.45/OUTPUT_PRES)

/OUTPUT,vm157,vrt
/COM,-----------------------VM157 RESULTS COMPARISON -----------------------
/COM,
/COM, NORMALIZED MODES (PRESSURE) CALCULATED
/COM, RATIO OF HOT END TO COLD END AMPLITUDES
/COM,
/COM,      |  TARGET  |  Mechanical APDL |  RATIO
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A3,' ',F10.3,' ',F13.3,' ',F15.3)
/COM,
/COM,-----------------------------------------------------------------------
/OUTPUT
*LIST,vm157,vrt
FINISH
```

VM158 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM158
/PREP7
MP,PRXY,,0.3
/TITLE, VM158, MOTION OF A BOBBING BUOY
C***            ELEMENTARY THEORETICAL FLUID MECHANICS, BRENKERT, PAGE 37
ANTYPE,TRANS
NLGEOM,ON                      ! LARGE DISPLACEMENTS
ET,1,PIPE288
SECTYPE,1,PIPE
SECDATA,1,.03                   ! DIAMETER, WALL THICKNESS
MP,EX,1,21E10
MP,DENS,1,8000
MP,PRXY,1,0.3
MP,DENS,2,1000
N,1,,,-9
N,7,,,1
FILL
E,1,2
EGEN,6,1,1
FINISH
/SOLU
NSUBST,20                      ! 20 SUBSTEPS
CNVTOL,U                       ! CONVERGENCE BASED ON DISPLACEMENTS
CNVTOL,F                       ! CONVERGENCE BASED ON FORCES
OUTPR,BASIC,LAST
OUTRES,NSOL,1
KBC,1
ALPHAD,3                       ! MASS DAMPING FOR SLOW DYNAMICS
ACEL,,,9.807
OCTYPE,BASIC,one
OCDATA,30,2,,1                 ! DEPTH, WATER DENSITY
OCTABLE,,,.3,.3,.3,0           ! DRAG COEFFICIENT
D,1,UX,,,7,,UY,ROTX,ROTY,ROTZ ! CONSTRAIN ALL BUT UZ DOF
TIME,30
/OUT,SCRATCH
SOLVE
FINISH
/POST26
NSOL,2,1,U,Z
/OUT,
PRVAR,2
/GRID,1
/AXLAB,Y,DISP
PLVAR,2                        ! DISPLAY TOP DISPLACEMENT VS. TIME
*GET,DISP,VARI,2,RTIME,30
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'DISP '
LABEL(1,2) = 'm '
*VFILL,VALUE(1,1),DATA,-.312
*VFILL,VALUE(1,2),DATA,DISP
*VFILL,VALUE(1,3),DATA,ABS(DISP/.312)
/COM
/OUT,vm158,vrt
/COM,------------------- VM158 RESULTS COMPARISON -------------
/COM,
/COM,              |    TARGET   |    ANSYS    |    RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F10.3,'   ',1F6.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm158,vrt
```

VM159 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM159
/PREP7
/TITLE, VM159, TEMPERATURE CONTROLLED HEATER
C***           REFERENCE - SELF-CHECKING (RESPONSE FOLLOWS INPUT REQUEST)
ANTYPE,TRANS
ET,1,MASS71,,,1            ! THERMAL MASS
ET,2,LINK34                ! CONVECTION ELEMENT
ET,3,COMBIN37,,,8,,1       ! CONTROL ELEMENT
R,1,2.7046E-4              ! THERMAL CAPACITANCE OF HEATER
R,2,2.7046E-3              ! THERMAL CAPACITANCE OF BOX
R,3,8.1812E-3              ! SURFACE AREA OF HEATER
R,4,4.1666E-2              ! SURFACE AREA OF BOX
R,5,,,,100,125,-10         ! CONTROL TEMPERATURES, HEAT FLOW
RMORE,,1                   ! INITIAL CONTROL STATUS (ON)
MP,HF,1,4
N,1
*REPEAT,4,1
E,1                        ! HEATER
TYPE,2
REAL,3
E,1,2                      ! CONVECTION LINK
TYPE,1
REAL,2
E,2                        ! BOX
TYPE,3
REAL,5
E,4,1,2                    ! CONTROL
TYPE,2
REAL,4
E,2,3                      ! CONVECTION LINK
FINISH
/SOLU
SOLCONTROL,0
TIME,.2
IC,1,TEMP,70               ! UNIFORM STARTING TEMPERATURE
IC,2,TEMP,70
KBC,1
D,3,TEMP,70
D,4,TEMP,0
AUTOTS,ON
OUTPR,,10
OUTRES,,ALL
DELTIM,0.001
/OUT,SCRATCH
SOLVE
FINISH
/POST26
NSOL,2,1,TEMP
NSOL,3,2,TEMP
ESOL,4,4,,NMISC,1,STAT
/OUT,
PRVAR,2,3,4
/GRID,1                   ! DISPLAY BOX TEMP VS. TIME
/AXLAB,Y,TEMP
PLVAR,3
/GRID,0                   ! DISPLAY STATUS VS. TIME
/AXLAB,Y,STAT
PLVAR,4
FINISH
/OUT,vm159,vrt
/COM,----------------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM159  NOT CONTAINED IN
/COM,THIS TABLE
/COM,----------------------------------------------------------------
/OUT
FINISH
```

```
*LIST,vm159,vrt
```

VM160 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM160
/PREP7
/TITLE, VM160, SOLID CYLINDER WITH HARMONIC TEMPERATURE LOAD
C***    HILDEBRAND, ADVANCED CALCULUS FOR APPLICATIONS, PAGE 447
ET,1,PLANE78               ! AXISYMMETRIC THERMAL SOLID
MP,KXX,1,1
N,1
N,9,20
FILL
NGEN,3,10,1,9,1,,2.5
E,1,3,23,21,2,13,22,11
EGEN,4,2,1
D,9,TEMP,80,,29,10         ! PEAK TEMPERATURE AT THETA=0
MODE,2,1                   ! SYMMETRIC MODE WITH 2 WAVES AROUND PERIPHERY
FINISH
/SOLU
OUTPR,ALL,LAST             ! PRINTOUT ELEMENT SOLUTION
/OUT,SCRATCH
SOLVE
FINISH
/POST1
SET,1,1,,,,0.0             ! STORE SOLUTION DATA AT 0 DEGREES
/OUT,
NSEL,S,NODE,,1,9           ! SELECT NODES 1-9
*GET,T1,NODE,1,TEMP
*GET,T2,NODE,3,TEMP
*GET,T3,NODE,5,TEMP
*GET,T4,NODE,7,TEMP
PRNSOL,TEMP                ! PRINT TEMPERATURE
SET,1,1,,,,90.0            ! STORE SOLUTION DATA AT 90 DEGREES
*GET,T5,NODE,1,TEMP
*GET,T6,NODE,3,TEMP
*GET,T7,NODE,5,TEMP
*GET,T8,NODE,7,TEMP
PRNSOL,TEMP                ! PRINT TEMPERATURE
*status,parm
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'T (ND=1) ','T (ND=3) ','T (ND=5) ','T (ND=7)'
LABEL(1,2) = 'F','F','F','F'
*VFILL,VALUE(1,1),DATA,0,5,20,45
*VFILL,VALUE(1,2),DATA,T1,T2,T3,T4
*VFILL,VALUE(1,3),DATA,ABS(0),ABS(T2/5),ABS(T3/20),ABS(T4/45)
/COM
/OUT,vm160,vrt
/COM,------------------- VM160 RESULTS COMPARISON -------------
/COM,
/COM,THETA=0       |      TARGET   |     Mechanical APDL    |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F13.1,'   ',1F18.3)
/NOPR
*VFILL,VALUE(1,1),DATA,0,-5,-20,-45
*VFILL,VALUE(1,2),DATA,T5,T6,T7,T8
*VFILL,VALUE(1,3),DATA,ABS(0),ABS(T6/5),ABS(T7/20),ABS(T8/45)
/GOPR
/COM,
/COM,THETA=90      |      TARGET   |     Mechanical APDL    |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F13.1,'   ',1F18.3)
/COM,-----------------------------------------------------------
/OUT
```

```
FINISH
*LIST,vm160,vrt
```

VM161 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM161
/PREP7
/TITLE, VM161, HEAT FLOW FROM AN INSULATED PIPE
C***  PRINCIPLES OF HEAT TRANSFER, KREITH, 2ND. PRINTING, PAGE 36, EX. 2-7
ANTYPE,STATIC
ET,1,SOLID90
MP,KXX,1,25
MP,KXX,2,.11
CSYS,1                      ! CYLINDRICAL C.S.
N,1,.12791666
N,2,.14583333
N,3,.1875
NGEN,3,3,1,3,1,,15
NGEN,3,10,1,9,1,,,.5
E,1,21,27,7,2,22,28,8
EMORE,11,24,17,4,12,25,18,5
EMORE,30,34,36,32
EGEN,2,1,1
MAT,2
EMODIF,2
NSEL,S,LOC,X,.12791666
SF,ALL,CONV,40,300          ! CONVECTION ON THE INSIDE
NSEL,S,LOC,X,.1875
SF,ALL,CONV,4,80            ! CONVECTION ON THE OUTSIDE
NSEL,ALL
OUTPR,,1
FINISH
/SOLU
/OUT,SCRATCH
SOLVE
FINISH
/POST1
SET,1,1
/OUT,
ESEL,S,ELEM,,1,1
FSUM,HEAT
*GET,Q1,FSUM,0,ITEM,HEAT
*SET,Q,ABS((Q1*360/30))
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'q '
LABEL(1,2) = 'BTU/hr'
*VFILL,VALUE(1,1),DATA,362
*VFILL,VALUE(1,2),DATA,Q
*VFILL,VALUE(1,3),DATA,ABS(Q/362)
/COM
/OUT,vm161,vrt
/COM,------------------- VM161 RESULTS COMPARISON -------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F13.1,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm161,vrt
```

VM162 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM162
/PREP7
/TITLE, VM162, CIRCULAR COOLING FIN OF RECTANGULAR PROFILE
C***      CONDUCTION HEAT TRANSFER, SCHNEIDER, 2ND. PRINTING, PAGE 82, ART. 4-10
ANTYPE,STATIC
ET,1,SOLID90
MP,KXX,1,15
CSYS,1
N,1,.04167
N,9,.0625
FILL
NGEN,3,10,1,9,1,,2.5
NGEN,3,30,1,29,1,,,.002604
E,1,3,23,21,61,63,83,81
EMORE,2,13,22,11,62,73,82,71
EMORE,31,33,53,51
EGEN,4,2,1
OUTPR,,1
D,1,TEMP,100,,81,10
NSEL,S,LOC,Z
SF,ALL,CONV,100,0.0
NSEL,S,LOC,Z,0.005208
SF,ALL,CONV,100,0.0
NSEL,S,LOC,X,0.0625
SF,ALL,CONV,100,0.0
NSEL,ALL
FINISH
/SOLU
/OUT,SCRATHC
SOLVE
FINISH
/POST1
SET,LAST
/OUT,
*GET,T,NODE,29,TEMP
FSUM,HEAT
*GET,Q1,FSUM,0,ITEM,HEAT
*SET,Q,ABS((Q1*360/5))
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'T2 ','q '
LABEL(1,2) = 'F','BTU/hr'
*VFILL,VALUE(1,1),DATA,53.22,102.05
*VFILL,VALUE(1,2),DATA,T,Q
*VFILL,VALUE(1,3),DATA,ABS(T/53.22),ABS(Q/102.05)
/COM
/OUT,vm162,vrt
/COM,------------------- VM162 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F13.2,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm162,vrt
```

VM163 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM163
```

```
/PREP7
SMRT,OFF
/TITLE, VM163 GROUNDWATER SEEPAGE
C***          A SIMPLE GUIDE TO FINITE ELEMENTS, R.J.OWEN AND E. HINTON, P.89
ANTYPE,STATIC             ! THERMAL ANALYSIS
ET,1,PLANE55,,,1,,,,1     ! AXISYMMETRIC, SUPRESS ALL PRINTOUT
MP,KXX,1,0.864            ! PERMEABILITY
K,1
*REPEAT,3,1,,3.5
KGEN,2,1,3,1,8.0
KGEN,2,1,2,1,18.0
K,9,18,10
K,10,8,10
K,11,8.0,3.5
L,1,4                     ! DEFINE LINE SEGMENTS AND MESH DIVISIONS
*REPEAT,3,1,1
L,10,9
L,11,8
L,4,7
LESIZE,ALL,,,8
A,1,4,5,2
A,2,5,6,3
A,4,7,8,5
A,11,8,9,10
ESIZE,,5
MSHK,2                    ! MAPPED AREA MESH IF POSSIBLE
MSHA,0,2D                 ! USING QUADS
AMESH,ALL                 ! MESH AREAS
NUMMRG,NODE               ! MERGE NODES AT BOTTOM OF CAISSON
NSEL,S,LOC,Y,7.0
D,ALL,TEMP,0
NSEL,S,LOC,Y,10
D,ALL,TEMP,3              ! PRESSURE HEAD
NSEL,ALL
FINISH
/SOLU
SOLVE
FINISH
/POST1
/CLABEL,,1
/CONTOUR,,20
/EDGE,,1
PLNSOL,TEMP          ! DISPLAY PRESSURE CONTOURS
/VSCALE,,-1
PLVECT,TG            ! DISPLAY THERMAL GRADIENT VECTORS
NSEL,S,LOC,Y,7.0
PRRSOL,HEAT          ! PRINT FLOWRATE THROUGH SOIL
FSUM,HEAT
*GET,Q1,FSUM,0,ITEM,HEAT
*SET,Q,(Q1/(2*3.14159265))
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'q '
LABEL(1,2) = 'CUBm/DAY'
*VFILL,VALUE(1,1),DATA,8.6
*VFILL,VALUE(1,2),DATA,Q
*VFILL,VALUE(1,3),DATA,ABS(Q/8.6)
/COM
/OUT,vm163,vrt
/COM,------------------- VM163 RESULTS COMPARISON -------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F13.1,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm163,vrt
```

VM164 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM164
/PREP7
/TITLE, VM164, DRYING OF A THICK WOODEN SLAB (DIFFUSION)
C***     HEAT, MASS AND MOMENTUM TRANS., ROHSENOW AND CHOI, 2ND. PR., PAGE 392
ANTYPE,TRANS
ET,1,LINK33
R,1,1                ! ARBITRARY AREA
MP,KXX,1,4E-5        ! DIFFUSION COEFFICIENT D
MP,DENS,1,1          ! ARBITRARY DENSITY AND CAPACITANCE
MP,C,1,1
N,1
N,11,(1/12)
FILL
E,1,2
EGEN,10,1,1
TUNIF,30             ! INITIAL MOISTURE CONCENTRATION (THAT OF WOOD)
D,11,TEMP,5          ! FINAL MOISTURE CONCENTRATION (AMBIENT)
FINISH
/SOLU
SOLCONTROL,0
AUTOTS,ON
OUTPR,,LAST
DELTIM,0.434
TIME,127             ! TIME AT END OF LOAD STEP
KBC,1                ! STEP BOUNDARY CONDITIONS
/OUT,SCRATCH
SOLVE
/POST1
SET,LAST
/OUT,
*GET,T,NODE,1,TEMP
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = '      C '
LABEL(1,2) = ' % '
*VFILL,VALUE(1,1),DATA,10
*VFILL,VALUE(1,2),DATA,T
*VFILL,VALUE(1,3),DATA,ABS(T/10)
/COM
/OUT,vm164,vrt
/COM,------------------- VM164 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F13.1,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm164,vrt
```

VM165 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM165
/PREP7
SMRT,OFF
/TITLE, VM165, CURRENT CARRYING FERROMAGNETIC CONDUCTOR
C***           PRINCIPLES OF ELECTRIC AND MAGNETIC FIELDS, BOAST, PAGE 225
ET,1,PLANE13           ! 2-D COUPLED FIELD SOLID
ET,2,INFIN9            ! 2-D INFINITE BOUNDARY ELEMENT
EMUNIT,MKS             ! MKS UNITS
```

```
MP,MURX,1,1             ! SET RELATIVE PERMEABILITY FOR AIR TO 1
TB,BH,2                 ! B-H CURVE FOR MATERIAL 2
TBPT,,150,.21           ! H AND B RESPECTIVELY
TBPT,,300,.55
TBPT,,460,.80
TBPT,,640,.95
TBPT,,720,1.0
TBPT,,890,1.1
TBPT,,1020,1.15
TBPT,,1280,1.25
TBPT,,1900,1.40
TBPLOT,BH,2
TBPLOT,NB,2
/WIND,1,TOP
/WIND,2,BOTTOM
/GTYPE,1,GRPH,1
/GTYPE,2,GRPH,1
/GCMD,1,TBPLOT,BH,2
/GCMD,2,TBPLOT,NB,2
GPLOT
/WIND,2,OFF
/WIND,1,FULL
SF=.0254                ! SET CONVERSION (INCHES TO METERS)
CSYS,1
K,1
K,2,.3,-2.5             ! INNER RADIUS OF RING
K,3,.45,-2.5            ! OUTER RADIUS OF RING
K,4,.75,-2.5            ! OUTER RADIUS OF SURROUNDING AIR
KPSCALE,ALL,,,SF,,,,,1 ! MOVE ORIGINAL KEYPOINTS TO NEW POSITION
CSYS,0
L,1,2
LESIZE,1,,,5
L,2,3
LESIZE,2,,,6
L,3,4
LSYMM,2,ALL
NUMMRG,KP               ! MERGE KEYPOINTS
L,4,8                   ! DEFINE OUTER RADIUS LINE SEGMENT
LESIZE,7,,,1
TYPE,2
ESIZE,,,1
LMESH,7                 ! MESH LINE SEGMENT (WITH BOUNDARY ELEMENT)
A,2,6,1,1
A,2,3,7,6
A,3,4,8,7
ASEL,S,AREA,,2
AATT,2                  ! ASSIGN MATERIAL 2 TO STEEL AREA
ASEL,ALL
ESIZE,,1                ! DEFAULT ELEMENT DIVISIONS=1
TYPE,1
AMESH,1,2
AMESH,3
FINISH
/SOLU                   ! ENTER SOLVER
BFA,2,JS,,,438559       ! APPLY CURRENT DENSITY JS(Z)
MAGSOLV
FINISH
/POST1
CSYS,1
NSEL,S,LOC,X,.325*SF
NSEL,A,LOC,X,.375*SF
NSEL,A,LOC,X,.425*SF
RSYS,1                  ! SET RESULTS C.S. TO CYLINDRICAL
PRNSOL,B,COMP           ! PRINT NODAL FLUX DENSITY
*GET,B1,NODE,21,B,SUM
*GET,B2,NODE,23,B,SUM
*GET,B3,NODE,25,B,SUM
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = '@ R=','@ R=','@ R='
LABEL(1,2) = '.325','.375','.425'
*VFILL,VALUE(1,1),DATA,.48,1.03,1.22
```

```
*VFILL,VALUE(1,2),DATA,B1,B2,B3
*VFILL,VALUE(1,3),DATA,ABS(B1/.48),ABS(B2/1.03),ABS(B3/1.22)
/COM
/OUT,vm165,vrt
/COM,------------------- VM165 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,PLANE13
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F13.2,'   ',1F15.3)
/OUT
FINISH

/CLEAR,NOSTART
/NOPR
/PREP7
SMRT,OFF
/TITLE, VM165, CURRENT CARRYING FERROMAGNETIC CONDUCTOR
ET,1,PLANE233          ! 2-D MAGNETIC SOLID
ET,2,INFIN9            ! 2-D INFINITE BOUNDARY ELEMENT
EMUNIT,MKS             ! MKS UNITS
MP,MURX,1,1            ! SET RELATIVE PERMEABILITY FOR AIR TO 1
TB,BH,2                ! B-H CURVE FOR MATERIAL 2
TBPT,,150,.21          ! H AND B RESPECTIVELY
TBPT,,300,.55
TBPT,,460,.80
TBPT,,640,.95
TBPT,,720,1.0
TBPT,,890,1.1
TBPT,,1020,1.15
TBPT,,1280,1.25
TBPT,,1900,1.40
TBPLOT,BH,2
TBPLOT,NB,2
/WIND,1,TOP
/WIND,2,BOTTOM
/GTYPE,1,GRPH,1
/GTYPE,2,GRPH,1
/GCMD,1,TBPLOT,BH,2
/GCMD,2,TBPLOT,NB,2
GPLOT
/WIND,2,OFF
/WIND,1,FULL
SF=.0254               ! SET CONVERSION (INCHES TO METERS)
CSYS,1
K,1
K,2,.3,-2.5            ! INNER RADIUS OF RING
K,3,.45,-2.5           ! OUTER RADIUS OF RING
K,4,.75,-2.5           ! OUTER RADIUS OF SURROUNDING AIR
KPSCALE,ALL,,,SF,,,,,1 ! MOVE ORIGINAL KEYPOINTS TO NEW POSITION
CSYS,0
L,1,2
LESIZE,1,,,5
L,2,3
LESIZE,2,,,6
L,3,4
LSYMM,2,ALL
NUMMRG,KP              ! MERGE KEYPOINTS
L,4,8                  ! DEFINE OUTER RADIUS LINE SEGMENT
LESIZE,7,,,1
TYPE,2
ESIZE,,,1
LMESH,7                ! MESH LINE SEGMENT (WITH BOUNDARY ELEMENT)
A,2,6,1,1
A,2,3,7,6
A,3,4,8,7
ASEL,S,AREA,,2
AATT,2                 ! ASSIGN MATERIAL 2 TO STEEL AREA
ASEL,ALL
ESIZE,,1               ! DEFAULT ELEMENT DIVISIONS=1
TYPE,1
AMESH,1,2
```

```
AMESH,3
FINISH

/SOLU                   ! ENTER SOLVER
BFA,2,JS,,,438559       ! APPLY CURRENT DENSITY JS(Z)
SOLVE
FINISH

/POST1
CSYS,1
NSEL,S,LOC,X,.325*SF
NSEL,A,LOC,X,.375*SF
NSEL,A,LOC,X,.425*SF
RSYS,1                  ! SET RESULTS C.S. TO CYLINDRICAL
PRNSOL,B,COMP           ! PRINT NODAL FLUX DENSITY
*GET,B1,NODE,44,B,SUM
*GET,B2,NODE,48,B,SUM
*GET,B3,NODE,52,B,SUM
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = '@ R=','@ R=','@ R='
LABEL(1,2) = '.325','.375','.425'
*VFILL,VALUE(1,1),DATA,.48,1.03,1.22
*VFILL,VALUE(1,2),DATA,B1,B2,B3
*VFILL,VALUE(1,3),DATA,ABS(B1/.48),ABS(B2/1.03),ABS(B3/1.22)
/COM
/OUT,vm165,vrt,,APPEND
/COM,PLANE233
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F13.2,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm165,vrt
```

VM166 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM166
/PREP7
SMRT,OFF
/TITLE, VM166, LONG CYLINDER IN A SINUSOIDAL MAGNETIC FIELD
/COM,   ELECTROMAGNETIC WORKSHOP, RAL-86-049, EMSON, PAGE 39
ANTYPE,HARMIC                    ! FULL HARMONIC ANALYSIS
ET,1,PLANE13                     ! 2-D COUPLED-FIELD SOLID (AZ DOF)
EMUNIT,MKS                       ! MKS UNITS
MP,MURX,1,1                      ! RELATIVE PERMEABILITY - AIR
MP,MURX,2,1                      ! RELATIVE PERMEABILITY - ALUMINUM
MP,RSVZ,2,(1/25380711)           ! RESISTIVITY - ALUMINUM
K,1
K,2,.03
K,3,.03,.03
K,4,,.03
CSYS,1
K,5,.05715
K,6,.05715,45
K,7,.05715,90
KGEN,2,5,7,1,.0127
KGEN,2,8,10,1,.77015
L,2,5
*REPEAT,3,1,1
L,5,8
*REPEAT,3,1,1
L,8,11
*REPEAT,3,1,1
CSYS,0
A,1,2,3,4                        ! DEFINE AREAS
CSYS,1
```

```
A,2,5,6,3
*REPEAT,3,3,3,3,3
A,3,6,7,4
*REPEAT,3,3,3,3,3
ASEL,S,AREA,,3,6,3
AATT,2
ASEL,ALL
LESIZE,1,,,4,.5                  ! DEFINE LINE SEGMENTS AND DIVISIONS
*REPEAT,3,1
LESIZE,4,,,5
*REPEAT,3,1
LESIZE,7,,,9,25
*REPEAT,3,1
MSHK,1                     ! MAPPED AREA MESH
MSHA,0,2D                  ! USING QUADS
ESIZE,,6
AMESH,ALL
PI=3.141592654
DTH=(7.5*PI)/180.                ! THETA INCREMENT
*DO,THP,0,90,3.75                ! IMPOSE EXTERIOR NODAL POTENTIALS
  NSEL,S,LOC,X,.83,.85           ! SELECT NODES AT OUTERMOST RADIUS
  NSEL,R,LOC,Y,(THP-1.),(THP+1.)
  TH=(THP*PI)/180
  VAL=-(COS(TH)*.084)            ! CALCULATE POTENTIAL
  D,ALL,AZ,VAL
  NSEL,ALL
*ENDDO
CSYS,0
NSEL,S,LOC,X,0
D,ALL,AZ,0                       ! IMPOSE DIRICHLET BOUNDARY CONDITION
NSEL,ALL
HARFRQ,60                        ! SET FREQUENCY = 60 HZ
FINI
/SOLU
SOLVE
FINI
/POST1
SET,1                            ! REAL RESULTS
NSEL,S,NODE,,1
PRNSOL,B,COMP                    ! PRINT NODAL REAL FLUX DENSITY AT ORIGIN
*GET,BR1,NODE,1,B,X
*GET,BR2,NODE,1,B,Y
SET,1,1,,1                       ! IMAGINARY RESULTS
PRNSOL,B,COMP                    ! PRINT NODAL IMAGINARY FLUX DENSITY AT ORIGIN
*GET,BI1,NODE,1,B,X
*GET,BI2,NODE,1,B,Y
ESEL,S,MAT,,2
POWERH    ! CALCULATE TIME-AVERAGE POWER LOSS
*DIM,LABEL,CHAR,5,2
*DIM,VALUE,,5,3
LABEL(1,1) = 'BX REAL ','BY REAL ','BX IM ','BY IM ','PWR LOSS '
LABEL(1,2) = 'T','T','T','T','W/m'
*VFILL,VALUE(1,1),DATA,0,-.00184,0,-.02102,2288
*VFILL,VALUE(1,2),DATA,BR1,BR2,BI1,BI2,PAVG
*VFILL,VALUE(1,3),DATA,1,ABS(BR2/.00184),1,ABS(BI2/.02102),ABS(PAVG/2288)
/OUT,vm166,vrt
/COM,------------------- VM166 RESULTS COMPARISON --------------
/COM,
/COM,RESULTS AT ORIGIN
/COM,
/COM,                |   TARGET   |   Mechanical APDL   |   RATIO
/COM,PLANE13
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F13.4,'   ',1F15.3)
/OUT
FINISH

/CLEAR,NOSTART
/NOPR
/PREP7
SMRT,OFF
ET,1,PLANE233,1,2                ! 2-D LF EMAG SOLID (AZ,VOLT DOF)
```

```
MP,MURX,1,1                       ! RELATIVE PERMEABILITY - AIR
MP,MURX,2,1                       ! RELATIVE PERMEABILITY - ALUMINUM
MP,RSVX,1,1.E9                    ! RESISTIVITY - AIR
MP,RSVX,2,(1/25380711)            ! RESISTIVITY - ALUMINUM
K,1
K,2,.03
K,3,.03,.03
K,4,,.03
CSYS,1
K,5,.05715
K,6,.05715,45
K,7,.05715,90
KGEN,2,5,7,1,.0127
KGEN,2,8,10,1,.77015
L,2,5
*REPEAT,3,1,1
L,5,8
*REPEAT,3,1,1
L,8,11
*REPEAT,3,1,1
CSYS,0
A,1,2,3,4                         ! DEFINE AREAS
CSYS,1
A,2,5,6,3
*REPEAT,3,3,3,3,3
A,3,6,7,4
*REPEAT,3,3,3,3,3
ASEL,S,AREA,,3,6,3
AATT,2
ASEL,ALL
LESIZE,1,,,4,.5                   ! DEFINE LINE SEGMENTS AND DIVISIONS
*REPEAT,3,1
LESIZE,4,,,5
*REPEAT,3,1
LESIZE,7,,,9,25
*REPEAT,3,1
MSHK,1                            ! MAPPED AREA MESH
MSHA,0,2D                         ! USING QUADS
ESIZE,,6
AMESH,ALL
PI=3.141592654
DTH=(7.5*PI)/180.                 ! THETA INCREMENT
*DO,THP,0,90,3.75                 ! IMPOSE EXTERIOR NODAL POTENTIALS
  NSEL,S,LOC,X,.83,.85            ! SELECT NODES AT OUTERMOST RADIUS
  NSEL,R,LOC,Y,(THP-1.),(THP+1.)
  TH=(THP*PI)/180
  VAL=-(COS(TH)*.084)             ! CALCULATE POTENTIAL
  D,ALL,AZ,VAL
  NSEL,ALL
*ENDDO
CSYS,0
NSEL,S,LOC,X,0
D,ALL,AZ,0                        ! IMPOSE DIRICHLET BOUNDARY CONDITION
NSEL,ALL
FINI

/SOLU
ANTYPE,HARMIC                     ! FULL HARMONIC ANALYSIS
HARFRQ,60                         ! SET FREQUENCY = 60 HZ
D,ALL,VOLT,0
SOLVE
FINI

/POST1
SET,1                             ! REAL RESULTS
NSEL,S,NODE,,1
PRNSOL,B,COMP                     ! PRINT NODAL REAL FLUX DENSITY AT ORIGIN
*GET,BR1,NODE,1,B,X
*GET,BR2,NODE,1,B,Y
SET,1,1,,1                        ! IMAGINARY RESULTS
PRNSOL,B,COMP                     ! PRINT NODAL IMAGINARY FLUX DENSITY AT ORIGIN
*GET,BI1,NODE,1,B,X
```

```
*GET,BI2,NODE,1,B,Y
ESEL,S,MAT,,2
POWERH    ! CALCULATE TIME-AVERAGE POWER LOSS
*DIM,LABEL,CHAR,5,2
*DIM,VALUE,,5,3
LABEL(1,1) = 'BX REAL ','BY REAL ','BX IM ','BY IM ','PWR LOSS '
LABEL(1,2) = 'T','T','T','T','W/m'
*VFILL,VALUE(1,1),DATA,0,-.00184,0,-.02102,2288
*VFILL,VALUE(1,2),DATA,BR1,BR2,BI1,BI2,PAVG
*VFILL,VALUE(1,3),DATA,1,ABS(BR2/.00184),1,ABS(BI2/.02102),ABS(PAVG/2288)
/COM,
/OUT,vm166,vrt,,APPEND
/COM,PLANE233
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F13.4,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm166,vrt
```

VM167 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM167
/PREP7
/TITLE, VM167, TRANSIENT EDDY CURRENTS IN A SEMI-INFINITE SOLID
/COM,   HOLMAN, J.P., 'HEAT TRANSFER', 4TH EDITION, MCGRAW HILL,
/COM,   INC., 1976, PAGE 104, EQN. 4-14 (ANALOGOUS FIELD SOLUTION)
ET,1,PLANE13                        ! 2-D COUPLED-FIELD SOLID, AZ DOF
EMUNIT,MKS                          ! MKS UNITS
MP,MURX,1,1                         ! RELATIVE PERMEABILITY - AIR
MP,MURX,2,1                         ! RELATIVE PERMEABILITY - ALUMINUM
MP,RSVX,2,4E-7                      ! RESISTIVITY - ALUMINUM
N,1
N,41,20
FILL,1,41,,,,,,20
NGEN,2,50,1,41,1,,.4
MAT,2
E,1,2,52,51
EGEN,40,1,-1
FINISH
/SOLU
ANTYPE,TRANS                        ! TRANSIENT ANALYSIS
NSEL,S,LOC,X,0
D,ALL,AZ,2                          ! APPLY STEP POTENTIAL
NSEL,INVE
IC,ALL,AZ,0                         ! INITIAL CONDITION ON REMAINING POTENTIALS
NSEL,S,LOC,X,20
D,ALL,AZ,0                          ! SET FAR-FIELD POTENTIAL TO ZERO
NSEL,ALL
KBC,1                               ! STEPPED BOUNDARY CONDITIONS
DELTIM,.0002,.0002,.005             ! DEFINE TIME STEP SIZES
AUTOTS,ON                           ! AUTO TIME-STEPPING
TIME,.15                            ! TIME AT END OF 1ST LOAD STEP
OUTRES,ALL,ALL
SOLVE
DELTIM,,,,ON                        ! CARRY OVER TIME STEP USED PREVIOUSLY
TIME,.24                            ! TIME AT END OF 2ND LOAD STEP
SOLVE
FINISH
/POST26
NSOL,2,4,A,Z                        ! STORE NODE 4 VECTOR POTENTIAL
NSOL,3,6,A,Z                        ! STORE NODE 6 VECTOR POTENTIAL
NSOL,4,8,A,Z                        ! STORE NODE 8 VECTOR POTENTIAL
DERIV,5,2                           ! CALCULATE DA/DT
DERIV,6,3
DERIV,7,4
ADD,5,5,,,JEDDY_4,,,-.25E7          ! FIND EDDY CURRENT, -(DA/DT)/(RESISTIVITY)
```

```
ADD,6,6,,,JEDDY_6,,,-.25E7
ADD,7,7,,,JEDDY_8,,,-.25E7
SOLU,8,DTIM                          ! STORE TIME STEP SIZE
SOLU,9,RESE                          ! STORE RESPONSE EIGENVALUE
SOLU,10,NCMIT                        ! STORE NO. OF CUMULATIVE ITERATIONS
STORE,MERGE                          ! MERGE DATA WITH PREVIOUSLY STORED DATA
/AXLAB,Y,A
/GROPT,AXNSC,2.0
PLVAR,2,3,4                          ! DISPLAY VECTOR POTENTIAL VS. TIME
/AXLAB,Y,EDDY
PLVAR,5,6,7                          ! DISPLAY EDDY CURRENT DENSITY VS. TIME
PRVAR,2,3,4,5,6,7                    ! PRINT VALUES
*GET,V1,VARI,2,RTIME,.15
*GET,V2,VARI,3,RTIME,.15
*GET,V3,VARI,4,RTIME,.15
*GET,E1,VARI,5,RTIME,.15
*GET,E2,VARI,6,RTIME,.15
*GET,E3,VARI,7,RTIME,.15
PRVAR,8,9,10                         ! PRINT SOLUTION SUMMARY DATA
FINISH
/POST1
NSEL,S,NODE,,4,8,2
ESLN,S,0
SET,,,,,.15                          ! SELECT ITERATION AT TIME=.15
PRITER
PRNSOL,B,COMP                        ! PRINT NODAL FLUX DENSITY
*GET,F1,NODE,4,B,Y
*GET,F2,NODE,6,B,Y
*GET,F3,NODE,8,B,Y
*STATUS,PARM
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = '@ X=','@ X=','@ X='
LABEL(1,2) = '.2517','.4574','.6914'
*VFILL,VALUE(1,1),DATA,.831,.282,.05
*VFILL,VALUE(1,2),DATA,V1,V2,V3
*VFILL,VALUE(1,3),DATA,ABS(V1/.831),ABS(V2/.282),ABS(V3/.05)
/COM
/OUT,vm167,vrt
/COM,------------------- VM167 RESULTS COMPARISON ---------------
/COM,
/COM,                    |   TARGET   |   Mechanical APDL   |   RATIO
/COM,PLANE13
/COM,
/COM,VECTOR POTENTIALS (WB/M)
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F14.3,'  ',F18.3,'   ',1F17.3)
/NOPR
*VFILL,VALUE(1,1),DATA,3.707,1.749,.422
*VFILL,VALUE(1,2),DATA,F1,F2,F3
*VFILL,VALUE(1,3),DATA,ABS(F1/3.707),ABS(F2/1.749),ABS(F3/.422)
/COM,
/COM,FLUX DENSITY (T)
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F14.3,'  ',F18.3,'   ',1F17.3)
/NOPR
*VFILL,VALUE(1,1),DATA,-.777E7,-.663E7,-.243E7
*VFILL,VALUE(1,2),DATA,E1,E2,E3
*VFILL,VALUE(1,3),DATA,ABS(E1/(.777E7)),ABS(E2/(.663E7)),ABS(E3/(.243E7))
/COM,
/COM,EDDY CURRENT DENSITY (A/M/M)
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F14.0,'  ',F18.0,'   ',1F17.3)
/COM,-----------------------------------------------------------
/OUT
FINISH

/CLEAR,NOSTART
/NOPR
/PREP7
/TITLE, VM167, TRANSIENT EDDY CURRENTS IN A SEMI-INFINITE SOLID
ET,1,PLANE233,1,2                    ! 2-D LF EMAG SOLID (AZ,VOLT DOF)
```

```
MP,MURX,1,1                           ! RELATIVE PERMEABILITY - AIR
MP,MURX,2,1                           ! RELATIVE PERMEABILITY - ALUMINUM
MP,RSVX,2,4E-7                        ! RESISTIVITY - ALUMINUM
MP,RSVX,1,1.E9                        ! RESISTIVITY - AIR
N,1
N,41,20
FILL,1,41,,,,,,20
NGEN,2,50,1,41,1,,.4
MAT,2
E,1,2,52,51
EGEN,40,1,-1
FINISH
/SOLU
D,ALL,VOLT,0
ANTYPE,TRANS                          ! TRANSIENT ANALYSIS
NSEL,S,LOC,X,0
D,ALL,AZ,2                            ! APPLY STEP POTENTIAL
NSEL,INVE
IC,ALL,AZ,0                           ! INITIAL CONDITION ON REMAINING POTENTIALS
NSEL,S,LOC,X,20
D,ALL,AZ,0                            ! SET FAR-FIELD POTENTIAL TO ZERO
NSEL,ALL
KBC,1                                 ! STEPPED BOUNDARY CONDITIONS
DELTIM,.0002,.0002,.005               ! DEFINE TIME STEP SIZES
AUTOTS,ON                             ! AUTO TIME-STEPPING
TIME,.15                              ! TIME AT END OF 1ST LOAD STEP
OUTRES,ALL,ALL
SOLVE
DELTIM,,,,ON                          ! CARRY OVER TIME STEP USED PREVIOUSLY
TIME,.24                              ! TIME AT END OF 2ND LOAD STEP
SOLVE
FINISH
/POST26
NSOL,2,4,A,Z                          ! STORE NODE 4 VECTOR POTENTIAL
NSOL,3,6,A,Z                          ! STORE NODE 6 VECTOR POTENTIAL
NSOL,4,8,A,Z                          ! STORE NODE 8 VECTOR POTENTIAL
/AXLAB,Y,A
/GROPT,AXNSC,2.0
PLVAR,2,3,4                           ! DISPLAY VECTOR POTENTIAL VS. TIME
*GET,V1,VARI,2,RTIME,.15
*GET,V2,VARI,3,RTIME,.15
*GET,V3,VARI,4,RTIME,.15
FINISH
/POST1
NSEL,S,NODE,,4,8,2
ESLN,S,0
SET,,,,,.15                           ! SELECT ITERATION AT TIME=.15
PRITER
PRNSOL,B,COMP                         ! PRINT NODAL FLUX DENSITY
*GET,F1,NODE,4,B,Y
*GET,F2,NODE,6,B,Y
*GET,F3,NODE,8,B,Y
*STATUS,PARM
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = '@ X=','@ X=','@ X='
LABEL(1,2) = '.2517','.4574','.6914'
/NOPR
*VFILL,VALUE(1,1),DATA,.831,.282,.05
*VFILL,VALUE(1,2),DATA,V1,V2,V3
*VFILL,VALUE(1,3),DATA,ABS(V1/.831),ABS(V2/.282),ABS(V3/.05)
/COM
/OUT,vm167,vrt,,APPEND
/COM,PLANE233
/COM,
/COM,VECTOR POTENTIALS (WB/M)
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F14.3,'  ',F18.3,'   ',1F17.3)
/COM,
/OUT
/NOPR
*VFILL,VALUE(1,1),DATA,3.707,1.749,.422
```

```
*VFILL,VALUE(1,2),DATA,F1,F2,F3
*VFILL,VALUE(1,3),DATA,ABS(F1/3.707),ABS(F2/1.749),ABS(F3/.422)
/COM,FLUX DENSITY (T)
/COM,
/OUT,vm167,vrt,,APPEND
/COM,FLUX DENSITY (T)
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F14.3,'  ',F18.3,'   ',1F17.3)
/COM,
/OUT
FINISH
*LIST,vm167,vrt
```

VM168 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM168
/PREP7
/TITLE, VM168, MAGNETIC FIELD IN A NONFERROUS SOLENOID
/COM,   PRINCIPLES OF ELECTRIC AND MAGNETIC FIELDS, BOAST, PG.243
ANTYPE,STATIC
ET,1,SOLID5,10                        ! 3D COUPLED-FIELD SOLID, MAG DOF
ET,2,SOURC36                          ! CURRENT SOURCE ELEMENT
EMUNIT,MKS                            ! MKS UNITS
MP,MURX,1,1                           ! RELATIVE PERMEABILITY - AIR
/COM    !**    DEFINE CONVENIENT PARAMETERS    !**
I=0.5                                 ! CURRENT
NI=115.5                              ! MMF
S=2.5                                 ! SOLENOID 1/2 LENGTH
R=0.5                                 ! SOLENOID RADIUS
THK=.0216                             ! SOLENOID THICKNESS
INM=.0254                             ! INCHES TO METER CONVERSION
INC=.0001                             ! SET SMALL RADIUS
TH=5                                  ! SET ANGLE
L=7.5                                 ! SET BOUNDARY LENGTH
R,1,1,NI,THK*INM,S*2*INM,1,50         ! COIL REAL CONSTANTS
CSYS,1
N,1,INC,-TH                           ! CREATE NODES FOR SOLID5
N,8,INC,-TH,S-.1
FILL
N,9,INC,-TH,S
N,10,INC,-TH,S+.1
N,19,INC,-TH,L-.1
FILL,10,19,,,,,2
N,20,INC,-TH,L
NGEN,4,20,1,20,1,R/3,,,5
NGEN,7,20,61,80,1,(5.5/6),,,10
NSEL,S,LOC,Z,0
DSYS,1
NLIST,ALL
NSEL,ALL
DSYS,0
NGEN,2,200,ALL,,,,(TH*2)
E,22,222,202,2,21,221,201,1           ! CREATE SOLID5 ELEMENTS
EGEN,19,1,-1
EGEN,9,20,-19
NUMMRG,NODE                           ! MERGE NODES NEAR X=0 AXIS
N,500,R                               ! CREATE NODES FOR SOURC36
N,501,R,90
N,502
TYPE,2
E,500,501,502                         ! CREATE SOURC36 ELEMENT
NSCALE,,ALL,,,INM,,INM                ! SCALE MODEL TO METERS
D,ALL,MAG,0                           ! SET MAG=0 EVERYWHERE
FINISH
/SOLU
MAGOPT                                ! RSP STRATEGY (DEFAULT)
OUTPR,ALL,NONE
```

```
SOLVE
FINISH
/POST1
PATH,FIELD,2,,48                       ! DEFINE PATH WITH NAME = "FIELD"
PPATH,1,1                              ! DEFINE PATH POINTS BY NODE
PPATH,2,20
PDEF,BZ,B,Z
PRPATH,BZ                              ! PRINT BZ ALONG COIL AXIS
/SHOW,,GRPH,1
PLPATH,BZ                              ! DISPLAY BZ ALONG COIL AXIS
*GET,S1A,PATH,0,MIN,BZ
*GET,S2A,PATH,0,MAX,BZ
*SET,S1,(S1A*1E6)
*SET,S2,(S2A*1E6)
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'BZ T ','BZ T'
LABEL(1,2) = 'Z=0','Z=.1905m'
*VFILL,VALUE(1,1),DATA,1120,2.12
*VFILL,VALUE(1,2),DATA,S2,S1
*VFILL,VALUE(1,3),DATA,ABS(S2/1120),ABS(S1/2.12)
/OUT,vm168,vrt
/COM,------------------- VM168 RESULTS COMPARISON --------------
/COM,ANSWERS MULTIPLIED BY 1E6
/COM,
/COM,                  |   TARGET   |   Mechanical APDL    |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F15.2,'   ',1F15.3)
/COM,----------------------------------------------------------
/COM,
/COM,----------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM168  NOT CONTAINED IN
/COM,THIS TABLE
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm168,vrt
```

VM169 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM169
/PREP7
smrt,off
/TITLE, VM169, PERMANENT MAGNET CIRCUIT WITH AN AIR GAP
!                MAGNETO-SOLID MECHANICS, MOON, PG. 275
!                USING TETRAHEDRAL SOLID ELEMENTS (SOLID98)
ET,1,SOLID98,10             ! TETRAHEDRAL COUPLED-FIELD SOLID
EMUNIT,MKS                  ! MKS UNITS
MP,MURX,1,1
MP,MURX,2,1E5               ! IRON RELATIVE PERMEABILITY
MP,MURX,3,5.30504           ! PERMANENT MAGNET RELATIVE PERMEABILITY
MP,MGXX,3,129900            ! MGXX
MP,MGZZ,3,-75000            ! MGZZ
LOCAL,11,0,,,,,,30          ! ROTATED LOCAL CARTESIAN SYSTEM
K,1
K,2,1.5E-2
K,3,2.5E-2
KGEN,2,1,3,1,,1E-2
KGEN,2,4,6,1,,2E-2
KGEN,2,7,9,1,,1E-3
KGEN,2,10,12,1,,1E-2
A,1,2,5,4                   ! CREATE AREAS
A,2,3,6,5
A,5,6,9,8
A,10,11,14,13
A,11,12,15,14
```

```
A,8,9,12,11
K,16,,,1E-2
L,1,16
VDRAG,1,2,3,4,5,6,20        ! DRAG AREAS TO CREATE VOLUMES
VSEL,S,,,1
VATT,3                      ! SET MATERIAL ATTRIBUTES
VSEL,S,,,6
VATT,1
VSEL,S,,,2,3
VSEL,A,,,4,5
VATT,2
VSEL,S,,,1,5
ESIZE,,1
MSHK,0                    ! FREE VOLUME MESH
MSHA,1,3D                 ! USING TETS
VMESH,ALL
VSEL,ALL
VMESH,6                     ! MESH AIR GAP
NSEL,,LOC,X,0
D,ALL,MAG,0                 ! SET FLUX-NORMAL BOUNDARY CONDITION
NSEL,ALL
WSORT,Y                     ! REORDER WAVEFRONT
FINISH
/SOLU
MAGSOLV,2                   ! RSP METHOD
FINISH
/POST1
RSYS,11
/VIEW,,6E-2,5E-2,6E-2
/EDGE,1,1
/DEVICE,VECTOR,1     ! TURN ON WIREFRAME MODE
PLVECT,B                    ! DISPLAY B VECTOR
/VSCALE,,,1                 ! SET FOR UNIFORM VECTOR SCALING
PLVECT,H                    ! DISPLAY H VECTOR
ESEL,,MAT,,1                ! SELECT AIR ELEMENTS
PRNSOL,B,COMP               ! PRINT B
NSORT,B,SUM
*GET,B1,SORT,,MAX
PRNSOL,H,COMP               ! PRINT H
NSORT,H,SUM
*GET,H1,SORT,,MAX
ESEL,,MAT,,3                ! SELECT PERMANENT MAGNET ELEMENTS
PRNSOL,B,COMP               ! PRINT B
NSORT,B,SUM
*GET,B2,SORT,,MAX
PRNSOL,H,COMP               ! PRINT H
NSORT,H,SUM
*GET,H2,SORT,,MAX
*status,parm
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'B T ','H A/m ','B T ','H A/m '
LABEL(1,2) = 'PMAG','PMAG','AIR','AIR'

*VFILL,VALUE(1,1),DATA,.7387,39150,.7387,587860
*VFILL,VALUE(1,2),DATA,B2,H2,B1,H1
*VFILL,VALUE(1,3),DATA,ABS(B2/.7387),ABS(H2/39150),ABS(B1/.7387),ABS(H1/587860)
/COM
/OUT,vm169,vrt
/COM,------------------- VM169 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET     |   Mechanical APDL     |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F12.4,'  ',F16.4,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
/DELETE,magsolv,out
*LIST,vm169,vrt
```

VM170 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM170
/PREP7
/TITLE, VM170, MAGNETIC FIELD FROM A SQUARE CURRENT LOOP
/COM,   REF. BOAST, "PRINCIPLES OF ELECTRIC AND MAGNETIC FIELDS"
/COM,   PG. 200
ET,1,LINK68               ! LINK68 ELEMENT
R,1,1                     ! ARBITRARY AREA
MP,RSVX,1,4.0E-8          ! RESISTIVITY
N,1                       ! DEFINE NODES FOR LOOP
N,2,1.5
N,3,1.5,,1.5
N,4,,,1.5
N,5                       ! NODES 1 AND 5 OVERLAP
N,6,,.35                  ! NODE FOR RESULTS EXTRACTION
E,1,2                     ! GENERATE ELEMENTS
EGEN,4,1,-1
D,5,VOLT,0                ! GROUND VOLTAGE IN WIRE
F,1,AMPS,7.5              ! APPLY CURRENT AT "CUT"
FINISH
/SOLU
OUTPR,ESOL,LAST           ! BASIC ELEMENT PRINTOUT
SOLVE                     ! SOLVE ELECTRIC CURRENT CONDUCTION
BIOT,NEW                  ! CALCULATE HS FIELD VIA BIOT-SAVART INTEG.
*GET,HX,NODE,6,HS,X       ! GET HS(X) AS A PARAMETER
*GET,HY,NODE,6,HS,Y       ! GET HS(Y)
*GET,HZ,NODE,6,HS,Z       ! GET HS(Z)
MUZRO=12.5664E-7          ! DEFINE FREE=SPACE PERMEABILITY
BX=MUZRO*HX               ! CALCULATE FLUX DENSITY
BY=MUZRO*HY
BZ=MUZRO*HZ
*status,parm                   ! SHOW PARAMETER STATUS
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'BX ','BY ','BZ '
LABEL(1,2) = 'TESLA','TESLA','TESLA'
*VFILL,VALUE(1,1),DATA,2.010E-6,-.662E-6,2.01E-6
*VFILL,VALUE(1,2),DATA,BX,BY,BZ
*VFILL,VALUE(1,3),DATA,ABS(BX/(2.01E-6)),ABS(BY/.662E-6),ABS(BZ/(2.01E-6))
/COM
/OUT,vm170,vrt
/COM,------------------- VM170 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET     |   Mechanical APDL     |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F12.9,'  ',F16.9,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm170,vrt
```

VM171 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM171
/PREP7
/TITLE, VM171, PERMANENT MAGNET CIRCUIT WITH AN ELASTIC KEEPER
/COM,   MAGNETO-SOLID MECHANICS, MOON, PG. 275
ET,1,PLANE13,4                  ! 2-D COUPLED-FIELD SOLID (UX,UY,AZ DOF'S)
ET,2,COMBIN14,,,2
R,1,1.6534E5                    ! SPRING CONSTANT
MP,EX,1,1E2
```

```
MP,EX,2,10E10
MP,EX,3,10E10
MP,EX,4,10E10
MP,NUXY,1,0.0
*REP,4,,1
MP,KXX,1,1                      ! APPLY DUMMY KXX TO PREVENT WARNING MSGS.
*REP,4,,1
EMUNIT,MKS                      ! MKS UNITS
MP,MURX,1,1                     ! AIR RELATIVE PERMEABILITY
MP,MURX,2,1E5                   ! IRON RELATIVE PERMEABILITY
MP,MURX,3,5.30504               ! PERMANENT MAGNET RELATIVE PERMEABILITY
MP,MGXX,3,149990.0              ! COERCIVE FORCE (X-DIRECTION)
MP,MURX,4,1E5                   ! KEEPER RELATIVE PERMEABILITY
N,1
N,6,5E-2
FILL
NGEN,6,6,1,6,1E-2,,1E-2
N,37,0,6E-2
N,38,5E-2,6E-2
MAT,3
E,2,3,9,8
EGEN,3,1,-1
MAT,2
E,1,2,8,7
EGEN,3,6,-1
E,5,6,12,11
EGEN,3,6,-1
MAT,4
E,25,26,32,31
EGEN,5,1,-1
MAT,1
E,19,20,26,25
E,23,24,30,29
TYPE,2                          ! SPRINGS
E,37,31
E,38,36
D,37,ALL,0,,38                  ! CONSTRAIN SPRING
ESEL,S,MAT,,2,3
NSLE
D,ALL,UX,0,,,,UY                ! CONSTRAIN PERMANENT MAGNET STRUCTURE
ESEL,ALL
NSEL,S,LOC,X,0
NSEL,A,LOC,X,5E-2
NSEL,A,LOC,Y,0
NSEL,A,LOC,Y,5E-2
D,ALL,AZ,0                      ! SET EXTERIOR FLUX-PARALLEL BOUNDARY
NSEL,ALL
CP,1,AZ,8,9,10,11,14            ! COUPLE INTERNAL NODES
CP,1,AZ,17,20,23,26
CP,1,AZ,27,28,29
NSLE                            ! SELECT ONLY NODES USED IN MODEL
D,ALL,UX,0                      ! CONSTRAIN ALL HORIZONTAL DISPLACEMENTS
D,ALL,TEMP,0                    ! CONSTRAIN UNUSED TEMP DOF
ESEL,S,MAT,,1                   ! SELECT KEEPER ELEMENTS
NSEL,S,LOC,Y,4E-2               ! SELECT NODES AT BOTTOM SURFACE
SF,ALL,MXWF                     ! APPLY MAXWELL PRESSURE SURFACE
NSEL,ALL
ESEL,ALL
FINISH
/SOLU
NLGEOM,ON                       ! ACTIVATE LARGE DEFLECTION
CNVTOL,F                        ! SET FORCE CONVERGENCE (USE DEFAULTS)
CNVTOL,CSG                      ! SET CSG CONVERGENCE (.001% OF DEFAULT)
SOLVE
FINISH
/POST1
NSEL,S,LOC,Y,4e-2
PRNSOL,U,COMP                   ! PRINT NODAL DISPLACEMENTS
*GET,Y1,NODE,25,U,Y
*SET,Y,ABS(Y1)
ESEL,S,MAT,,3
NSLE
```

```
PRNSOL,B,COMP                    ! PRINT NODAL FLUX DENSITY IN PERMANENT MAGNET
*GET,B,NODE,2,B,X
NSEL,ALL
ESEL,S,MAT,,2,4                  ! SELECT ONLY ELEMENTS OF IRONAND KEEPER
/EDGE,1,1
/DSCALE,1,1                      ! TRUE SCALING OPTION
PLDISP,1                         ! DISPLAY DEFLECTED AND UNDEFLECTED SHAPE
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'DEFL ','MFLUX '
LABEL(1,2) = 'm','T'
*VFILL,VALUE(1,1),DATA,1.5E-3,.2496
*VFILL,VALUE(1,2),DATA,Y,B
*VFILL,VALUE(1,3),DATA,ABS(Y/1.5E-3),ABS(B/.2495)
/COM
/OUT,vm171,vrt
/COM,------------------- VM171 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm171,vrt
```

VM172 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM172
/PREP7
smrt,off
/TITLE, VM172, STRESS ANALYSIS OF A LONG, THICK, ISOTROPIC SOLENOID
/COM,   MAGNETO-SOLID MECHANICS, MOON, PG. 275, 2D ANALYSIS
ANTYPE,STATIC                        ! COUPLED FIELD ANALYSIS
ET,1,PLANE13,,,1                     ! PLANE13, AZ DOF, AXISYMMETRIC OPTION
ET,2,PLANE13,4,,1                    ! PLANE13, AZ,UX,UY DOF, AXISYMMETRIC OPTION
MP,EX,2,10.76E10                     ! SOLENOID MODULUS OF ELASTICITY
MP,NUXY,2,.35                        ! SOLENOID POISSON RATIO
EMUNIT,MKS                           ! MKS UNITS
MP,MURX,1,1                          ! RELATIVE PERMEABILITY=1.0
MP,MURX,2,1
K,1
K,2,1E-2
K,3,2E-2
L,1,2
LESIZE,1,,,5
L,2,3
LESIZE,2,,,20
LGEN,2,ALL,,,,2E-3
A,1,2,5,4                            ! AREA 1=AIR
A,2,3,6,5                            ! AREA 2=SOLENOID
ASEL,S,AREA,,2
AATT,2,,2
ASEL,ALL
ESIZE,,1
MSHK,2                     ! MAPPED AREA MESH IF POSSIBLE
MSHA,0,2D                  ! USING QUADS
AMESH,ALL
ESEL,S,MAT,,2
NSLE,S
NSEL,R,LOC,Y,2E-3
CP,1,UY,ALL                          ! COUPLE SOLENOID NODAL UY DISP.
NSEL,S,LOC,X,2E-2                      ! SELECT NODES AT OUTER RADIUS
CP,2,AZ,ALL                          ! COUPLE AZ TO ENSURE FLUX-PARALLEL B.C.
FINISH
/SOLU
```

```
NSEL,S,LOC,X,0
D,ALL,AZ,0                          ! SET FLUX PARALLEL B.C.
ESEL,S,MAT,,2
BFE,ALL,JS,,,,1E+6                    ! APPLY CURRENT DENSITY LOAD
NSLE
NSEL,R,LOC,Y,0
DSYM,SYMM,2                         ! APPLY STRUCTURAL SYMMETRY B.C.
NSEL,ALL
ESEL,ALL
KBC,1                               ! STEP BOUNDARY CONDITIONS
OUTRES,,LAST
SOLVE
FINISH
/POST1
SET,1
ESEL,S,MAT,,2                       ! SELECT SOLENOID NODES AND ELEMENTS
NSLE
/AXLAB,X,DISTANCE
/AXLAB,Y,STRESS - 2-D MODEL
/GTHK,AXIS,2
!/YRANGE,0,150
PATH,COIL1,2,,48                     ! DEFINE PATH WITH NAME = "COIL1"
PPATH,1,2                           ! DEFINE PATH POINTS BY NODE
PPATH,2,13
PDEF,SZ,S,Z
PDEF,BY,B,Y
!/YRANGE,500,1500
PLPATH,SZ                           ! DISPLAY CIRCUM STRESS THRU SOLENOID
!/YRANGE,0,125
/AXLAB,Y,FLUX DENSITY - 2-D MODEL
PLPATH,BY                           ! DISPLAY AXIAL FLUX DENSITY THRU SOLENOID
NSEL,S,LOC,X,1e-2
NSEL,A,LOC,X,1.3e-2
NSEL,A,LOC,X,1.7e-2
PRNSOL,B,COMP                       ! PRINT AXIAL FLUX DENSITY
PRNSOL,S,COMP                       ! PRINT COMPONENT STRESSES
*GET,B1,NODE,7,B,SUM
*GET,B2,NODE,19,B,SUM
*GET,B3,NODE,27,B,SUM
*GET,S1,NODE,7,S,Z
*GET,S2,NODE,19,S,Z
*GET,S3,NODE,27,S,Z
*DIM,LABEL,CHAR,6,2
*DIM,VALUE,,6,3
LABEL(1,1) = 'B, T ','B, T ','B, T ','PRS ','PRS ','PRS '
LABEL(1,2) = 'R=1E-2','R=1.3E-2','R=1.7E-2','R=1E-2','R=1.3E-2','R=1.7E-2'
*VFILL,VALUE(1,1),DATA,0.01257,8.796E-3,3.77E-3,146.7,97.79,62.44
*VFILL,VALUE(1,2),DATA,B1,B2,B3,S1,S2,S3
V1=B1/0.01257
V2=B2/8.796E-3
V3=B3/3.77E-3
V4=S1/146.7
V5=S2/97.79
V6=S3/62.44
*VFILL,VALUE(1,3),DATA,V1,V2,V3,V4,V5,V6
SAVE,TABLE_1
FINISH
RESUME,TABLE_1
/COM
/OUT,vm172,vrt
/COM,------------------- VM172 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   ANSYS   |   RATIO
/COM,
/COM,PRESSURES HAVE UNITS OF N/M**2
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',e12.5,'  ',e12.5,'   ',1F5.3)
/COM,
/COM,-----------------------------------------------------------
/COM,
/OUT
```

```
FINISH
*LIST,vm172,vrt
/DELETE,TABLE_1
```

VM173 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM173
/PREP7
/TITLE, VM173, CENTERLINE TEMPERATURE OF AN ELECTRICAL WIRE
C***      HEAT, MASS AND MOMENTUM TRANS., ROHSENOW AND CHOI, 2ND. PR., PAGE 106,
C***      EX. 6.5, USING SOLID5 ELEMENTS
ET,1,SOLID5,1                    ! SOLID5, TEMP,VOLT,MAG DOF OPTION
MP,KXX,1,13                      ! THERMAL CONDUCTIVITY
MP,RSVX,1,8.983782E-8            ! ELECTRICAL RESISTIVITY
CSYS,1
N,1,1E-10,-5                     ! MOVE AWAY FROM ORIGIN FOR THETA SPEC.
N,6,.03125,-5
FILL
NGEN,2,10,1,6,1,,10              ! MODEL 10 DEG. SECTOR
NGEN,2,20,1,16,1,,,-(1/12)       ! ARBITRARY Z-LENGTH OF 1 INCH
NUMMRG,NODE                      ! MERGE COINCIDENT NODES AT ORIGIN
E,2,12,1,1,22,32,21,21           ! GENERATE ELEMENTS
E,2,3,13,12,22,23,33,32
EGEN,4,1,2
CP,1,TEMP,1,21                   ! COUPLING TO ENSURE AXIAL SYMMETRY
CP,2,TEMP,2,12,22,32             ! COUPLING TO ENSURE CIRCUMFERENTIAL SYMMETRY
CPSGEN,5,1,2
NSEL,S,LOC,Z,0
D,ALL,VOLT,0                     ! SET VOLTAGES
NSEL,INVE
D,ALL,VOLT,-(.1/12)              ! .1 VOLT/FT OVER 1 IN LENGTH
NSEL,S,LOC,X,.03125
SF,ALL,CONV,5,70
NSEL,ALL
FINISH
/SOLU
SOLVE
FINISH
/POST1
NSEL,S,LOC,X,0
PRNSOL,TEMP                      ! RESULTS AT CENTERLINE
*GET,T,NODE,1,TEMP
NSEL,S,LOC,X,.03125
PRNSOL,TEMP                      ! RESULTS AT OUTER RADIUS
*GET,TEMP,NODE,6,TEMP        ! GET TEMPERATURE AT SURFACE NODE
PI=2*ASIN(1)
LENG=2*(0.375/12)*SIN(PI/36) ! LENGTH ALONG 10 DEG ON OUTER FACE
AREA=LENG*36                 ! COMPUTE AREA OF OUTER FACE (360 DEG)
HRATE=AREA*5.0*(TEMP-70)     ! TOTAL HEAT DISSIPATION RATE
*status,parm                      ! SHOW PARAMETER STATUS
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'T(CL) ','T(S) ','Q '
LABEL(1,2) = 'DEG F','DEG F','BTU/hr/ft'
*VFILL,VALUE(1,1),DATA,419.9,417.9,341.5
*VFILL,VALUE(1,2),DATA,T,TEMP,HRATE
*VFILL,VALUE(1,3),DATA,ABS(T/419.9),ABS(TEMP/417.9),ABS(HRATE/341.5)
/COM
/OUT,vm173,vrt
/COM,------------------- VM173 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
```

```
FINISH
*LIST,vm173,vrt
```

VM174 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM174
/PREP7
MP,PRXY,,0.3
MP,PRXY,,0.3
SMRT,OFF
/TITLE, VM174, BIMETALLIC BEAM UNDER THERMAL LOAD
/COM, THEORY OF THERMAL STRESS, BOLEY AND WEINER,
/COM, 1985 PRINTING, PG. 429
ANTYPE,STATIC                   ! COUPLED FIELD STATIC ANALYSIS
NLGEOM,ON                       ! LARGE DEFLECTION
ET,1,PLANE13,4,,2               ! 2-D COUPLED FIELD SOLID, PLANE STRESS
MP,EX,1,10E6
MP,EX,2,10E6
MP,ALPX,1,14.5E-6
MP,ALPX,2,2.5E-6
MP,KXX,1,5                      ! THERMAL CONDUCTIVITY
MP,KXX,2,5
MP,PRXY,1,0.3
MP,PRXY,2,0.3
K,1                             ! DEFINE GEOMETRY
K,2,5
KGEN,3,1,2,1,,.05
L,1,2
*REPEAT,3,2,2
LESIZE,ALL,,,5
A,1,2,4,3
AATT,2
A,3,4,6,5
ESIZE,,1
AMESH,ALL
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,.05
D,ALL,UY
NSEL,S,LOC,Y,.1
D,ALL,TEMP,400.0                ! APPLY TOP SURFACE TEMPERATURE
NSEL,S,LOC,Y,0
D,ALL,TEMP,400.0                ! APPLY BOTTOM SURFACE TEMPERATURE
NSEL,S,LOC,X,5
DSYM,SYMM,0,X
NSEL,ALL
FINISH
/SOLU
CNVTOL,F,,,,0.1                 ! CONVERGENCE BASED ON FORCE ONLY
SOLVE
FINISH
/POST1
SET,1
/DSCALE,1,1                     ! TRUE SCALING OPTION
PLDISP,1                        ! DISPLAY DEFLECTED AND UNDEFLECTED SHAPE
NSEL,S,LOC,X,5
NSEL,R,LOC,Y,.05
PRNSOL,U,COMP                   ! PRINT DISPLACEMENTS
NPOST=NODE(5,0.05,0)
*GET,Y,NODE,NPOST,U,Y
PRNSOL,TEMP                     ! PRINT TEMPERATURES
*GET,T,NODE,NPOST,TEMP
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'Y ','TEMP,'
LABEL(1,2) = 'IN',' F'
*VFILL,VALUE(1,1),DATA,.9,400
```

```
*VFILL,VALUE(1,2),DATA,Y,T
*VFILL,VALUE(1,3),DATA,ABS(Y/.9),ABS(T/400)
/COM
/OUT,vm174,vrt
/COM,------------------- VM174 RESULTS COMPARISON -------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,PLANE13
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/OUT
FINISH
!
LABEL=
VALUE=
!
/PREP7
DDELE,ALL,ALL
ACLEAR,ALL
ET,1,PLANE223,11,,0             ! 2-D COUPLED FIELD SOLID, PLANE STRESS
AMESH,ALL
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,.05
D,ALL,UY
NSEL,S,LOC,Y,.1
D,ALL,TEMP,400.0                ! APPLY TOP SURFACE TEMPERATURE
NSEL,S,LOC,Y,0
D,ALL,TEMP,400.0                ! APPLY BOTTOM SURFACE TEMPERATURE
NSEL,S,LOC,X,5
DSYM,SYMM,0,X
NSEL,ALL
FINISH
/SOLU
CNVTOL,F,,,,0.1                 ! CONVERGENCE BASED ON FORCE ONLY
SOLVE
FINISH
/POST1
SET,1
/DSCALE,1,1                     ! TRUE SCALING OPTION
PLDISP,1                        ! DISPLAY DEFLECTED AND UNDEFLECTED SHAPE
NSEL,S,LOC,X,5
NSEL,R,LOC,Y,.05
PRNSOL,U,COMP                   ! PRINT DISPLACEMENTS
NPOST=NODE(5,0.05,0)
*GET,Y,NODE,NPOST,U,Y
PRNSOL,TEMP                     ! PRINT TEMPERATURES
*GET,T,NODE,NPOST,TEMP
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'Y ','TEMP,'
LABEL(1,2) = 'IN',' F'
*VFILL,VALUE(1,1),DATA,.9,400
*VFILL,VALUE(1,2),DATA,Y,T
*VFILL,VALUE(1,3),DATA,ABS(Y/.9),ABS(T/400)
/COM
/OUT,vm174,vrt,,APPEND
/COM,PLANE223
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
*LIST,vm174,vrt
```

VM175 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM175
/PREP7
```

```
SMRT,OFF
/TITLE, VM175, NATURAL FREQUENCY OF A PIEZOELECTRIC TRANSDUCER
/COM,         COMPUTATION OF THE VIBRATIONAL MODES FOR PIEZOELECTRIC
/COM,         ARRAY TRANSDUCERS USING A MIXED FINITE ELEMENT
/COM,         PERTURBATION METHOD, BOUCHER, D., LAGIER, M., MAERFELD,
/COM,         C., IEEE TRANS. SONICS AND ULTRASONICS, VOL. SU-28,
/COM,         NO. 5, SEPTEMBER 1981., PG. 318-330
/COM,
ET,1,SOLID5,3                    ! 3-D COUPLED-FIELD SOLID, PIEZO OPTION
MP,DENS,3,7500                   ! DENSITY
MP,PERX,3,804.6                  ! PERMITTIVITY (X AND Y DIRECTION)
MP,PERZ,3,659.7                  ! PERMITTIVITY (Z DIRECTION)
TB,PIEZ,3                        ! DEFINE PIEZ. TABLE
TBDATA,16,10.5                   ! E61 PIEZOELECTRIC CONSTANT
TBDATA,14,10.5                   ! E52 PIEZOELECTRIC CONSTANT
TBDATA,3,-4.1                    ! E13 PIEZOELECTRIC CONSTANT
TBDATA,6,-4.1                    ! E23 PIEZOELECTRIC CONSTANT
TBDATA,9,14.1                    ! E33 PIEZOELECTRIC CONSTANT
TB,ANEL,3                        ! DEFINE STRUCTURAL TABLE
TBDATA,1,13.2E10,7.1E10,7.3E10   ! INPUT [C] MATRIX
TBDATA,7,13.2E10,7.3E10
TBDATA,12,11.5E10
TBDATA,16,3.0E10
TBDATA,19,2.6E10
TBDATA,21,2.6E10

L=10E-3                          ! SET LENGTH
W=10E-3                          ! SET WIDTH
H=20E-3                          ! SET HEIGHT
K,1
K,2,L
K,3,L,W
K,4,,W
KGEN,2,1,4,1,,,H
L,1,5
LESIZE,1,,,4
ESIZE,,2
MSHK,1                  ! MAPPED VOLUME MESH
MSHA,0,3D               ! USING HEX
V,1,2,3,4,5,6,7,8
MAT,3
VMESH,1
NSEL,S,LOC,X,0
DSYM,SYMM,X                      ! SYMMETRY BOUNDARY CONSTRAINTS
NSEL,S,LOC,Y,0
DSYM,SYMM,Y
NSEL,ALL
FINISH
/out,scratch
/SOLU
ANTYP,MODAL
MODOPT,LANB,10,50000,150000      ! BLOCK LANCZOS, EXTRACT 10 MODES
MXPAND,10                        ! EXPAND ALL MODES
/COM,                            ** RESONANCE FREQUENCY B.C.'S **
NSEL,S,LOC,Z,0
D,ALL,VOLT,0                     ! GROUND BOTTOM ELECTRODE
NSEL,S,LOC,Z,H
D,ALL,VOLT,0                     ! SHORT-CIRCUIT TOP ELECTRODE
NSEL,ALL
SOLVE
*GET,F1,MODE,2,FREQ
*GET,F2,MODE,5,FREQ
FINISH
/out
/POST1
/VIEW,1,1,1,1
/VUP,,Z
/TYPE,,4
*DO,I,1,10
SET,LS,I
PLDISP,1                         ! DISPLAY ANTI-RESONANCE MODE SHAPES
*ENDDO
```

```
FINISH
/out,scratch
/SOLU
ANTYPE,MODAL
MODOPT,LANB,10,50000,150000        ! BLOCK LANCZOS, EXTRACT 10 MODES
MXPAND,10
/COM,                              ** ANTI-RESONANCE FREQUENCY B.C.'S **
NSEL,S,LOC,Z,H
DDELE,ALL,VOLT                     ! DELETE VOLT CONSTRAINTS ON TOP ELECTRODE
CP,1,VOLT,ALL                      ! COUPLE VOLT DOF ON TOP ELECTRODE
NSEL,ALL
SOLVE
*GET,F3,MODE,4,FREQ
*GET,F4,MODE,8,FREQ
FINISH
/out
/POST1
*DO,I,1,10
SET,LS,I
PLDISP,1                           ! DISPLAY RESONANCE MODE SHAPES
*ENDDO
*STATUS,PARM
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'F1 ','F2 '
LABEL(1,2) = 'Hz','Hz'
*VFILL,VALUE(1,1),DATA,66560,88010
*VFILL,VALUE(1,2),DATA,F1,F2
*VFILL,VALUE(1,3),DATA,ABS(F1/66560),ABS(F2/88010)
/COM
/OUT,vm175,vrt
/COM,------------------- VM175 RESULTS COMPARISON -------------
/COM
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM, SOLID5
/COM,
/COM, SHORT CIRCUIT
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM
/NOPR
*VFILL,VALUE(1,1),DATA,81590,93410
*VFILL,VALUE(1,2),DATA,F3,F4
*VFILL,VALUE(1,3),DATA,ABS(F3/81590),ABS(F4/93410)
/COM, OPEN CIRCUIT
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH

/CLEAR,NOSTART
/PREP7
SMRT,OFF
/TITLE, VM175, NATURAL FREQUENCY OF A PIEZOELECTRIC TRANSDUCER
ET,1,SOLID226,1001                 ! 3-D 20-NODE COUPLED-FIELD SOLID, PIEZO OPTION
MP,DENS,3,7500                     ! DENSITY
MP,PERX,3,804.6                    ! PERMITTIVITY (X AND Y DIRECTION)
MP,PERZ,3,659.7                    ! PERMITTIVITY (Z DIRECTION)
TB,PIEZ,3                          ! DEFINE PIEZ. TABLE
TBDATA,16,10.5                     ! E61 PIEZOELECTRIC CONSTANT
TBDATA,14,10.5                     ! E52 PIEZOELECTRIC CONSTANT
TBDATA,3,-4.1                      ! E13 PIEZOELECTRIC CONSTANT
TBDATA,6,-4.1                      ! E23 PIEZOELECTRIC CONSTANT
TBDATA,9,14.1                      ! E33 PIEZOELECTRIC CONSTANT
TB,ANEL,3                          ! DEFINE STRUCTURAL TABLE
TBDATA,1,13.2E10,7.1E10,7.3E10     ! INPUT [C] MATRIX
TBDATA,7,13.2E10,7.3E10
TBDATA,12,11.5E10
TBDATA,16,3.0E10
TBDATA,19,2.6E10
TBDATA,21,2.6E10
```

```
L=10E-3                              ! SET LENGTH
W=10E-3                              ! SET WIDTH
H=20E-3                              ! SET HEIGHT
K,1
K,2,L
K,3,L,W
K,4,,W
KGEN,2,1,4,1,,,H
L,1,5
LESIZE,1,,,4
ESIZE,,2
MSHK,1                     ! MAPPED VOLUME MESH
MSHA,0,3D                  ! USING HEX
V,1,2,3,4,5,6,7,8
MAT,3
VMESH,1
NSEL,S,LOC,X,0
DSYM,SYMM,X                          ! SYMMETRY BOUNDARY CONSTRAINTS
NSEL,S,LOC,Y,0
DSYM,SYMM,Y
NSEL,ALL
FINISH
/out,scratch
/SOLU
ANTYP,MODAL
MODOPT,LANB,10,50000,150000          ! BLOCK LANCZOS, EXTRACT 10 MODES
MXPAND,10                            ! EXPAND ALL MODES
/COM,                                ** RESONANCE FREQUENCY B.C.'S **
NSEL,S,LOC,Z,0
D,ALL,VOLT,0                         ! GROUND BOTTOM ELECTRODE
NSEL,S,LOC,Z,H
D,ALL,VOLT,0                         ! SHORT-CIRCUIT TOP ELECTRODE
NSEL,ALL
SOLVE
*GET,F1,MODE,2,FREQ
*GET,F2,MODE,5,FREQ
FINISH
/out
/POST1
/VIEW,1,1,1,1
/VUP,,Z
/TYPE,,4
*DO,I,1,10
SET,LS,I
PLDISP,1                             ! DISPLAY ANTI-RESONANCE MODE SHAPES
*ENDDO
FINISH
/out,scratch
/SOLU
ANTYPE,MODAL
MODOPT,LANB,10,50000,150000          ! BLOCK LANCZOS, EXTRACT 10 MODES
MXPAND,10
/COM,                                ** ANTI-RESONANCE FREQUENCY B.C.'S **
NSEL,S,LOC,Z,H
DDELE,ALL,VOLT                       ! DELETE VOLT CONSTRAINTS ON TOP ELECTRODE
CP,1,VOLT,ALL                        ! COUPLE VOLT DOF ON TOP ELECTRODE
NSEL,ALL
SOLVE
*GET,F3,MODE,4,FREQ
*GET,F4,MODE,8,FREQ
FINISH
/out
/POST1
*DO,I,1,10
SET,LS,I
PLDISP,1                             ! DISPLAY RESONANCE MODE SHAPES
*ENDDO
*STATUS,PARM
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'F1 ','F2 '
```

```
LABEL(1,2) = 'Hz','Hz'
*VFILL,VALUE(1,1),DATA,66560,88010
*VFILL,VALUE(1,2),DATA,F1,F2
*VFILL,VALUE(1,3),DATA,ABS(F1/66560),ABS(F2/88010)
/COM
/OUT,vm175,vrt,,APPEND
/COM, SOLID226
/COM,
/COM, SHORT CIRCUIT
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,
/NOPR
*VFILL,VALUE(1,1),DATA,81590,93410
*VFILL,VALUE(1,2),DATA,F3,F4
*VFILL,VALUE(1,3),DATA,ABS(F3/81590),ABS(F4/93410)
/COM, OPEN CIRCUIT
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F14.0,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm175,vrt
```

VM176 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM176
/PREP7
SMRT,OFF
/TITLE, VM176, FREQUENCY RESPONSE OF ELECTRICAL INPUT ADMITTANCE FOR A
/COM           PIEZOELECTRIC TRANSDUCER
/COM    KAGAWA AND YAMABUCHI, FINITE ELEMENT SIMULATION OF A COMPOSITE
/COM    PIEZOELECTRIC ULTRASONIC TRANSDUCER, IEEE TRANS. SONICS AND
/COM    ULTRASONICS, VOL. SU-26, NO.2, MARCH 1979
ET,1,SOLID5,0                     ! 3-D COUPLED-FIELD SOLID
MP,DENS,3,7730                    ! NEPEC DENSITY
MP,EX,2,7.03E10                   ! ALUMINUM MODULUS OF ELASTICITY
MP,NUXY,2,.345                    ! ALUMINUM POISSON RATIO
MP,DENS,2,2690                    ! ALUMINUM DENSITY
MP,EX,4,10E9                      ! ADHESIVE MODULUS OF ELASTICITY
MP,DENS,4,1700                    ! ADHESIVE DENSITY
MP,NUXY,4,.38                     ! ADHESIVE POISSON RATIO

TB,PIEZ,3                         ! DEFINE PIEZO. TABLE FOR NEPEC
TBDATA,3,-6.10                    ! PIEZO MATRIX CONSTANTS
TBDATA,6,-6.10
TBDATA,9,15.70
MP,PERX,3,993.55                  ! PERMITTIVITY
TB,ANEL,3                         ! DEFINE STRUCTURAL TABLE FOR NEPEC
TBDATA,1,12.80E10,6.8E10,6.6E10   ! INPUT [C] MATRIX FOR NEPEC
TBDATA,7,12.8E10,6.6E10
TBDATA,12,11.0E10
TBDATA,16,2.1E10
TBDATA,19,2.1E10
TBDATA,21,2.1E10

/COM                              ** DEFINE GEOMETRIC PARAMETERS **
R=27.5E-3                         ! DISK RADIUS
HA=15.275E-3                      ! ALUMINUM 1/2 HEIGHT LOCATION
HN=5E-3                           ! NEPEC 1/2 HEIGHT
HB=5.275E-3                       ! ADHESIVE MATERIAL HEIGHT
RDIV=5                            ! NO. ELEMENTS ALONG RADIUS
HADV=3                            ! NO. ELEMENTS ALONG ALUMINUM HEIGHT
HNDV=2                            ! NO. ELEMENTS ALONG NEPEC HEIGHT
HBDV=1                            ! NO. ELEMENTS ALONG ADHESIVE HEIGHT
ZRO=1E-5                          ! DEFINE ZERO FOR KEYPOINT LOCATION
CSYS,1
```

```
K,1,ZRO,-5                          ! DEFINE KEYPOINTS FOR MESH, WEDGE ELEMENTS
K,2,R,-5                            ! ARE NOT ALLOWED BY MESH MODULE SO KEYPOINTS
K,3,R,-5,HN                         ! ARE DEFINED NEAR ZERO AND LATER MERGED
K,4,ZRO,-5,HN
K,5,R,-5,HB
K,6,ZRO,-5,HB
K,7,R,-5,HA
K,8,ZRO,-5,HA
KGEN,2,1,8,1,,10
L,2,3                               ! DEFINE LINE SEGMENTS
LESIZE,1,,,HNDV
L,3,5
LESIZE,2,,,HBDV
L,5,7
LESIZE,3,,,HADV
L,2,10
LESIZE,4,,,1
V,11,3,4,12,10,2,1,9                ! CREATE NEPEC VOLUME
VATT,3                              ! ASSIGN MATERIAL ATTRIBUTES
V,13,5,6,14,11,3,4,12               ! CREATE ADHESIVE VOLUME
VSEL,S,VOLU,,2
VATT,4                              ! ASSIGN MATERIAL ATTRIBUTES
V,15,7,8,16,13,5,6,14               ! CREATE ALUMINUM VOLUME
VSEL,S,VOLU,,3
VATT,2                              ! ASSIGN MATERIAL ATTRIBUTES
VSEL,ALL
MSHK,1                              ! MAPPED VOLUME MESH
MSHA,0,3D                           ! USING HEX
ESIZE,,RDIV
SHPP,OFF                            ! TURN OFF SHAPE CHECKING TO ALLOW
!                                     FOR WEDGE SHAPE MESH OF SOLIDS
VMESH,ALL                           ! MESH ALL VOLUMES
NUMMRG,NODE                         ! MERGE NODES TO CREATE WEDGE ELMENTS
!                                     AT AXIS
NSEL,S,LOC,Y,-5
DSYM,SYMM,Y,1                       ! SYMMETRY B.C. AT THETA=-5 DEG.
NSEL,S,LOC,Y,5
DSYM,SYMM,Y,1                       ! SYMMETRY B.C. AT THETA=5 DEG.
NSEL,S,LOC,X,0,.001
DSYM,SYMM,X,1                       ! SYMMETRY B.C. AT X=0
NSEL,S,LOC,Z,0
DSYM,SYMM,Z,1                       ! SYMMETRY B.C. AT Z=0
NSEL,S,LOC,Z,HN                     ! SELECT NODES AT TOP ELECTRODE
CP,1,VOLT,ALL                       ! COUPLE VOLT DOF ON ELECTRODE
*GET,N1,NODE,,NUM,MIN               ! GET NODE ON ELECTRODE
D,N1,VOLT,-0.5                      ! APPLY -0.5 VOLT TO TOP ELECTRODE
NSEL,S,LOC,Z,0                      ! SELECT NODES AT SYMMETRY PLANE
D,ALL,VOLT,0.0                      ! SET VOLT TO ZERO AT SYMMETRY PLANE
NSEL,ALL
FINISH
/out,scratch
/SOLU
EQSLV,SPARSE    ! USING SPARSE MATRIX SOLVER
ANTYPE,HARMIC                       ! PERFORM HARMONIC ANALYSIS
OUTRES,ALL,ALL                      ! STORE EVERY SUBSTEP
HARFRQ,5000,35000                   ! SOLVE FOR FREQ=20KHZ AND 35KHZ
NSUBST,2
KBC,1                               ! STEP BOUNDARY CONDITIONS
EQSLV,ICCG                          ! ICCG SOLVER
SOLVE
HARFRQ,39000,45000                  ! SOLVE FOR FREQ=42KHZ AND 45KHZ
SOLVE
HARFRQ,46000,54000                  ! SOLVE FOR FREQ=50KHZ AND 54KHZ
SOLVE
FINISH
/out
/POST26
RFORCE,2,N1,AMPS                    ! STORE CHARGES ON ELECTRODE
PI2=(3.14159*2.)
PROD,3,2,1,,MHOS,,,PI2              ! CALCULATE ADMITTANCE (10 DEG. SLICE)
PROD,4,3,,,MMHO,,,36000             ! CALCULATE TOTAL ADMITTANCE (MMHOS)
PRVAR,4                             ! PRINT ELECTRICAL ADMITTANCE VS. FREQUENCY
```

```
*GET,F1,VARI,4,RTIME,20000
*GET,F2,VARI,4,RTIME,35000
*GET,F3,VARI,4,RTIME,42000
*GET,F4,VARI,4,RTIME,45000
*GET,F5,VARI,4,RTIME,50000
*GET,F6,VARI,4,RTIME,54000
*STATUS,PARM
*DIM,LABEL,CHAR,6,2
*DIM,VALUE,,6,3
LABEL(1,1) = 'Y MMHOS ','Y MMHOS','Y MMHOS ','Y MMHOS ','Y MMHOS ','Y MMHOS '
LABEL(1,2) = '@20 kHz','@35 kHz','@42 kHz','@45 kHz','@50 kHz','@54 kHz'
*VFILL,VALUE(1,1),DATA,.41,.9,2,0,.39,.65
*VFILL,VALUE(1,2),DATA,F1,F2,F3,F4,F5,F6
*VFILL,VALUE(1,3),DATA,ABS(F1/.41),ABS(F2/0.9),ABS(F3/2),0,ABS(F5/.39),ABS(F6/0.65)
/COM
/OUT,vm176,vrt
/COM,------------------- VM176 RESULTS COMPARISON -------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,SOLID5
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/OUT

FINISH

/CLEAR,NOSTART
/PREP7
SMRT,OFF
ET,1,SOLID186,,1                  ! 3-D STRUCTURAL SOLID
MP,DENS,3,7730                    ! NEPEC DENSITY
MP,EX,2,7.03E10                   ! ALUMINUM MODULUS OF ELASTICITY
MP,NUXY,2,.345                    ! ALUMINUM POISSON RATIO
MP,DENS,2,2690                    ! ALUMINUM DENSITY
MP,EX,4,10E9                      ! ADHESIVE MODULUS OF ELASTICITY
MP,DENS,4,1700                    ! ADHESIVE DENSITY
MP,NUXY,4,.38                     ! ADHESIVE POISSON RATIO

ET,2,SOLID226,1001                ! 3-D COUPLED-FIELD SOLID
TB,PIEZ,3                         ! DEFINE PIEZO. TABLE FOR NEPEC
TBDATA,3,-6.10                    ! PIEZO MATRIX CONSTANTS
TBDATA,6,-6.10
TBDATA,9,15.70
MP,PERX,3,993.55                  ! PERMITTIVITY
TB,ANEL,3                         ! DEFINE STRUCTURAL TABLE FOR NEPEC
TBDATA,1,12.80E10,6.8E10,6.6E10  ! INPUT [C] MATRIX FOR NEPEC
TBDATA,7,12.8E10,6.6E10
TBDATA,12,11.0E10
TBDATA,16,2.1E10
TBDATA,19,2.1E10
TBDATA,21,2.1E10

/COM                              ** DEFINE GEOMETRIC PARAMETERS **
R=27.5E-3                         ! DISK RADIUS
HA=15.275E-3                      ! ALUMINUM 1/2 HEIGHT LOCATION
HN=5E-3                           ! NEPEC 1/2 HEIGHT
HB=5.275E-3                       ! ADHESIVE MATERIAL HEIGHT
RDIV=5                            ! NO. ELEMENTS ALONG RADIUS
HADV=3                            ! NO. ELEMENTS ALONG ALUMINUM HEIGHT
HNDV=2                            ! NO. ELEMENTS ALONG NEPEC HEIGHT
HBDV=1                            ! NO. ELEMENTS ALONG ADHESIVE HEIGHT
ZRO=1E-5                          ! DEFINE ZERO FOR KEYPOINT LOCATION
CSYS,1
K,1,ZRO,-5                        ! DEFINE KEYPOINTS FOR MESH, WEDGE ELEMENTS
K,2,R,-5                          ! ARE NOT ALLOWED BY MESH MODULE SO KEYPOINTS
K,3,R,-5,HN                       ! ARE DEFINED NEAR ZERO AND LATER MERGED
K,4,ZRO,-5,HN
K,5,R,-5,HB
K,6,ZRO,-5,HB
K,7,R,-5,HA
K,8,ZRO,-5,HA
KGEN,2,1,8,1,,10
```

```
L,2,3                           ! DEFINE LINE SEGMENTS
LESIZE,1,,,HNDV
L,3,5
LESIZE,2,,,HBDV
L,5,7
LESIZE,3,,,HADV
L,2,10
LESIZE,4,,,1
V,11,3,4,12,10,2,1,9            ! CREATE NEPEC VOLUME
VATT,3,,2                       ! ASSIGN MATERIAL ATTRIBUTES
V,13,5,6,14,11,3,4,12           ! CREATE ADHESIVE VOLUME
VSEL,S,VOLU,,2
VATT,4,,1                       ! ASSIGN MATERIAL ATTRIBUTES
V,15,7,8,16,13,5,6,14           ! CREATE ALUMINUM VOLUME
VSEL,S,VOLU,,3
VATT,2,,1                       ! ASSIGN MATERIAL ATTRIBUTES
VSEL,ALL
MSHK,1                          ! MAPPED VOLUME MESH
MSHA,0,3D                       ! USING HEX
ESIZE,,RDIV
SHPP,OFF                        ! TURN OFF SHAPE CHECKING TO ALLOW
!                                 FOR WEDGE SHAPE MESH OF SOLIDS
TYPE,1
VMESH,ALL                       ! MESH ALL VOLUMES
NUMMRG,NODE                     ! MERGE NODES TO CREATE WEDGE ELMENTS
!                                 AT AXIS
NSEL,S,LOC,Y,-5
DSYM,SYMM,Y,1                   ! SYMMETRY B.C. AT THETA=-5 DEG.
NSEL,S,LOC,Y,5
DSYM,SYMM,Y,1                   ! SYMMETRY B.C. AT THETA=5 DEG.
NSEL,S,LOC,X,0,.001
DSYM,SYMM,X,1                   ! SYMMETRY B.C. AT X=0
NSEL,S,LOC,Z,0
DSYM,SYMM,Z,1                   ! SYMMETRY B.C. AT Z=0
NSEL,S,LOC,Z,HN                 ! SELECT NODES AT TOP ELECTRODE
CP,1,VOLT,ALL                   ! COUPLE VOLT DOF ON ELECTRODE
*GET,N1,NODE,,NUM,MIN           ! GET NODE ON ELECTRODE
D,N1,VOLT,-0.5                  ! APPLY -0.5 VOLT TO TOP ELECTRODE
NSEL,S,LOC,Z,0                  ! SELECT NODES AT SYMMETRY PLANE
D,ALL,VOLT,0.0                  ! SET VOLT TO ZERO AT SYMMETRY PLANE
NSEL,ALL
FINISH
/out,scratch
/SOLU
ANTYPE,HARMIC                   ! PERFORM HARMONIC ANALYSIS
OUTRES,ALL,ALL                  ! STORE EVERY SUBSTEP
HARFRQ,5000,35000               ! SOLVE FOR FREQ=20KHZ AND 35KHZ
NSUBST,2
KBC,1                           ! STEP BOUNDARY CONDITIONS
SOLVE
HARFRQ,39000,45000              ! SOLVE FOR FREQ=42KHZ AND 45KHZ
SOLVE
HARFRQ,46000,54000              ! SOLVE FOR FREQ=50KHZ AND 54KHZ
SOLVE
FINISH
/out
/POST26
RFORCE,2,N1,CHRG                ! STORE CHARGE ON ELECTRODE
PI2=(3.14159*2.)
PROD,3,2,1,,MHOS,,,PI2          ! CALCULATE ADMITTANCE (10 DEG. SLICE)
PROD,4,3,,,MMHO,,,36000         ! CALCULATE TOTAL ADMITTANCE (MMHOS)
PRVAR,4                         ! PRINT ELECTRICAL ADMITTANCE VS. FREQUENCY
*GET,F1,VARI,4,RTIME,20000
*GET,F2,VARI,4,RTIME,35000
*GET,F3,VARI,4,RTIME,42000
*GET,F4,VARI,4,RTIME,45000
*GET,F5,VARI,4,RTIME,50000
*GET,F6,VARI,4,RTIME,54000
*STATUS,PARM
*DIM,LABEL,CHAR,6,2
*DIM,VALUE,,6,3
LABEL(1,1) = 'Y MMHOS ','Y MMHOS','Y MMHOS ','Y MMHOS ','Y MMHOS ','Y MMHOS '
```

```
LABEL(1,2) = '@20 kHz','@35 kHz','@42 kHz','@45 kHz','@50 kHz','@54 kHz'
*VFILL,VALUE(1,1),DATA,.41,.9,2,0,.39,.65
*VFILL,VALUE(1,2),DATA,F1,F2,F3,F4,F5,F6
*VFILL,VALUE(1,3),DATA,ABS(F1/.41),ABS(F2/0.9),ABS(F3/2),0,ABS(F5/.39),ABS(F6/0.65)
/COM
/OUT,vm176,vrt,,APPEND
/COM,SOLID226
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT

FINISH
*LIST,vm176,vrt
```

VM177 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM177
/PREP7
/TITLE, VM177, NATURAL FREQUENCY OF SUBMERGED RING
/COM, REF. "FINITE ELEMENT SOLUTION OF FLUID STRUCTURE
/COM, INTERACTION PROBLEMS"  SCHROEDER & MARCUS
/COM, SHOCK & VIBRATION SYMPOSIUM, SAN DIEGO, 1975
/COM, USING FLUID30 AND SHELL63 AND FULL HARMONIC ANALYSIS (ANTYPE=3)
/OUT,SCRATCH

ET,1,FLUID30,,                    ! FLUID ELEMENTS INTERFACING WITH STRUCTURE
ET,2,SHELL63                     ! SHELL ELEMENTS TO MODEL STEEL RING
ET,3,FLUID30,,1                  ! NON-INTERFACING FLUID ELEMENTS

R,1,1
R,2,0.25

MP,DENS,1,0.001156        ! DENSITY DEFINES IN SLUGS PER CUBIC INCH
MP,SONC,1,57480.0                ! SPEED OF SOUND IN WATER, INCHES PER SECOND
MP,EX,2,30.E6           ! DEFINES IN POUNDS PER SQUARE INCH
MP,DENS,2,0.0089       ! DENSITY DEFINES IN SLUGS PER CUBIC INCH
MP,NUXY,2,0.3

PI = ACOS(-1)

CSYS,1
N,1,10.0
N,7,30.0
FILL
NGEN,9,10,1,10,1,0,(90/8)
NGEN,2,100,1,99,1,0,0,1          ! DEFINE UPPER PLANE OF NODES
E,1,101,111,11,2,102,112,12
EGEN,6,1,-1
EGEN,8,10,-6

TYPE,2
REAL,2
MAT,2
E,1,101,111,11
EGEN,8,10,-1
NSEL,S,LOC,X,10.0
ESLN
ESEL,INVE

TYPE,3
REAL,1
MAT,1
EMODIF,ALL                       ! CHANGE ELEMENT TYPE TO TYPE 3
ESEL,ALL

NSEL,S,LOC,X,10
```

```
SF,ALL,FSI                      ! COUPLE STRUCTURAL MOTION & FLUID PRESS.
NSEL,ALL

D,7,PRES,0.0,,87,10             ! SET PRESSURE AT OUTER RADIUS TO ZERO
D,107,PRES,0.0,,187,10

NSEL,S,LOC,X,10.0
NSEL,R,LOC,Y,90.0
DSYM,SYMM,X
NSEL,S,LOC,X,10.0
NSEL,R,LOC,Y,0.0
DSYM,SYMM,Y
NSEL,ALL

D,1,UZ,0.0,,7,6
D,81,UZ,0.0,,87,6

F,1,FX,1.0                      ! EXCITE THE EVEN MODES OF VIBRATION
F,81,FY,0,1.0
SAVE
FINISH


/SOLU
ANTYPE,MODAL
MODOPT,UNSYM,5
MXPAND,5,,,YES
SOLVE
FINISH


/SOLU
ANTYPE,HARMIC                   ! FULL HARMONIC ANALYSIS
HARFRQ,10.56,10.58           ! SELECT FREQUENCY RANGE TO EXCITE THE 1ST MODE

NSUBST,10,10,10
KBC,1
OUTRES,,1
SOLVE
FINISH

/POST26
NSOL,2,1,U,X
NSOL,3,41,U,X
NSOL,4,81,U,Y
/OUT,
PRVAR,2,3,4                     ! PRINT DISPLACEMENTS OF RING VS. FREQUENCY
/COM,
/COM, GETTING THE FREQUENCY AT WHICH RESONANCE OCCURS
/COM, EXPECT THE FREQUENCY TO BE SAME FOR ALL 3 VARIABLES
/COM,
*GET,MAXFRQ1,VARI,2,EXTREM,TMAX
*GET,MAXFRQ2,VARI,3,EXTREM,TMAX
*GET,MAXFRQ3,VARI,4,EXTREM,TMIN
FINISH

/POST1
SET,1,4
PLDISP,1
SET,1,4,,1
PLDISP,1
*GET,F1,ACTIVE,0,SET,FREQ
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'F1'
LABEL(1,2) = 'Hz'
*VFILL,VALUE(1,1),DATA,10.198
*VFILL,VALUE(1,2),DATA,(MAXFRQ1)
*VFILL,VALUE(1,3),DATA,ABS(MAXFRQ1/10.198)
FINISH
SAVE,TABLE_1
/CLEAR, NOSTART                 ! CLEAR DATABASE BEFORE STARTING PART 2
```

```
/PREP7
/COM,
/COM, USING FLUID29 AND BEAM188 AND UNSYMMETRIC MATRIX MODAL ANALYSIS (ANTYPE=2)
/COM,
/OUT,SCRATCH

ET,1,FLUID29                    ! FLUID ELEMENTS INTERFACING WITH STRUCTURE
ET,2,BEAM188                    ! BEAM ELEMENTS TO MODEL STEEL RING
ET,3,FLUID29,,1                 ! NON-INTERFACING FLUID ELEMENTS

MP,EX,1,1
MP,DENS,1,0.001156    ! DENSITY DEFINES IN SLUGS PER CUBIC INCH
MP,SONC,1,57480.0               ! SPEED OF SOUND IN WATER, INCHES PER SECOND
MP,EX,2,30.E6     ! DEFINES IN POUNDS PER SQUARE INCH
MP,DENS,2,0.0089     ! DENSITY DEFINES IN SLUGS PER CUBIC INCH
MP,NUXY,2,0.3

R,1,1
SECT,2,BEAM,RECT
SECD,0.25,1
PI=ACOS(-1)
CSYS,1
N,1,10.0
N,7,30.0
FILL
NGEN,9,10,1,10,1,0,(90/8)
E,1,2,12,11                     ! DEFINE FLUID ELEMENTS INTERFACE WITH STRUCTURE
EGEN,6,1,-1
EGEN,8,10,-6
TYPE,2
MAT,2
SECN,2
E,1,11                          ! DEFINE BEAM ELEMENTS TO MODEL STEEL RING
EGEN,8,10,-1
ESEL,,TYPE,,2
NSLE
NSEL,R,LOC,Y,90
DSYM,SYMM,X                     ! APPLY SYMMETRY BOUNDARY CONDITION ON RING
NSLE
NSEL,R,LOC,Y,0
DSYM,SYMM,Y
ESEL,ALL
NSEL,S,LOC,X,10
ESLN
ESEL,INVE
TYPE,3
MAT,1
REAL,1
EMODIF,ALL                      ! DEFINE UNCOUPLED FLUID ELEMENTS
NSEL,ALL
ESEL,S,TYPE,,1                  ! DEFINE FLUID-STRUCTURE INTERFACE
NSEL,R,LOC,X,10
SF,ALL,FSI                      ! COUPLE STRUCTURAL MOTION & FLUID PRESS.
ESEL,ALL
NSEL,S,LOC,X,30
D,ALL,PRES,0.0                  ! SET PRESSURE AT OUTER RADIUS TO ZERO
NSEL,ALL
ESEL,S,TYPE,,2
NSLE
D,ALL,UZ,,,,,ROTX,ROTY
ALLS,ALL
FINISH
/SOLU
ANTYPE,MODAL                    ! MODAL ANALYSIS
MODOPT,UNSYM,4,               ! SELECT UNSYMMETRIC MATRIX MODE EXTRACTION
MXPAND,4,,,YES               ! EXPAND THE MODES

SOLVE
FINISH
/POST1
SET,1,1
```

```
PLDISP,1
/OUT,
*GET,F1,ACTIVE,0,SET,FREQ
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'F1'
LABEL(1,2) = 'Hz'
*VFILL,VALUE(1,1),DATA,10.198
*VFILL,VALUE(1,2),DATA,F1
*VFILL,VALUE(1,3),DATA,ABS(F1/10.198)
SAVE,TABLE_2
FINISH
/CLEAR, NOSTART                  ! CLEAR DATABASE BEFORE STARTING PART 3


/PREP7
/COM,
/COM,    USING FLUID30 AND SHELL181 AND FULL HARMONIC ANALYSIS (ANTYPE=3)
/COM,
/OUT,SCRATCH

ET,1,FLUID30,,                    ! FLUID ELEMENTS INTERFACING WITH STRUCTURE
ET,2,SHELL181,,,2                 ! SHELL ELEMENTS TO MODEL STEEL RING
ET,3,FLUID30,,1                   ! NON-INTERFACING FLUID ELEMENTS

R,1,1

SECTYPE,1,SHELL
SECDATA,0.25,2,0,3

MP,DENS,1,0.001156    ! DENSITY DEFINES IN SLUGS PER CUBIC INCH
MP,SONC,1,57480.0                ! SPEED OF SOUND IN WATER, INCHES PER SECOND
MP,EX,2,30.E6     ! DEFINES IN POUNDS PER SQUARE INCH
MP,DENS,2,0.0089     ! DENSITY DEFINES IN SLUGS PER CUBIC INCH
MP,NUXY,2,0.3

PI=ACOS(-1)
CSYS,1
N,1,10.0
N,7,30.0
FILL
NGEN,9,10,1,10,1,0,(90/8)
NGEN,2,100,1,99,1,0,0,1          ! DEFINE UPPER PLANE OF NODES
E,1,101,111,11,2,102,112,12
EGEN,6,1,-1
EGEN,8,10,-6

TYPE,2
SECNUM,1
MAT,2
E,1,101,111,11
EGEN,8,10,-1
NSEL,S,LOC,X,10.0
ESLN
ESEL,INVE
TYPE,3
REAL,1
MAT,1
EMODIF,ALL                       ! CHANGE ELEMENT TYPE TO TYPE 3
ESEL,ALL

NSEL,S,LOC,X,10
SF,ALL,FSI                       ! COUPLE STRUCTURAL MOTION & FLUID PRESS.
NSEL,ALL

D,7,PRES,0.0,,87,10              ! SET PRESSURE AT OUTER RADIUS TO ZERO
D,107,PRES,0.0,,187,10

NSEL,S,LOC,X,10.0
NSEL,R,LOC,Y,90.0
DSYM,SYMM,X
NSEL,S,LOC,X,10.0
```

```
NSEL,R,LOC,Y,0.0
DSYM,SYMM,Y
NSEL,ALL

D,1,UZ,0.0,,7,6
D,81,UZ,0.0,,87,6
F,1,FX,1.0
F,81,FY,0,1.0
ALLSEL,ALL
FINISH

/SOLU
ANTYPE,MODAL
MODOPT,UNSYM,5
MXPAND,5,,,YES
SOLVE
FINISH


/SOLU
ANTYPE,HARMIC                      ! FULL HARMONIC ANALYSIS
HARFRQ,10.64,10.66             ! SELECT FREQUENCY RANGE TO EXCITE THE 1ST MODE

NSUBST,10,10,10
KBC,1
OUTRES,,1
SOLVE
FINISH

/POST26
NSOL,2,1,U,X
NSOL,3,41,U,X
NSOL,4,81,U,Y
/OUT,
PRVAR,2,3,4                        ! PRINT DISPLACEMENTS OF RING VS. FREQUENCY
/COM,
/COM, GETTING THE FREQUENCY AT WHICH RESONANCE OCCURS
/COM, EXPECT THE FREQUENCY TO BE SAME FOR ALL 3 VARIABLES
/COM,
*GET,MAXFRQ1,VARI,2,EXTREM,TMAX
*GET,MAXFRQ2,VARI,3,EXTREM,TMAX
*GET,MAXFRQ3,VARI,4,EXTREM,TMIN

*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'F1'
LABEL(1,2) = 'Hz'
*VFILL,VALUE(1,1),DATA,10.198
*VFILL,VALUE(1,2),DATA,(MAXFRQ1)
*VFILL,VALUE(1,3),DATA,ABS(MAXFRQ1/10.198)
SAVE,TABLE_3
FINISH
/CLEAR,NOSTART

/PREP7
/COM,
/COM,    USING FLUID220 AND SHELL281 AND FULL HARMONIC ANALYSIS (ANTYPE=3)
/COM,
/OUT,SCRATCH

ET,1,FLUID220,,                    ! FLUID ELEMENTS INTERFACING WITH STRUCTURE
ET,2,SHELL281,,,                   ! SHELL ELEMENTS TO MODEL STEEL RING
ET,3,FLUID220,,1                   ! NON-INTERFACING FLUID ELEMENTS

R,1,1

SECTYPE,1,SHELL
SECDATA,0.25,2,0,3

MP,DENS,1,0.001156    ! DENSITY DEFINES IN SLUGS PER CUBIC INCH
MP,SONC,1,57480.0                  ! SPEED OF SOUND IN WATER, INCHES PER SECOND
MP,EX,2,30.E6     ! DEFINES IN POUNDS PER SQUARE INCH
```

```
MP,DENS,2,0.0089     ! DENSITY DEFINES IN SLUGS PER CUBIC INCH
MP,NUXY,2,0.3

PI=ACOS(-1)

CSYS,1

CYLINDER,10,30,0,-1,0,90

LSEL,S,LINE,,1,3,2
LSEL,A,LINE,,6,8,2
LESIZE,ALL,,,6
LSEL,ALL

LSEL,S,LINE,,2,4,2
LSEL,A,LINE,,5,7,2
LESIZE,ALL,,,8
LSEL,ALL

LSEL,S,LINE,,9,12,1
LESIZE,ALL,,,1
LSEL,ALL

TYPE,1
MAT,1
REAL,1
VMESH,1
ALLSEL,ALL

NSEL,S,LOC,X,10.0
ESLN
ESEL,INVE
TYPE,3
REAL,1
MAT,1
EMODIF,ALL
ALLSEL,ALL

TYPE,2
SECNUM,1
MAT,2
ASEL,S,AREA,,4
NSLA,S,1
ESURF
ALLSEL,ALL

ESEL,S,TYPE,,1
NSLE,S
NSEL,R,LOC,X,10
SF,ALL,FSI
ALLSEL,ALL

NSEL,S,LOC,Y,0,90
NSEL,R,LOC,X,30
D,ALL,PRES,0
NSEL,ALL

NSEL,S,LOC,X,10
NSEL,R,LOC,Y,90
DSYM,SYMM,X
NSEL,S,LOC,X,10.0
NSEL,R,LOC,Y,0.0
DSYM,SYMM,Y
NSEL,ALL

NSEL,S,NODE,,203
NSEL,A,NODE,,174
NSEL,A,NODE,,191
NSEL,A,NODE,,175
D,ALL,UZ,0
NSEL,ALL
ALLSEL,ALL
```

```
F,203,FX,1.0
F,191,FY,0,1.0
FINI

/SOLU
ANTYPE,MODAL
MODOPT,UNSYM,5
MXPAND,5,,,YES
SOLVE
FINISH


/SOLU
ANTYPE,HARMIC                    ! FULL HARMONIC ANALYSIS
HARFRQ,10.27,10.29             ! SELECT FREQUENCY RANGE TO EXCITE THE 1ST MODE

NSUBST,10,10,10
KBC,1
OUTRES,,1
SOLVE
FINISH

/POST26
NSOL,2,203,U,X
NSOL,3,211,U,X
NSOL,4,191,U,Y
/OUT,
PRVAR,2,3,4                      ! PRINT DISPLACEMENTS OF RING VS. FREQUENCY
/COM,
/COM, GETTING THE FREQUENCY AT WHICH RESONANCE OCCURS
/COM, EXPECT THE FREQUENCY TO BE SAME FOR ALL 3 VARIABLES
/COM,
*GET,MAXFRQ1,VARI,2,EXTREM,TMAX
*GET,MAXFRQ2,VARI,3,EXTREM,TMAX
*GET,MAXFRQ3,VARI,4,EXTREM,TMIN

*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'F1'
LABEL(1,2) = 'Hz'
*VFILL,VALUE(1,1),DATA,10.198
*VFILL,VALUE(1,2),DATA,(MAXFRQ1)
*VFILL,VALUE(1,3),DATA,ABS(MAXFRQ1/10.198)
SAVE,TABLE_4
FINISH
/CLEAR,NOSTART

/PREP7
/COM,
/COM,    USING FLUID221 AND SHELL281 AND FULL HARMONIC ANALYSIS (ANTYPE=3)
/COM,
/OUT,SCRATCH

ET,1,FLUID221,,                  ! FLUID ELEMENTS INTERFACING WITH STRUCTURE
ET,2,SHELL281,,,                 ! SHELL ELEMENTS TO MODEL STEEL RING
ET,3,FLUID221,,1                 ! NON-INTERFACING FLUID ELEMENTS

R,1,1

SECTYPE,1,SHELL
SECDATA,0.25,2,0,3

MP,DENS,1,0.001156    ! DENSITY DEFINES IN SLUGS PER CUBIC INCH
MP,SONC,1,57480.0           ! SPEED OF SOUND IN WATER, INCHES PER SECOND
MP,EX,2,30.E6     ! DEFINES IN POUNDS PER SQUARE INCH
MP,DENS,2,0.0089   ! DENSITY DEFINES IN SLUGS PER CUBIC INCH
MP,NUXY,2,0.3

PI=ACOS(-1)

CSYS,1
```

```
CYLINDER,10,30,0,-1,0,90

LSEL,S,LINE,,1,3,2
LSEL,A,LINE,,6,8,2
LESIZE,ALL,,,8
LSEL,ALL

LSEL,S,LINE,,2,4,2
LSEL,A,LINE,,5,7,2
LESIZE,ALL,,,10
LSEL,ALL

LSEL,S,LINE,,9,12,1
LESIZE,ALL,,,1
LSEL,ALL

TYPE,1
MAT,1
REAL,1
VMESH,1
ALLSEL,ALL

NSEL,S,LOC,X,10.0
ESLN
ESEL,INVE
TYPE,3
REAL,1
MAT,1
EMODIF,ALL
ALLSEL,ALL

TYPE,2
SECNUM,1
MAT,2
ASEL,S,AREA,,4
NSLA,S,1
ESURF
ALLSEL,ALL

ESEL,S,TYPE,,1
NSLE,S
NSEL,R,LOC,X,10
SF,ALL,FSI
ALLSEL,ALL

NSEL,S,LOC,Y,0,90
NSEL,R,LOC,X,30
D,ALL,PRES,0
NSEL,ALL

NSEL,S,LOC,X,10
NSEL,R,LOC,Y,90
DSYM,SYMM,X
NSEL,S,LOC,X,10.0
NSEL,R,LOC,Y,0.0
DSYM,SYMM,Y
NSEL,ALL

NSEL,S,NODE,,386
NSEL,A,NODE,,387
NSEL,A,NODE,,423
NSEL,A,NODE,,407
D,ALL,UZ,0
NSEL,ALL
ALLSEL,ALL

F,423,FX,1.0
F,407,FY,0,1.0
FINI

/SOLU
```

```
ANTYPE,MODAL
MODOPT,UNSYM,5
MXPAND,5,,,YES
SOLVE
FINISH

/SOLU
ANTYPE,HARMIC                     ! FULL HARMONIC ANALYSIS
HARFRQ,10.33,10.35                ! SELECT FREQUENCY RANGE TO EXCITE THE 1ST BENDING MODE

NSUBST,10,10,10
KBC,1
OUTRES,,1
SOLVE
FINISH

/POST26
NSOL,2,423,U,X
NSOL,3,433,U,X
NSOL,4,407,U,Y
/OUT,
PRVAR,2,3,4                       ! PRINT DISPLACEMENTS OF RING VS. FREQUENCY
/COM,
/COM, GETTING THE FREQUENCY AT WHICH RESONANCE OCCURS
/COM, EXPECT THE FREQUENCY TO BE SAME FOR ALL 3 VARIABLES
/COM,
*GET,MAXFRQ1,VARI,2,EXTREM,TMAX
*GET,MAXFRQ2,VARI,3,EXTREM,TMAX
*GET,MAXFRQ3,VARI,4,EXTREM,TMIN

*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'F1'
LABEL(1,2) = 'Hz'
*VFILL,VALUE(1,1),DATA,10.198
*VFILL,VALUE(1,2),DATA,(MAXFRQ1)
*VFILL,VALUE(1,3),DATA,ABS(MAXFRQ1/10.198)
SAVE,TABLE_5
FINISH
/CLEAR,NOSTART
/NOPR
RESUME,TABLE_1
/COM
/OUT,vm177,vrt
/COM,------------------- VM177 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS USING FLUID30 & SHELL63
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING FLUID29 & BEAM188
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM,RESULTS USING FLUID30 & SHELL181
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_4
/GOPR
/COM,
```

```
/COM,RESULTS USING FLUID220 & SHELL281
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_5
/GOPR
/COM,
/COM,RESULTS USING FLUID221 & SHELL281
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm177,vrt
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
/DELETE,TABLE_4
/DELETE,TABLE_5
```

VM178 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM178
/TITLE, VM178, TWO DIMENSIONAL DOUBLE CANTILEVER BEAM PROBLEM
/COM, REFERENCE:" J.F.MANDELL, ET AL., PREDICTION OF DELAMINATION IN
/COM,             WIND TURBINE BLADE STRUCTURAL DETAILS
/COM,             JOURNAL OF SOLAR ENERGY ENGINEERING, VOL. 25, 2003, PG: 522-530
/COM,
/OUT,SCRATCH
/PREP7
DL=200                      ! WIDTH OF BEAM
DH=10                       ! THICKNESS OF BEAM
PP=10                       ! LOADING
A=DL*0.3                    ! CRACK LENGTH
ET,1,PLANE182               ! 2D 4-NODE STRUCTURAL SOLID ELEMENT
KEYOPT,1,3,2                ! PLANE STRAIN

!MATERIAL PROPERTIES
YOUNG = 210000              ! YOUNG'S MODULUS
NU = 0.3                    ! POISSION'S RATIO
MP,EX,1,YOUNG               !MPa
MP,PRXY,1,NU

RECTNG,0,DL,DH/2            !DEFINE AREAS
RECTNG,0,DL,0,-DH/2
LSEL,S,LINE,,2,8,2          !DEFINE LINE DIVISION
LESIZE,ALL,DH/4
LSEL,INVE
LESIZE,ALL, , ,200
ALLSEL,ALL
TYPE,1                      !MESH AREAS
AMESH,1,2
NSEL,S,LOC,X,A,DL
NUMMRG,NODES
ALLSEL

NSEL,S,LOC,X,DL             !APPLY CONSTRAINTS
D,ALL,ALL
NSEL,ALL

NSEL,S,LOC,X,A
NSEL,R,LOC,Y,0
CM,CRACK1,NODE
ALLS
FINISH
```

```
/OUT,SCRATCH
/SOLU
NSEL,S,LOC,X
NSEL,R,LOC,Y,DH/2           !APPLY LOADING
F,ALL,FY,PP
NSEL,S,LOC,X
NSEL,R,LOC,Y,-DH/2          !APPLY LOADING
F,ALL,FY,-PP
NSEL,ALL

CINT,NEW,1                  ! DEFINE CRACK ID
CINT,TYPE,VCCT
CINT,CTNC,CRACK1            ! DEFINE CRACK TIP NODE COMPONENT
CINT,SYMM,OFF               ! SYMMETRY OFF
CINT,NORMAL                 ! DEFINE CRACK PLANE NORMAL
CINT,LIST
ALLSEL,ALL

SOLVE
FINISH

/OUT,SCRATCH
/POST1
/SHOW
/ESHAPE,1
/GRAPHICS,POWER
PRCINT,1
CRACK=NODE(A,0.0,0.0)
*GET,G1_ANSYS,CINT,1,,CRACK,,1,,G1
*GET,G2_ANSYS,CINT,1,,CRACK,,1,,G2
PLNSOL, U,Y, 0,1.0
*GET,UY_MIN,PLNSOL,0,MIN
*GET,UY_MAX,PLNSOL,0,MAX
CC=UY_MAX-UY_MIN            ! Displacement between cantilever arms at critical load

/OUT
G_ANSYS=ABS(G1_ANSYS)+ABS(G2_ANSYS)
G_REF=(3*PP*CC)/(2*A*1)          ! equation (1) in the reference, B=1 for this case
/COM
/OUT,vm178,vrt
/COM, -------------- VM 178 RESULTS COMPARISON -------------
/COM,
/COM,              |  TARGET    |      Mechanical APDL     |  RATIO
/COM,
/COM,      G COMPUTATION FOR VCCT
/COM,
*VWRITE, 'G',  G_REF, G_ANSYS, G_ANSYS/G_REF
(1X,A8,'     ', F10.5, '       ', F14.5, '     ', F15.3)
/OUT
FINISH
*LIST, vm178,vrt
```

VM179 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM179
/PREP7
/TITLE, VM179, DYNAMIC DOUBLE ROTATION OF A JOINTED BEAM
C***   REFERENCE -- ANY BASIC MECHANICS TEXT
ANTYPE,TRANS                ! FULL TRANSIENT DYNAMIC ANALYSIS
NLGEOM,ON                   ! LARGE DEFLECTION
TRNOPT,FULL,,,,,HHT         ! USE HHT METHOD
TINTP,.1                    ! 10 PERCENT NUMERICAL DAMPING
ET,1,MPC184,6,,,0           ! REVOLUTE JOINT
ET,2,BEAM188,,,3
ET,3,MASS21
R,1,,,,,.25,.25
```

```
SECT,2,BEAM,RECT
SECD,1,1
MP,EX,1,70E9                 ! ALUMINUM MATERIAL PROPERTIES
MP,DENS,1,1E-6
MP,NUXY,1,.35
N,1,0
N,2,1.0
N,3,1.0
N,4,2.0
TYPE,3
REAL,1
E,2
E,3
TYPE,2
SECNUM,2
MAT,1
E,1,2                        ! BEAM ELEMENTS
E,3,4
SECTYPE,1,JOINT,REVO
LOCAL,11,0,1,0,0,90,0,0
SECJOINT,,11,11
SECLOCK,4,-0.08727,0.08727  ! JOINT LOCK-UP WHEN STOP ENGAGED
TYPE,1
SECN,1
E,2,3                        ! JOINT ELEMENT
D,1,UX,0,,,,UY,UZ,ROTX,ROTY ! ALLOW ONLY Z-ROTATION AT PINNED END
KBC,1
FINISH
/OUTPUT,SCRATCH              ! SEND SUBSEQUENT OUTPUT TO SCRATCH FILE
/SOLU
PRED,ON
CNVTOL,M
NSUBST,100,1000,10
F,1,MZ,.7854                 ! BEGIN ROTZ WITH NON-ZERO ACCELERATION
TIME,.05
SOLVE
NSUBST,60
TIME,1               ! DELTA THETA-Z = 45 DEG. ( AT 1 SEC )
SOLVE
F,1,MZ,-.7854        ! SLOW ROTZ W/ "INSTANTANEOUS" REVERSAL OF APPLIED MOMENT
TIME,1.05
SOLVE
NSUBST,60
TIME,2               ! DELTA THETA-Z = 90 DEG. ( AT 2 SEC )
SOLVE
FINISH
/POST1
SET,2
PRNSOL,DOF
*GET,DX1,NODE,4,U,X
*GET,DY1,NODE,4,U,Y
*GET,RZ1,NODE,4,ROT,Z
ESEL,S,TYPE,,1
ETABLE,ROT_STAT,NMISC,1
ETABLE,ROTATE,NMISC,9
ESEL,ALL
PRETAB,ROTATE,ROT_STAT
SET,4
PRNSOL,DOF
*GET,DX2,NODE,4,U,X
*GET,DY2,NODE,4,U,Y
*GET,RZ2,NODE,4,ROT,Z
ESEL,S,TYPE,,1
ETABLE,REFL
ESEL,ALL
PRETAB,ROTATE,ROT_STAT
FINISH
PARSAV
/COPY,,rdb,,rest,rdb           ! SAVE THE FILES NEEDED FOR RESTART (NOT NEEDED
/COPY,,ldhi,,rest,ldhi         ! FOR STRAIGHT-THRU RUN)
/COPY,,r001,,rest,r001
/COPY,,rst,,rest,rst           ! NEEDED FOR CONTINUITY OF THE RESULTS FILE
```

```
/CLEAR,NOSTART                ! CLEAR THE DATABASE (TO SIMULATE RESTART)
/COM,
/COM,        -----     RESTART  ANALYSIS    -----
/COPY,rest,rdb,,file,rdb      ! COPY THE FILES NEEDED FOR RESTART (NOT NEEDED
/COPY,rest,ldhi,,file,ldhi    ! FOR STRAIGHT-THRU RUN)
/COPY,rest,r001,,file,r001
/COPY,rest,rst,,file,rst
/SOLU
ANTYPE,,REST         ! USE RESTART ANALYSIS TO DEFINE MORE LOADSTEPS
F,1,MZ,0             ! REMOVE M1, ALLOW ROTZ MOTION TO STABILIZE
TIME,2.05
SOLVE
NSUBST,60
FJ,5,MX,-0.5         ! DELTA THETA-X = 5 DEG., THEN STOP ( AT 3 SEC )
TIME,3
SOLVE
FINISH
PARRES               ! RESTORE PARAMETERS FROM INITIAL RUN
/POST1
SET,LAST
PRNSOL,DOF
*GET,DX3,NODE,4,U,X
*GET,DY3,NODE,4,U,Y
*GET,DZ3,NODE,4,U,Z
*GET,RX3,NODE,4,ROT,X
*GET,RZ3,NODE,4,ROT,Z
ESEL,S,TYPE,,1
ETABLE,ROT_STAT,NMISC,1
ETABLE,ROTATE,NMISC,9
ESEL,ALL
PRETAB,ROTATE,ROT_STAT
*status,parm
*DIM,LABEL,CHAR,11,2
*DIM,VALUE,,11,3
LABEL(1,1) = 'DX T1 ','DY T1 ','AZ T1 ','DX T2 ','DY T2 '
LABEL(6,1) = 'AZ T2 ','DX T3 ','DY T3 ','DZ T3 ','AX T3 ','AZ T3 '
LABEL(1,2) = 'in','in','rad','in','in','rad','in','in','in'
LABEL(10,2) = 'RAD','RAD'
*VFILL,VALUE(1,1),DATA,-.5858,1.4142,.7854,-2,2,1.5708,-2,1.9962,.08716
*VFILL,VALUE(10,1),DATA,.08727,1.5708
*VFILL,VALUE(1,2),DATA,DX1,DY1,RZ1,DX2,DY2,RZ2,DX3,DY3,DZ3
*VFILL,VALUE(10,2),DATA,RX3,RZ3
V1 = ABS(DX1/.5858)
V2 = (DY1/1.4142)
V3 = (RZ1/.7854)
V4 = ABS(DX2/2)
V5 = (DY2/2)
V6 = (RZ2/1.5708)
V7 = ABS(DX3/2)
V8 = (DY3/1.9962)
*VFILL,VALUE(1,3),DATA,V1,V2,V3,V4,V5,V6,V7,V8
*VFILL,VALUE(9,3),DATA,(DZ3/.08716),(RX3/.08727),(RZ3/1.5708)
/COM
/OUT,vm179,vrt
/COM,------------------- VM179 RESULTS COMPARISON -------------
/COM,
/COM,                |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT

FINISH
*LIST,vm179,vrt
```

VM180 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM180
/PREP7
smrt,off
/TITLE, VM180, BENDING OF A CURVED BEAM
C***    THEORY OF ELASTICITY, TIMOSHENKO & GOODIER, 3RD ED., P. 78
ANTYPE,STATIC         ! STATIC ANALYSIS
ET,1,PLANE183
ET,2,BEAM188
KEYOPT,2,3,3
SECT,2,BEAM,ASEC
SECD,1,1,,1,,1E-6
MP,EX,1,30E6
MP,NUXY,1,0
CSYS,1
K,1,3.5
K,2,3.5,90
KGEN,2,1,2,1,1.0
L,2,4                 ! CREATE STIFFENING BEAM ELEMENTS
LESIZE,1,,,4
TYPE,2
SECN,2
LMESH,1
L,1,2                 ! CREATE CURVED BEAM
LESIZE,2,,,25
L,3,4
LESIZE,3,,,25
ESIZE,,4
A,1,2,4,3
AATT,1,1,1
MSHAPE,1,2D
MSHKEY,0
AMESH,1
NROTAT,ALL
ESEL,S,TYPE,,2
NSLE
D,ALL,UZ,,,,,ROTX,ROTY
ALLS
DK,1,ALL,,,1          ! DEFINE KEYPOINT CONSTRAINTS AND FORCES
DK,3,UY,,,1           ! IN GLOBAL CYLINDRICAL COORDINATE SYSTEM
FK,2,FY,100
FK,4,FY,-100
FINISH
/SOLU
SOLVE
FINISH
/POST1
RSYS,1
NSEL,R,LOC,X,3.5      ! SELECT INNER RADIUS NODES
NSEL,U,LOC,Y,90
PRNSOL,S,COMP
NSORT,S,Y
*GET,SI,SORT,,MAX
NSEL,ALL
NSEL,R,LOC,X,4.5      ! SELECT OUTER RADIUS NODES
NSEL,U,LOC,Y,90
PRNSOL,S,COMP
NSORT,S,Y
*GET,SO,SORT,,MIN
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'INR STR ','OTR STR '
LABEL(1,2) = 'psi ','psi '
*VFILL,VALUE(1,1),DATA,655,-555
*VFILL,VALUE(1,2),DATA,SI,SO
*VFILL,VALUE(1,3),DATA,ABS(SI/655),ABS(SO/555)
/COM
/OUT,vm180,vrt
/COM,------------------- VM180 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
```

```
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm180,vrt
```

VM181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM181
/PREP7
SMRT,OFF
/TITLE, VM181, NATURAL FREQUENCY OF A FLAT CIRCULAR PLATE WITH A CLAMPED EDGE
C***          FORMULAS FOR NATURAL FREQUENCY AND MODE SHAPE, BLEVINS, PAGE 241
ET,1,PLANE183,,,1       ! AXISYMMETRIC ELEMENTS
MP,EX,1,3E7
MP,DENS,1,0.00073
MP,PRXY,1,0.3
K,1
K,2,17
KGEN,2,1,2,1,,.5
L,1,2
L,3,4
LESIZE,ALL,,,10        ! TEN DIVISIONS ALONG LENGTH
ESIZE,,1
A,1,2,4,3
MSHAPE,1,2D
MSHKEY,0
AMESH,1
NSEL,R,LOC,X,0
D,ALL,UX
NSEL,ALL
DK,2,ALL,,,1
DK,4,UX,,,1
FINISH
/SOLU
ANTYPE,MODAL           ! MODAL ANALYSIS
MODOPT,LANP,9
SOLVE
*GET,F1,MODE,1,FREQ
*GET,F2,MODE,2,FREQ
*GET,F3,MODE,3,FREQ
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'F (0,0) ','F (0,1) ','F (0,2) '
LABEL(1,2) = 'Hz','Hz','Hz'
*VFILL,VALUE(1,1),DATA,172.64,671.79,1505.7
*VFILL,VALUE(1,2),DATA,F1,F2,F3
*VFILL,VALUE(1,3),DATA,ABS(F1/172.64),ABS(F2/671.79),ABS(F3/1505.7)
/COM
/OUT,vm181,vrt
/COM,------------------- VM181 RESULTS COMPARISON --------------
/COM,
/COM,              |    TARGET   |        Mechanical APDL   |        RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F18.2,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm181,vrt
```

VM182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM182
/PREP7
/TITLE, VM182; TRANSIENT RESPONSE OF A SPRING-MASS SYSTEM
C***                   R. K. VIERCK, "VIBRATION ANALYSIS", 2ND EDITION, SEC.5-8
ANTYPE,MODAL              ! MODE-FREQUENCY ANALYSIS
MODOPT,LANB,2,,,          ! PRINT TWO REDUCED MODE SHAPES
ET,1,COMBIN40,,,2         ! UY DOF
R,1,6,,2                  ! K1=6 N/M     M1=2 KG
R,2,16,,2                 ! K2=16 N/M    M2=2 KG
N,1
N,2,0,1
N,3,0,2
REAL,1
E,1,2
REAL,2
E,2,3
D,3,ALL
OUTPR,,ALL
FINISH
/SOLU
SOLVE
FINISH
/SOLU
ANTYPE,TRANS              ! TRANSIENT DYNAMIC ANALYSIS
TRNOPT,MSUP,2             ! MODE SUPERPOSITION, BOTH MODES
DELTIM,0.01               ! INTEGRATION TIME STEP = .01
OUTPR,,NONE
OUTRES,,1
KBC,1                     ! STEP BOUNDARY CONDITIONS
F,1,FY,0                  ! FORCE = 0 AT TIME = 0 (INIT. CONDITIONS)
SOLVE
TIME,1.8
F,1,FY,50                 ! FORCE = 50N FROM TIME = 0 TO 1.8 SEC
SOLVE
TIME,2.4
F,1,FY,0                  ! FORCE = 0 FROM TIME = 1.8 TO 2.4 SEC
SOLVE
FINISH
/POST26
FILE,,rdsp                ! REDUCED DISPLACEMENTS FILE
NSOL,2,1,U,Y,UY1
NSOL,3,2,U,Y,UY2
/GRID,1
/AXLAB,Y,DISP
PLVAR,2,3                 ! DISPLAY DISPLACEMENT RESPONSE VS. TIME
PRVAR,2,3
*GET,Y1,VARI,2,RTIME,1.3
*GET,Y2,VARI,3,RTIME,1.3
*GET,Y3,VARI,2,RTIME,2.4
*GET,Y4,VARI,3,RTIME,2.4
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'DISP 1 ','DISP 2 '
LABEL(1,2) = 'm','m'
*VFILL,VALUE(1,1),DATA,14.48,3.99
*VFILL,VALUE(1,2),DATA,Y1,Y2
*VFILL,VALUE(1,3),DATA,ABS(Y1/14.48),ABS(Y2/3.99)
SAVE,TABLE_1
*VFILL,VALUE(1,1),DATA,18.32,6.14
*VFILL,VALUE(1,2),DATA,Y3,Y4
*VFILL,VALUE(1,3),DATA,ABS(Y3/18.32),ABS(Y4/6.14),
SAVE,TABLE_2
RESUME,TABLE_1
/COM
/OUT,vm182,vrt
/COM,------------------- VM182 RESULTS COMPARISON --------------
```

```
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS AT T=1.3 S
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS AT T=2.4 S
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
/DELETE,TABLE_1
/DELETE,TABLE_2
FINISH
*LIST,vm182,vrt
```

VM183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM183
/PREP7
/TITLE, VM183,  HARMONIC RESPONSE OF A SPRING-MASS SYSTEM
C***  R.K. VIERCK, "VIBRATION ANALYSIS", 2ND EDITION, SECTION 4-2
ANTYPE,MODAL           ! MODE - FREQUENCY ANALYSIS
MODOPT,LANB,2,,,
ET,1,COMBIN40,,,2      ! UY DOF
R,1,6,,2               ! K1=6 N/M     M1=2 KG
R,2,16,,2              ! K2=16 N/M    M2=2 KG
N,1
N,2,0,1
N,3,0,2
REAL,1
E,1,2
REAL,2
E,2,3
OUTPR,,ALL
D,3,ALL
FINISH
/SOLU
SOLVE
FINISH
/SOLU
ANTYPE,HARMIC          ! HARMONIC ANALYSIS
HROPT,MSUP,2           ! MODE SUPERPOSITION USING TWO MODES
HARFRQ,0.1,1.0         ! RANGE OF FREQUENCIES FROM 0.1 TO 1.0 HZ
F,1,FY,50
KBC,1                  ! STEP BOUNDARY CONDITIONS
NSUBST,50
OUTPR,,NONE
OUTRES,,1
SOLVE
FINISH
/POST26
FILE,,rfrq             ! REDUCED FREQUENCIES FILE
NSOL,2,1,U,Y,UY1
NSOL,3,2,U,Y,UY2
/GRID,1
/AXLAB,Y,DISP
PLVAR,2,3              ! DISPLAY DISPLACEMENT RESPONSE VS. FREQUENCY
PRVAR,2,3
*GET,Y1,VARI,2,RTIME,.226
*GET,Y2,VARI,3,RTIME,.226
*GET,Y3,VARI,2,RTIME,.910
```

```
*GET,Y4,VARI,3,RTIME,.910
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'DISP 1 ','DISP 2 '
LABEL(1,2) = 'm','m'
*VFILL,VALUE(1,1),DATA,-1371.7,-458.08
*VFILL,VALUE(1,2),DATA,Y1,Y2
*VFILL,VALUE(1,3),DATA,ABS(Y1/1371.7),ABS(Y2/458.08)
SAVE,TABLE_1
*VFILL,VALUE(1,1),DATA,-.8539,.1181
*VFILL,VALUE(1,2),DATA,Y3,Y4
*VFILL,VALUE(1,3),DATA,ABS(Y3/.8539),ABS(Y4/.1181),
SAVE,TABLE_2
RESUME,TABLE_1
/COM
/OUT,vm183,vrt
/COM,------------------- VM183 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS AT .226 Hz
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS AT .910 Hz
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm183,vrt

/DELETE,TABLE_1
/DELETE,TABLE_2
FINISH
```

VM184 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM184
/PREP7
smrt,off
/TITLE, VM184, STRAIGHT CANTILEVER BEAM
C***  ANY BASIC MECHANICS OF MATERIALS TEXT
C***  USING SOLID5 HEXAHEDRONS
ANTYPE,STATIC         ! STATIC ANALYSIS
ET,1,SOLID5,2         ! MULTI-FIELD SOLID5
MP,EX,1,1E7
MP,NUXY,1,0.3
K,1
K,2,6
KGEN,2,1,2,1,,.2
KGEN,2,1,4,1,,,.1
L,1,2
LESIZE,ALL,,,10
ESIZE,,1
V,1,2,4,3,5,6,8,7
VMESH,1
NSEL,S,LOC,X,0
D,ALL,ALL              ! CONSTRAIN LEFT END
NSEL,ALL
FK,2,FX,0.25           ! APPLY AXIAL FORCES
*REPEAT,4,2
NOORDER
FINISH
```

```
/SOLU
SOLVE
FKDELE,ALL,FX           ! DELETE AXIAL FORCES
FK,2,FY,0.25            ! APPLY IN-PLANE LOADS
*REPEAT,4,2
SOLVE
FKDELE,ALL,FY           ! DELETE IN-PLANE LOADS
FK,2,FZ,0.25            ! APPLY OUT-OF-PLANE LOADS
*REPEAT,4,2
SOLVE
FINISH
/POST1                  ! PRINT END DISPLACEMENTS AS RATIO OF Mechanical APDL:TARGET
CSYS,0
*CREATE,MAC             ! DEFINE MACRO TO CALCULATE Mechanical APDL:TARGET RATIOS
SET,ARG1,1
LCDEF,ARG1,ARG1
NSEL,S,LOC,X,6          ! SELECT NODE AT END OF BEAM
PRNSOL,U,COMP           ! PRINT DISPLACEMENTS
LCFACT,ARG1,ARG2        ! APPLY SCALE FACTOR "ARG2" TO LOAD CASE 1
LCASE,ARG1
PRNSOL,U,COMP           ! PRINT DISPLACEMENTS
*END
/COM                    *** USE MACRO TO PROCESS ALL 3 LOADCASES  ***
*USE,MAC,1,(1/3E-5)
SET,1,1
LCSEL,S,0,0
N1=NODE(6,0,0)
*GET,UX1,NODE,N1,U,X
*USE,MAC,2,(1/.108)
SET,2,1
LCSEL,S,0,0
*GET,UY1,NODE,N1,U,Y
*USE,MAC,3,(1/.432)
SET,3,1
LCSEL,S,0,0
*GET,UZ1,NODE,N1,U,Z
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'DEFL X ','DEFL Y ','DEFL Z '
LABEL(1,2) = 'in','in','in'
*VFILL,VALUE(1,1),DATA,3E-5,.108,.432
*VFILL,VALUE(1,2),DATA,UX1,UY1,UZ1
*VFILL,VALUE(1,3),DATA,ABS(UX1/(3E-5)),ABS(UY1/.108),ABS(UZ1/.432)
SAVE,TABLE_1
FINISH
/CLEAR, NOSTART
/PREP7
smrt,off
MOPT,VMESH,MAIN
MOPT,AMESH,ALTE
/TITLE, VM184, STRAIGHT CANTILEVER BEAM
C***  USING SOLID92 TETRAHEDRONS
ANTYPE,STATIC           ! STATIC ANALYSIS
ET,1,SOLID92            ! STRUCTURAL SOLID92
MP,EX,1,1E7
MP,NUXY,1,0.3
K,1
K,2,,.2
KGEN,2,1,2,1,,,.1
KGEN,2,1,4,1,(2/3)
ESIZE,,1
V,1,2,4,3,5,6,8,7
VMESH,1
VGEN,9,1,1,1,(2/3),,,4 ! GENERATE 9 VOLUMES TO COMPLETE BEAM
NSEL,S,LOC,X,0
D,ALL,ALL               ! CONSTRAIN LEFT END
SAVE
/COM                    *** GET NODE NUMBERS FOR LOAD APPLICATION ***
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.1
NSEL,R,LOC,Z,.05
*GET,MIDD,NDMX
```

```
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.2
NSEL,R,LOC,Z,.05
*GET,TOPP,NDMX
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.0
NSEL,R,LOC,Z,.05
*GET,BOTT,NDMX
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.1
NSEL,R,LOC,Z,.10
*GET,LFT,NDMX
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.1
NSEL,R,LOC,Z,.00
*GET,RGHT,NDMX
NSEL,ALL
/COM                   *** APPLY LOADS TO PARAMETRIC NODE NUMBERS ***
F,RGHT,FX,(1/6)
F,LFT,FX,(1/6)
F,TOPP,FX,(1/6)
F,BOTT,FX,(1/6)
F,MIDD,FX,(1/3)
FINISH
/SOLU
SOLVE
FDELE,ALL              ! REMOVE ALL FORCES
F,RGHT,FY,(1/6)
F,LFT,FY,(1/6)
F,TOPP,FY,(1/6)
F,BOTT,FY,(1/6)
F,MIDD,FY,(1/3)
SOLVE
FDELE,ALL              ! REMOVE ALL FORCES
F,RGHT,FZ,(1/6)
F,LFT,FZ,(1/6)
F,TOPP,FZ,(1/6)
F,BOTT,FZ,(1/6)
F,MIDD,FZ,(1/3)
SOLVE
FINISH
/POST1                 ! PRINT END DISPLACEMENTS AS RATIO OF Mechanical APDL:TARGET
/COM                   *** USE MACRO TO PROCESS ALL 3 LOADCASES  ***
*USE,MAC,1,(1/3E-5)
SET,1,1
LCSEL,S,0,0
N1=NODE(6,0,0)
*GET,UX2,NODE,N1,U,X
*USE,MAC,2,(1/.108)
SET,2,1
LCSEL,S,0,0
*GET,UY2,NODE,N1,U,Y
*USE,MAC,3,(1/.432)
SET,3,1
LCSEL,S,0,0
*GET,UZ2,NODE,N1,U,Z
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'DEFL X ','DEFL Y ','DEFL Z '
LABEL(1,2) = 'in','in','in'
*VFILL,VALUE(1,1),DATA,3E-5,.108,.432
*VFILL,VALUE(1,2),DATA,UX2,UY2,UZ2
*VFILL,VALUE(1,3),DATA,ABS(UX2/(3E-5)),ABS(UY2/.108),ABS(UZ2/.432)
SAVE,TABLE_2
FINISH
/CLEAR, NOSTART
/PREP7
smrt,off
MOPT,VMESH,MAIN
MOPT,AMESH,ALTE
/COM                   *** REPEAT USING SOLID98 TETRAHEDRONS ***
RESUME                 ! RESTORE PREP7 DATABASE
```

```
ET,1,SOLID98,2          ! MULTI-FIELD SOLID98
/COM                    *** GET NODE NUMBERS FOR LOAD APPLICATION ***
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.1
NSEL,R,LOC,Z,.05
*GET,MIDD,NDMX
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.2
NSEL,R,LOC,Z,.05
*GET,TOPP,NDMX
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.0
NSEL,R,LOC,Z,.05
*GET,BOTT,NDMX
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.1
NSEL,R,LOC,Z,.10
*GET,LFT,NDMX
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.1
NSEL,R,LOC,Z,.0
*GET,RGHT,NDMX
NSEL,ALL
/COM                    *** APPLY LOADS TO PARAMETRIC NODE NUMBERS ***
F,RGHT,FX,(1/6)
F,LFT,FX,(1/6)
F,TOPP,FX,(1/6)
F,BOTT,FX,(1/6)
F,MIDD,FX,(1/3)
FINISH
/SOLU
SOLVE
FDELE,ALL               ! REMOVE ALL FORCES
F,RGHT,FY,(1/6)
F,LFT,FY,(1/6)
F,TOPP,FY,(1/6)
F,BOTT,FY,(1/6)
F,MIDD,FY,(1/3)
SOLVE
FDELE,ALL               ! REMOVE ALL FORCES
F,RGHT,FZ,(1/6)
F,LFT,FZ,(1/6)
F,TOPP,FZ,(1/6)
F,BOTT,FZ,(1/6)
F,MIDD,FZ,(1/3)
SOLVE
FINISH
/POST1                  ! PRINT END DISPLACEMENTS AS RATIO OF Mechanical APDL:THEORY
/COM                    *** USE MACRO TO PROCESS ALL 3 LOADCASES  ***
*USE,MAC,1,(1/3E-5)
SET,1,1
LCSEL,S,0,0
N1=NODE(6,0,0)
*GET,UX3,NODE,N1,U,X
*USE,MAC,2,(1/.108)
SET,2,1
LCSEL,S,0,0
*GET,UY3,NODE,N1,U,Y
*USE,MAC,3,(1/.432)
SET,3,1
LCSEL,S,0,0
*GET,UZ3,NODE,N1,U,Z
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'DEFL X ','DEFL Y ','DEFL Z '
LABEL(1,2) = 'in','in','in'
*VFILL,VALUE(1,1),DATA,3E-5,.108,.432
*VFILL,VALUE(1,2),DATA,UX3,UY3,UZ3
*VFILL,VALUE(1,3),DATA,ABS(UX3/(3E-5)),ABS(UY3/.108),ABS(UZ3/.432)
SAVE,TABLE_3
FINISH
/CLEAR,NOSTART
```

```
/PREP7
smrt,off
MOPT,VMESH,MAIN
MOPT,AMESH,ALTE
/TITLE, VM184, STRAIGHT CANTILEVER BEAM
C***  USING SOLID187 TETRAHEDRONS
ANTYPE,STATIC          ! STATIC ANALYSIS
ET,1,SOLID187           ! STRUCTURAL SOLID92
MP,EX,1,1E7
MP,NUXY,1,0.3
K,1
K,2,,.2
KGEN,2,1,2,1,,,.1
KGEN,2,1,4,1,(2/3)
ESIZE,,1
V,1,2,4,3,5,6,8,7
VMESH,1
VGEN,9,1,1,1,(2/3),,,4 ! GENERATE 9 VOLUMES TO COMPLETE BEAM
NSEL,S,LOC,X,0
D,ALL,ALL              ! CONSTRAIN LEFT END
SAVE
/COM                   *** GET NODE NUMBERS FOR LOAD APPLICATION ***
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.1
NSEL,R,LOC,Z,.05
*GET,MIDD,NDMX
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.2
NSEL,R,LOC,Z,.05
*GET,TOPP,NDMX
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.0
NSEL,R,LOC,Z,.05
*GET,BOTT,NDMX
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.1
NSEL,R,LOC,Z,.10
*GET,LFT,NDMX
NSEL,S,LOC,X,6
NSEL,R,LOC,Y,.1
NSEL,R,LOC,Z,.00
*GET,RGHT,NDMX
NSEL,ALL
/COM                   *** APPLY LOADS TO PARAMETRIC NODE NUMBERS ***
F,RGHT,FX,(1/6)
F,LFT,FX,(1/6)
F,TOPP,FX,(1/6)
F,BOTT,FX,(1/6)
F,MIDD,FX,(1/3)
FINISH
/SOLU
SOLVE
FDELE,ALL              ! REMOVE ALL FORCES
F,RGHT,FY,(1/6)
F,LFT,FY,(1/6)
F,TOPP,FY,(1/6)
F,BOTT,FY,(1/6)
F,MIDD,FY,(1/3)
SOLVE
FDELE,ALL              ! REMOVE ALL FORCES
F,RGHT,FZ,(1/6)
F,LFT,FZ,(1/6)
F,TOPP,FZ,(1/6)
F,BOTT,FZ,(1/6)
F,MIDD,FZ,(1/3)
SOLVE
FINISH
/POST1                 ! PRINT END DISPLACEMENTS AS RATIO OF Mechanical APDL:TARGET
/COM                   *** USE MACRO TO PROCESS ALL 3 LOADCASES  ***
*USE,MAC,1,(1/3E-5)
SET,1,1
LCSEL,S,0,0
```

```
N1=NODE(6,0,0)
*GET,UX2,NODE,N1,U,X
*USE,MAC,2,(1/.108)
SET,2,1
LCSEL,S,0,0
*GET,UY2,NODE,N1,U,Y
*USE,MAC,3,(1/.432)
SET,3,1
LCSEL,S,0,0
*GET,UZ2,NODE,N1,U,Z
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'DEFL X ','DEFL Y ','DEFL Z '
LABEL(1,2) = 'in','in','in'
*VFILL,VALUE(1,1),DATA,3E-5,.108,.432
*VFILL,VALUE(1,2),DATA,UX2,UY2,UZ2
*VFILL,VALUE(1,3),DATA,ABS(UX2/(3E-5)),ABS(UY2/.108),ABS(UZ2/.432)
SAVE,TABLE_4
RESUME,TABLE_1
/COM                    *** CLIPPED AND CAPPED DISPLAY OF STRESS CONTOURS  ***
NSEL,ALL
/VIEW,1,2,1,1
EPLOT                   ! ELEMENT PLOT
/TYPE,1,CAP             ! DISPLAY TYPE CAP
/DIST,1,.2
/FOCUS,1,.3,.15,.09     ! SET FOCUS FOR SECTION LOCATION
PLNSOL,S,X              ! STRESS CONTOUR PLOT
/COM
/OUT,vm184,vrt
/COM,------------------- VM184 RESULTS COMPARISON ------------
/COM,
/COM,                     TARGET   |    Mechanical APDL   |    RATIO
/COM, SOLID5
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.6,'  ',F15.6,'   ',1F16.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM, SOLID92
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.6,'  ',F15.6,'   ',1F16.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM, SOLID98
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.6,'  ',F15.6,'   ',1F16.3)
/NOPR
RESUME,TABLE_4
/GOPR
/COM,
/COM, SOLID187
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.6,'  ',F15.6,'   ',1F16.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
/DELETE,MAC
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
/DELETE,TABLE_4
*LIST,vm184,vrt
```

VM185 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM185
/PREP7
SMRT,OFF
/TITLE, VM185, AC ANALYSIS OF A SLOT EMBEDDED CONDUCTOR
C***    KONRAD, A., "INTEGRODIFFERENTIAL FINITE ELEMENT FORMULATION
C***    OF TWO-DIMENSIONAL STEADY-STATE SKIN EFFECT PROBLEMS",
C***    IEEE TRANS. MAGNETICS, VOL. MAG-18, NO. 1, JAN. 1982
C***    PP. 284-292.
C***
ET,1,PLANE13                       ! PLANE13, AZ DOF, (FOR AIR)
ET,2,PLANE13,6                     ! PLANE13, AZ VOLT DOF, (FOR CONDUCTOR)
EMUNIT,MKS                         ! DEFINE SYSTEM UNITS
MP,MURX,1,1                        ! RELATIVE PERMEABILITY
MP,MURX,2,1
RES=1.724E-8                       ! DEFINE RESISTIVITY OF CONDUCTOR
MP,RSVZ,2,RES                      ! CONDUCTOR RESISTIVITY
A=6.45E-3                          ! DEFINE GEOMETRY IN TERMS OF PARAMETERS
B=8.55E-3
C=8.45E-3
D=18.85E-3
E=8.95E-3
F=(D-E)/2

PTXY,0,0,D,0,D,C,D-F,C             ! CREATE POLYGON AREA OF CONDUCTOR
PTXY,D-F,B+C,F,B+C,F,C,0,C
POLY
RECTNG,F,F+E,B+C,B+C+A             ! CREATE AIR AREA
AGLUE,1,2                          ! GLUE AREAS TOGETHER

ASEL,S,AREA,,3
AATT,1,,1                          ! SET ATTRIBUTES FOR AIR
ASEL,S,AREA,,1
AATT,2,,2                          ! SET ATTRIBUTES FOR CONDUCTOR
ASEL,ALL
ESIZE,D/15                         ! SET ELEMENT EDGE LENGTH
MSHK,0                             ! FREE AREA MESH
MSHA,1,2D                          ! USING TRIS
AMESH,ALL                          ! MESH AREAS
ESEL,S,MAT,,2                      ! SELECT ALL NODES IN CONDUCTOR
NSLE,S
CP,1,VOLT,ALL                      ! COUPLE ALL NODES IN VOLT
I=1.0                              ! DEFINE TOTAL CURRENT
ASUM                               ! CALCULATE AREA ATTRIBUTES
*GET,AREA,AREA,1,AREA              ! GET AREA OF CONDUCTOR
*GET,N1,NODE,,NUM,MIN              ! SELECT A NODE IN THE CONDUCTOR
F,N1,AMPS,I                        ! APPLY 1 AMP TOTAL CURRENT
ESEL,ALL
NSEL,S,LOC,Y,.02345                ! SELECT NODES AT TOP PLANE
D,ALL,AZ,0                         ! SET FLUX PARALLEL B.C.
NSEL,ALL
FINISH
/SOLU
ANTYPE,HARMIC                      ! HARMONIC ANALYSIS
HARFRQ,45                          ! SET OPERATING FREQUENCY
SOLVE
FINISH
/POST1
SET,1,1                            ! RETRIEVE REAL SOLUTION
ETABLE,JT,NMISC,7                  ! STORE TOTAL CURRENT DENSITY
ETABLE,JS,SMISC,1                  ! STORE SOURCE CURRENT DENSITY
ETABLE,JE,NMISC,6                  ! STORE EDDY CURRENT DENSITY
/PNUM,MAT,1
/EDGE,1,1
/NUM,1
/GFILE,500
JPEG,QUAL,100
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```
/TRIAD,OFF
/PLOPTS,LOGO,0
/PLOPTS,INFO,2
/PLOPTS,WP,0
/RGB,INDEX,100,100,100,0
/RGB,INDEX,80,80,80,13
/RGB,INDEX,60,60,60,14
/RGB,INDEX,0,0,0,15
PLNSOL,A,Z                          ! DISPLAY FLUX LINES
/NUM,0
ESEL,MAT,2                          ! SELECT COPPER ONLY
PLETAB,JT,1                         ! DISPLAY TOTAL CURRENT DENSITY
PLETAB,JE,1                         ! DISPLAY EDDY CURRENT DENSITY
*GET,JSR,ELEM,1,ETAB,JS             ! GET REAL COMPONENT OF JS
ACRE=JSR*RES/I                      ! CALCULATE AC RESISTANCE/LENGTH
SET,1,1,,1                          ! READ IN IMAGINARY DATA
ETABLE,REFL                         ! REFILL ELEMENT TABLE WITH IMAG. DATA
*GET,JSI,ELEM,1,ETAB,JS             ! GET IMAGINARY COMPONENT OF JS
ACRA=JSI*RES/I                      ! CALCULATE AC REACTANCE/LENGTH
DCRE=RES/AREA                       ! CALCULATE DC RESISTANCE/LENGTH
RAT=ACRE/DCRE                       ! AC/DC LOSS RATIO
/OUTPUT
/GOPR
*STATUS,PARM                             ! SHOW PARAMETER STATUS
*DIM,LABEL,CHAR,5,2
*DIM,VALUE,,5,3
LABEL(1,1) = 'JS ','JS ','Impedance','Impedance','LOSS '
LABEL(1,2) = '(RE)','(IM)','(RE)','(IM)','RATIO'
*VFILL,VALUE(1,1),DATA,10183,27328,0.175e-3,0.471e-3,2.33
*VFILL,VALUE(1,2),DATA,JSR,JSI,ACRE,ACRA,RAT
*VFILL,VALUE(1,3),DATA,ABS(JSR/10183),ABS(JSI/27328),ABS(ACRE)/0.175e-3,ABS(ACRA)/0.471e-3,ABS(RAT/2.33)
/COM
/OUT,vm185,vrt
/COM,------------------- VM185 RESULTS COMPARISON -------------------------
/COM,
/COM,                 |     TARGET     |   Mechanical APDL   |   RATIO
/COM,PLANE13
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A9,'   ',F12.6,'  ',F15.6,'   ',F12.3)
/OUT
FINISH

/CLEAR,NOSTART
/NOPR
/PREP7
SMRT,OFF
/TITLE, VM185, AC ANALYSIS OF A SLOT EMBEDDED CONDUCTOR
ET,1,PLANE233                       ! PLANE233, AZ DOF, (FOR AIR)
ET,2,PLANE233,1                     ! PLANE233, AZ VOLT DOF, (FOR CONDUCTOR)
EMUNIT,MKS                          ! DEFINE SYSTEM UNITS
MP,MURX,1,1                         ! RELATIVE PERMEABILITY
MP,MURX,2,1
RES=1.724E-8                        ! DEFINE RESISTIVITY OF CONDUCTOR
MP,RSVZ,2,RES                       ! CONDUCTOR RESISTIVITY
A=6.45E-3                           ! DEFINE GEOMETRY IN TERMS OF PARAMETERS
B=8.55E-3
C=8.45E-3
D=18.85E-3
E=8.95E-3
F=(D-E)/2

PTXY,0,0,D,0,D,C,D-F,C              ! CREATE POLYGON AREA OF CONDUCTOR
PTXY,D-F,B+C,F,B+C,F,C,0,C
POLY
RECTNG,F,F+E,B+C,B+C+A              ! CREATE AIR AREA
AGLUE,1,2                           ! GLUE AREAS TOGETHER

ASEL,S,AREA,,3
AATT,1,,1                           ! SET ATTRIBUTES FOR AIR
ASEL,S,AREA,,1
AATT,2,,2                           ! SET ATTRIBUTES FOR CONDUCTOR
ASEL,ALL
```

```
ESIZE,D/15                          ! SET ELEMENT EDGE LENGTH
MSHK,0                              ! FREE AREA MESH
MSHA,1,2D                           ! USING TRIS
AMESH,ALL                           ! MESH AREAS
ESEL,S,MAT,,2                       ! SELECT ALL NODES IN CONDUCTOR
NSLE,S
CP,1,VOLT,ALL                       ! COUPLE ALL NODES IN VOLT
I=1.0                               ! DEFINE TOTAL CURRENT
ASUM                                ! CALCULATE AREA ATTRIBUTES
*GET,AREA,AREA,1,AREA               ! GET AREA OF CONDUCTOR
*GET,N1,NODE,,NUM,MIN               ! SELECT A NODE IN THE CONDUCTOR
F,N1,AMPS,I                         ! APPLY 1 AMP TOTAL CURRENT
ESEL,ALL
NSEL,S,LOC,Y,.02345                 ! SELECT NODES AT TOP PLANE
D,ALL,AZ,0                          ! SET FLUX PARALLEL B.C.
NSEL,ALL
FINISH

/SOLU
ANTYPE,HARMIC                       ! HARMONIC ANALYSIS
HARFRQ,45                           ! SET OPERATING FREQUENCY
SOLVE
FINISH

/POST1
/PNUM,MAT,1
/EDGE,1,1
/NUM,1
/GFILE,500
JPEG,QUAL,100
/TRIAD,OFF
/PLOPTS,LOGO,0
/PLOPTS,INFO,2
/PLOPTS,WP,0
/RGB,INDEX,100,100,100,0
/RGB,INDEX,80,80,80,13
/RGB,INDEX,60,60,60,14
/RGB,INDEX,0,0,0,15
/NUM,0
SET,1,1                             ! RETRIEVE REAL SOLUTION
ETABLE,JT,NMISC,1                   ! STORE TOTAL CURRENT DENSITY
ESEL,MAT,2                          ! SELECT COPPER ONLY
PLETAB,JT,1                         ! DISPLAY TOTAL CURRENT DENSITY
JSR=VOLT(N1)/RES
ACRE=JSR*RES/I                      ! CALCULATE AC RESISTANCE/LENGTH

SET,1,1,,1                          ! RETRIEVE IMAG SOLUTION
ETABLE,JT,NMISC,1                   ! STORE TOTAL CURRENT DENSITY
ESEL,MAT,2                          ! SELECT COPPER ONLY
PLETAB,JT,1                         ! DISPLAY TOTAL CURRENT DENSITY
JSI=VOLT(N1)/RES
ACRA=JSI*RES/I                      ! CALCULATE AC REACTANCE/LENGTH

DCRE=RES/AREA                       ! CALCULATE DC RESISTANCE/LENGTH
RAT=ACRE/DCRE                       ! AC/DC LOSS RATIO
/GOPR
*DIM,LABEL,CHAR,5,2
*DIM,VALUE,,5,3
LABEL(1,1) = 'JS ','JS ','Impedance','Impedance','LOSS '
LABEL(1,2) = '(RE)','(IM)','(RE)','(IM)','RATIO'
*VFILL,VALUE(1,1),DATA,10183,27328,0.175e-3,0.471e-3,2.33
*VFILL,VALUE(1,2),DATA,JSR,JSI,ACRE,ACRA,RAT
*VFILL,VALUE(1,3),DATA,ABS(JSR/10183),ABS(JSI/27328),ABS(ACRE/0.175e-3),ABS(ACRA/0.471e-3),ABS(RAT/2.33)
/COM
/OUT,vm185,vrt,,APPEND
/COM,PLANE233
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A9,'   ',F12.6,'  ',F15.6,'   ',F12.3)
/COM,------------------------------------------------------------------
/COM,
/OUT
FINISH
```

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*LIST,vm185,vrt
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VM186 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM186
/PREP7
/TITLE, VM186, TRANSIENT ANALYSIS OF A SLOT EMBEDDED CONDUCTOR
C***            KONRAD, IEEE TRANS., MAGNETICS, VOL. MAG-18, NO. 1, JAN. 1982
/NOPR
ANTYPE,TRANS                  ! NONLINEAR TRANSIENT DYNAMIC ANALYSIS
ET,1,PLANE13                  ! PLANE13, AZ DOF, (FOR AIR)
ET,2,PLANE13,6                ! PLANE13, AZ VOLT DOF, (FOR CONDUCTOR)
EMUNIT,MUZRO,1                ! SET MUZERO=1
MP,MURX,1,1                   ! RELATIVE PERMEABILITY
MP,MURX,2,1                   ! RELATIVE PERMEABILITY (CONDUCTOR)
MP,RSVX,2,1                   ! RESISTIVITY (CONDUCTOR)
N,1
N,8,,7
FILL
NGEN,2,8,1,8,1,1
MAT,2
TYPE,2
E,1,2,10,9
EGEN,4,1,-1
MAT,1
TYPE,1
E,5,6,14,13
EGEN,3,1,-1
CP,1,AZ,1,9                   ! COUPLE AZ TO ENSURE 1-D SOLUTION
*REPEAT,5,1,,1,1
ESEL,,MAT,,2
NSLE
CP,6,VOLT,ALL                 ! COUPLE VOLT IN CONDUCTOR
ESEL,ALL
NSEL,S,LOC,Y,7
D,ALL,AZ,0                    ! FLUX-PARALLEL B.C.
NSEL,ALL
FINISH
/SOLU
EQSLV,JCG,1E-9                ! USE THE JACOBI CONJUGATE GRADIENT SOLVER
T=1E-8                        ! INITIALIZE TIME PARAMETER
C=0                           ! INITIALIZE COUNTER PARAMETER
N=80                          ! NUMBER OF TIME INCREMENTS PER TURN
PI=2*ASIN(1)                  ! VALUE OF PI
CON=2*PI/N                    ! SET TIME INCREMENT
NEQIT,1                       ! 1 ITERATION PER TIME STEP
*CREATE,LOAD                  ! CREATE MACRO TO SET UP LOAD STEPS
TIME,T
I=4*SIN(T)                    ! CALCULATE CURRENT
F,1,AMPS,I                    ! APPLY CURRENT TO A NODE IN CONDUCTOR
T=T+CON                       ! INCREMENT TIME
C=C+1                         ! INCREMENT COUNTER
OUTRES,ALL,1
*IF,C,EQ,((N*.75)+1),THEN     ! SET FOR PRINTOUT AT DESIRED TIME POINTS
 OUTPR,,1
*ELSEIF,C,EQ,(N+1),THEN
 OUTPR,,1
*ELSE
 OUTPR,,0
*ENDIF
SOLVE
*END
*DO,I,1,81                    ! REPEAT MACRO EXECUTION
 *USE,LOAD                    ! EXECUTE MACRO
*ENDDO
FINISH
/POST26
```

```
NUMVAR,12                     ! INCREASE STORAGE ARRAY SIZE
ESOL,2,1,,NMISC,6,JE          ! STORE JE
*REPEAT,4,1,1
ESOL,6,1,,VOLUME              ! STORE VOLUME
*REPEAT,4,1,1
PROD,2,2,6                    ! CALCULATE IE=JE*VOLUME
*REPEAT,4,1,1,1
ADD,2,2,3,4,IE                ! SUMM IE OVER ALL CONDUCTOR ELEMENTS
ADD,10,2,5,,IE                ! IE TOTAL
ESOL,2,1,,SMISC,1,JS          ! STORE JS
*REPEAT,4,1,1
PROD,2,2,6                    ! CALCULATE IS=JS*VOLUME
*REPEAT,4,1,1,1
ADD,2,2,3,4,IS                ! SUM IS OVER ALL CONDUCTOR ELEMENTS
ADD,11,2,5,,IS                ! IS TOTAL
ESOL,2,1,,NMISC,7,JT          ! STORE JT
*REPEAT,4,1,1
PROD,2,2,6                    ! CALCULATE IT=JT*VOLUME
*REPEAT,4,1,1,1
ADD,2,2,3,4,IT                ! SUM IT OVER ALL CONDUCTOR ELEMENTS
ADD,12,2,5,,IT                ! IT TOTAL
/AXLAB,Y,CURRENT
/GROPT,AXNSC,2.0
PRVAR,10,11,12                ! PRINT EDDY, SOURCE, AND TOTAL CURRENT
PLVAR,10,11,12                ! DISPLAY EDDY, SOURCE, AND TOTAL CURRENT
FINISH
/POST1
SET,61,1,,,4.7124
*GET,A1,NODE,1,A,Z
*GET,A2,NODE,4,A,Z
*GET,A3,NODE,7,A,Z
SET,81,1,,,6.2832
*GET,A4,NODE,1,A,Z
*GET,A5,NODE,4,A,Z
*GET,A6,NODE,7,A,Z
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'NODE ','NODE ','NODE '
LABEL(1,2) = '1','4','7'
*VFILL,VALUE(1,1),DATA,-15.18,-14.68,-4
*VFILL,VALUE(1,2),DATA,A1,A2,A3
*VFILL,VALUE(1,3),DATA,ABS(A1/15.18),ABS(A2/14.68),ABS(A3/4)
SAVE,TABLE_1
*VFILL,VALUE(1,1),DATA,-3.26,-.92,0
*VFILL,VALUE(1,2),DATA,A4,A5,A6
*VFILL,VALUE(1,3),DATA,ABS(A4/3.26),ABS(A5/.92),
SAVE,TABLE_2
RESUME,TABLE_1
/COM
/OUT,vm186,vrt
/COM,------------------- VM186 RESULTS COMPARISON --------------
/COM,
/COM, VECTOR POTENTIAL |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,PLANE13
/COM
/COM,RESULTS AT T=(3*PI/2)
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/COM,
/COM,RESULTS AT T=(2*PI)
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,----------------------------------------------------------
/COM,
/OUT
FINISH

/CLEAR,NOSTART
/NOPR
```

```
/PREP7
/TITLE, VM186, TRANSIENT ANALYSIS OF A SLOT EMBEDDED CONDUCTOR
ANTYPE,TRANS                  ! NONLINEAR TRANSIENT DYNAMIC ANALYSIS
ET,1,PLANE233,0               ! PLANE233, AZ DOF, (FOR AIR)
ET,2,PLANE233,1,2             ! PLANE233, AZ VOLT DOF,EDDY CURRENTS (FOR CONDUCTOR)
EMUNIT,MUZRO,1                ! SET MUZERO=1
MP,MURX,1,1                   ! RELATIVE PERMEABILITY
MP,MURX,2,1                   ! RELATIVE PERMEABILITY (CONDUCTOR)
MP,RSVX,2,1                   ! RESISTIVITY (CONDUCTOR)
N,1
N,8,,7
FILL
NGEN,2,8,1,8,1,1
MAT,2
TYPE,2
E,1,2,10,9
EGEN,4,1,-1
MAT,1
TYPE,1
E,5,6,14,13
EGEN,3,1,-1
CP,1,AZ,1,9                   ! COUPLE AZ TO ENSURE 1-D SOLUTION
*REPEAT,5,1,,1,1
ESEL,,MAT,,2
NSLE
CP,6,VOLT,ALL                 ! COUPLE VOLT IN CONDUCTOR
ESEL,ALL
NSEL,S,LOC,Y,7
D,ALL,AZ,0                    ! FLUX-PARALLEL B.C.
NSEL,ALL
FINISH
/SOLU
EQSLV,JCG,1E-9                ! USE THE JACOBI CONJUGATE GRADIENT SOLVER
T=1E-8                        ! INITIALIZE TIME PARAMETER
C=0                           ! INITIALIZE COUNTER PARAMETER
N=80                          ! NUMBER OF TIME INCREMENTS PER TURN
PI=2*ASIN(1)                  ! VALUE OF PI
CON=2*PI/N                    ! SET TIME INCREMENT
NEQIT,1                       ! 1 ITERATION PER TIME STEP
*CREATE,LOAD                  ! CREATE MACRO TO SET UP LOAD STEPS
TIME,T
I=4*SIN(T)                    ! CALCULATE CURRENT
F,1,AMPS,I                    ! APPLY CURRENT TO A NODE IN CONDUCTOR
T=T+CON                       ! INCREMENT TIME
C=C+1                         ! INCREMENT COUNTER
OUTRES,ALL,1
*IF,C,EQ,((N*.75)+1),THEN     ! SET FOR PRINTOUT AT DESIRED TIME POINTS
 OUTPR,,1
*ELSEIF,C,EQ,(N+1),THEN
 OUTPR,,1
*ELSE
 OUTPR,,0
*ENDIF
SOLVE
*END
*DO,I,1,81                    ! REPEAT MACRO EXECUTION
 *USE,LOAD                    ! EXECUTE MACRO
*ENDDO
FINISH
/POST26
NUMVAR,12                     ! INCREASE STORAGE ARRAY SIZE

ESOL,2,1,,NMISC,1,JT          ! STORE JT
*REPEAT,4,1,1
PROD,2,2,6                    ! CALCULATE IT=JT*VOLUME
*REPEAT,4,1,1,1
ADD,2,2,3,4,IT                ! SUM IT OVER ALL CONDUCTOR ELEMENTS
ADD,12,2,5,,IT                ! IT TOTAL
/AXLAB,Y,CURRENT
/GROPT,AXNSC,2.0
PRVAR,12                ! PRINT EDDY, SOURCE, AND TOTAL CURRENT
PLVAR,12                ! DISPLAY EDDY, SOURCE, AND TOTAL CURRENT
```

```
FINISH
/POST1
SET,61,1,,,4.7124
*GET,A1,NODE,1,A,Z
*GET,A2,NODE,4,A,Z
*GET,A3,NODE,7,A,Z
SET,81,1,,,6.2832
*GET,A4,NODE,1,A,Z
*GET,A5,NODE,4,A,Z
*GET,A6,NODE,7,A,Z
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'NODE ','NODE ','NODE '
LABEL(1,2) = '1','4','7'
*VFILL,VALUE(1,1),DATA,-15.18,-14.68,-4
*VFILL,VALUE(1,2),DATA,A1,A2,A3
*VFILL,VALUE(1,3),DATA,ABS(A1/15.18),ABS(A2/14.68),ABS(A3/4)
SAVE,TABLE_1
*VFILL,VALUE(1,1),DATA,-3.26,-.92,0
*VFILL,VALUE(1,2),DATA,A4,A5,A6
*VFILL,VALUE(1,3),DATA,ABS(A4/3.26),ABS(A5/.92),
SAVE,TABLE_2
RESUME,TABLE_1
/COM
/OUT,vm186,vrt,,APPEND
/COM,PLANE233
/COM
/COM,RESULTS AT T=(3*PI/2)
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F15.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/COM,
/COM,RESULTS AT T=(2*PI)
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F15.2,'   ',1F15.3)
/COM,----------------------------------------------------------
/COM,
/OUT
FINISH
*LIST,vm186,vrt

/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,LOAD
FINISH
```

VM187 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM187
/PREP7
smrt,off
/TITLE, VM187, BENDING OF A CURVED BEAM
C***  FORMULAS FOR STRESS AND STRAIN, ROARK, 4TH ED.
ANTYPE,STATIC
ET,1,SOLID5,2             ! USING SOLID5 HEXAHEDRONS, DISPLACEMENT DOF ONLY
MP,EX,,1E7
MP,NUXY,,.25
CSYS,1
K,1,4.12                  ! DEFINE KEYPOINTS
K,2,4.32
KGEN,2,1,2,1,,,.1
KGEN,2,1,4,1,,90
L,1,5
LESIZE,1,,,20
V,1,2,4,3,5,6,8,7         ! DEFINE VOLUME
ESIZE,,1
```

```
VMESH,1                    ! CREATE NODES AND ELEMENTS
NSEL,S,LOC,Y,0
D,ALL,ALL,0                ! BOUNDARY CONDITIONS AND LOADING
NSEL,ALL
FK,5,FY,.25                ! APPLY LOAD
*REPEAT,4,1
NOORDER
FINISH
/SOLU
SOLVE
FINISH
*CREATE,MAC                ! CREATE A MACRO TO DO POSTPROCESSING
/POST1
CSYS,0
NSEL,S,LOC,X,0,.001,,1     ! SELECT NODES AT FREE END OF BEAM
PRNSOL,U,COMP
LCDEF,1,1
LCFACT,1,(1/.08854)
LCASE,1
PRNSOL,U,COMP
FINISH
*END
*GET,U1,NODE,5,U,Y
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'DEFL '
LABEL(1,2) = 'in '
*VFILL,VALUE(1,1),DATA,.08854
*VFILL,VALUE(1,2),DATA,U1
*VFILL,VALUE(1,3),DATA,ABS(U1/.08854)
SAVE,TABLE_1
*USE,MAC                   ! EXECUTE POSTPROCESSING MACRO
/CLEAR, NOSTART
/PREP7
smrt,off
/TITLE, VM187, BENDING OF A CURVED BEAM
ET,1,SOLID92               ! USING SOLID92 TETRAHEDRONS
MP,EX,,1E7
MP,NUXY,,.25
CSYS,1
K,1,4.12                   ! DEFINE KEYPOINTS
K,2,4.32
KGEN,2,1,2,1,,,.1
KGEN,2,1,4,1,,4.5
V,1,2,4,3,5,6,8,7          ! DEFINE VOLUMES
VGEN,20,1,1,1,,4.5,,4
ESIZE,,1
VMESH,ALL                  ! CREATE NODES AND ELEMENTS
NSEL,S,LOC,Y,0
D,ALL,ALL,0                ! BOUNDARY CONDITIONS AND LOADING
NSEL,S,LOC,Y,90
CP,1,UY,ALL                ! COUPLE UY DOF ON LOADED FACE
NSEL,R,LOC,X,4.32
NSEL,R,LOC,Z,0
F,ALL,FY,1                 ! APPLY LOAD
NSEL,ALL
SAVE
FINISH
/SOLU
SOLVE
FINISH
*USE,MAC                   ! EXECUTE POSTPROCESSING MACRO
NDE=NODE(0,4.32,0)
*GET,UY2,NODE,NDE,U,Y
*SET,U2,(UY2/(1/.08854))
*status,parm
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'DEFL '
LABEL(1,2) = 'in '
*VFILL,VALUE(1,1),DATA,.08854
*VFILL,VALUE(1,2),DATA,U2
```

```
*VFILL,VALUE(1,3),DATA,ABS(U2/.08854)
SAVE,TABLE_2
/PREP7
smrt,off
RESUME
ET,1,SOLID98,2            ! ANALYZE AGAIN USING SOLID98 TETRAHEDRONS
FINISH
/SOLU
SOLVE
FINISH
*USE,MAC                  ! EXECUTE POSTPROCESSING MACRO
NDE=NODE(0,4.32,0)
*GET,UY3,NODE,NDE,U,Y
*SET,U3,(UY3/(1/.08854))
*status,parm
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'DEFL '
LABEL(1,2) = 'in '
*VFILL,VALUE(1,1),DATA,.08854
*VFILL,VALUE(1,2),DATA,U3
*VFILL,VALUE(1,3),DATA,ABS(U3/.08854)
SAVE,TABLE_3
/PREP7
smrt,off
RESUME
ET,1,SOLID187             ! ANALYZE AGAIN USING SOLID187 TETRAHEDRONS
FINISH
/SOLU
SOLVE
FINISH
*USE,MAC                  ! EXECUTE POSTPROCESSING MACRO
NDE=NODE(0,4.32,0)
*GET,UY3,NODE,NDE,U,Y
*SET,U3,(UY3/(1/.08854))
*status,parm
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'DEFL '
LABEL(1,2) = 'in '
*VFILL,VALUE(1,1),DATA,.08854
*VFILL,VALUE(1,2),DATA,U3
*VFILL,VALUE(1,3),DATA,ABS(U3/.08854)
SAVE,TABLE_4
RESUME,TABLE_1
/COM
/OUT,vm187,vrt
/COM,------------------- VM187 RESULTS COMPARISON ------------
/COM,
/COM,                      TARGET   |    Mechanical APDL   |    RATIO
/COM, SOLID5
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.6,'  ',F15.6,'   ',1F16.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM, SOLID92
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.6,'  ',F15.6,'   ',1F16.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM, SOLID98
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.6,'  ',F15.6,'   ',1F16.3)
/NOPR
RESUME,TABLE_4
```

```
/GOPR
/COM,
/COM, SOLID187
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.6,'  ',F15.6,'   ',1F16.3)
/COM,-------------------------------------------------------------
/OUT
FINISH
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
/DELETE,TABLE_4
/DELETE,MAC
*LIST,vm187,vrt
```

VM188 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM188
/PREP7
SMRT,OFF
/TITLE, VM188, FORCE CALCULATION ON A CURRENT CARRYING CONDUCTOR
/COM,   REF:  MOON, FRANCIS C., MAGNETO-SOLID MECHANICS, PG. 418, 1984
ET,1,PLANE53                       ! 8-NODE QUADRILATERAL MAGNETICS ELEMENT
ET,2,INFIN9                        ! 2-D INFINITE BOUNDARY ELEMENT
EMUNIT,MKS                         ! MKS UNITS
MP,MURX,1,1                        ! MATERIAL 1 RELATIVE PERMEABILITY=1.0
MP,MURX,2,1                        ! MATERIAL 2 RELATIVE PERMEABILITY=1.0
D=.01                              ! DEFINE GEOMETRY IN TERMS OF PARAMETERS
A=.012
T=.002
OB=.04                             ! OUTER BOUNDARY SIZE
X1=D/2-T/2
X2=D/2+T/2
GP=.0002                           ! GAP FOR THIN AIR LAYER NEXT TO CONDUCTOR
RECTNG,0,OB,0,OB                   ! DEFINE BOOLEAN AREAS
RECTNG,0,.012,0,.012
RECTNG,X1,X2,0,A/2
RECTNG,X1-GP,X2+GP,0,A/2+GP
AOVLAP,ALL                         ! OVERLAP AREAS
ASEL,S,AREA,,3
AATT,2                             ! ASSIGN MATERIAL ATTRIBUTE TO CONDUCTOR
ASEL,ALL
KSEL,S,LOC,X,0,.012                ! SELECT KEYPOINTS FOR KESIZE SPEC.
KSEL,R,LOC,Y,0,.012
KESIZE,ALL,A/8                     ! ASSIGN ELEMENT SIZE AT KEYPOINTS
KSEL,INVE
KESIZE,ALL,OB/5
KSEL,ALL
LSEL,S,LOC,X,OB                    ! SELECT FAR-FIELD BOUNDARY LINES
LSEL,A,LOC,Y,OB
TYPE,2
LMESH,ALL                          ! MESH WITH INFINITE LINE ELMENTS
LSEL,ALL
MSHK,0                             ! FREE AREA MESH
MSHA,0,2D                          ! USING QUADS
TYPE,1
/OUT,MESH,LIS
AMESH,ALL                          ! MESH AREAS WITH PLANE53
/OUT
FINISH
/SOLU
ANTYPE,STATIC                      ! STATIC MAGNETICS ANALYSIS
ESEL,S,MAT,,2                      ! SELECT CONDUCTOR ELEMENTS
BFE,ALL,JS,,,,1E6                  ! APPLY CURRENT DENSITY TO CONDUCTOR
NSLE,S                             ! SELECT NODES IN CONDUCTOR REGION
BF,ALL,MVDI,1                      ! APPLY VIRTUAL WORK DISPLACEMENT = 1
```

```
NSEL,INVE                          ! SELECT ALL OTHER NODES
BF,ALL,MVDI,0                      ! APPLY VIRTUAL WORK DISPLACEMENT = 0
NSEL,ALL
ESEL,ALL
SOLVE
FINISH
/POST1
ETABLE,FMAGX,FMAG,X                ! STORE J*B FORCE INFORMATION
ETABLE,FVWX,NMISC,3                ! STORE VIRTUAL WORK FORCE
SSUM                               ! SUM TABLE ENTRIES
*GET,FXL,SSUM,,ITEM,FMAGX          ! GET J*B FORCE AS PARAMETER
FXL=FXL*2                          ! TOTAL LORENTZ FORCE
*GET,FXVW,SSUM,,ITEM,FVWX          ! GET VIRTUAL WORK FORCE AS PARAMETER
FXVW=FXVW*2                        ! TOTAL VIRTUAL WORK FORCE
PATH,MAXWELL,4,,48                 ! DEFINE PATH WITH NAME = "MAXWELL"
PPATH,1,,.012,0,0                  ! DEFINE PATH POINTS BY LOCATION
PPATH,2,,.012,.012,0
PPATH,3,,0,.012,0
PPATH,4,,0,0,0
FOR2D                              ! COMMAND MACRO FOR MAXWELL STRESS FORCE CALC
FXM=FX*2                           ! TOTAL MAXWELL FORCE (SYMMETRY)
*STATUS,PARM                       ! SHOW RESULTS
/PBC,PATH,1                        ! ACTIVATE PATH B.C. FOR DISPLAY
PLF2D                              ! DISPLAY FLUX LINES
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'F (LRNZ) ','F (MAXW) ','F (VW) '
LABEL(1,2) = 'N/m','N/m','N/m'
*VFILL,VALUE(1,1),DATA,-9.684E-3,-9.684E-3,-9.684E-3
*VFILL,VALUE(1,2),DATA,FXL,FXM,FXVW
*VFILL,VALUE(1,3),DATA,ABS(FXL/(9.684E-3)),ABS(FXM/(9.684E-3)),ABS(FXVW/(9.684E-3))
/COM
/OUT,vm188,vrt
/COM,------------------- VM188 RESULTS COMPARISON --------------
/COM,
/COM,              |    TARGET   |        Mechanical APDL   |        RATIO
/COM,PLANE53
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.6,'  ',F18.6,'   ',1F15.3)
/OUT
FINISH

/CLEAR,NOSTART
/NOPR
/PREP7
SMRT,OFF
ET,1,PLANE233                      ! 8-NODE QUADRILATERAL EMAG ELEMENT
KEYOPT,1,7,1
ET,2,INFIN9                        ! 2-D INFINITE BOUNDARY ELEMENT
MP,MURX,1,1                        ! MATERIAL 1 RELATIVE PERMEABILITY=1.0
MP,MURX,2,1                        ! MATERIAL 2 RELATIVE PERMEABILITY=1.0
D=.01                              ! DEFINE GEOMETRY IN TERMS OF PARAMETERS
A=.012
T=.002
OB=.04                             ! OUTER BOUNDARY SIZE
X1=D/2-T/2
X2=D/2+T/2
GP=.0002                           ! GAP FOR THIN AIR LAYER NEXT TO CONDUCTOR
RECTNG,0,OB,0,OB                   ! DEFINE BOOLEAN AREAS
RECTNG,0,.012,0,.012
RECTNG,X1,X2,0,A/2
RECTNG,X1-GP,X2+GP,0,A/2+GP
AOVLAP,ALL                         ! OVERLAP AREAS
ASEL,S,AREA,,3
AATT,2                             ! ASSIGN MATERIAL ATTRIBUTE TO CONDUCTOR
ASEL,ALL
KSEL,S,LOC,X,0,.012                ! SELECT KEYPOINTS FOR KESIZE SPEC.
KSEL,R,LOC,Y,0,.012
KESIZE,ALL,A/8                     ! ASSIGN ELEMENT SIZE AT KEYPOINTS
KSEL,INVE
KESIZE,ALL,OB/5
KSEL,ALL
```

```
LSEL,S,LOC,X,OB                      ! SELECT FAR-FIELD BOUNDARY LINES
LSEL,A,LOC,Y,OB
TYPE,2
LMESH,ALL                            ! MESH WITH INFINITE LINE ELEMENTS
LSEL,ALL
MSHK,0                               ! FREE AREA MESH
MSHA,0,2D                            ! USING QUADS
TYPE,1
AMESH,ALL                            ! MESH AREAS
FINISH

/SOLU
ANTYPE,STATIC                        ! STATIC MAGNETICS ANALYSIS
ESEL,S,MAT,,2                        ! SELECT CONDUCTOR ELEMENTS
BFE,ALL,JS,,,,1E6                    ! APPLY CURRENT DENSITY TO CONDUCTOR
ESEL,ALL
SOLVE
FINISH

/POST1
ESEL,S,MAT,,2
NSLE
ESLN
EMFT                                 ! SUM UP MAXWELL FORCES ACTING ON THE CONDUCTOR
FMXW=_FXSUM*2
ALLS
FINISH

/PREP7
KEYOP,1,8,1                         ! CALCULATE LORENTZ FORCE
FINISH

/SOLU
SOLVE
FINISH

/POST1
ESEL,S,MAT,,2
NSLE
EMFT                                 ! SUM UP LORENTZ FORCES ACTING ON THE CONDUCTOR
FJxB=_FXSUM*2
ALLS
FINI

/POST1
PATH,MAXWELL,4,,48                   ! DEFINE PATH WITH NAME = "MAXWELL"
PPATH,1,,.012,0,0                    ! DEFINE PATH POINTS BY LOCATION
PPATH,2,,.012,.012,0
PPATH,3,,0,.012,0
PPATH,4,,0,0,0
/PBC,PATH,1                          ! ACTIVATE PATH B.C. FOR DISPLAY
PLF2D

*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'F (LRNZ) ','F (MAXW) '
LABEL(1,2) = 'N/m','N/m'
*VFILL,VALUE(1,1),DATA,-9.684E-3,-9.684E-3
*VFILL,VALUE(1,2),DATA,FJxB,FMXW
*VFILL,VALUE(1,3),DATA,ABS(FJxB/(9.684E-3)),ABS(FMXW/(9.684E-3))
/COM
/OUT,vm188,vrt,,APPEND
/COM,PLANE233
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.6,'  ',F18.6,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm188,vrt
```

VM189 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM189
/TITLE,VM189,STRESS RELAXATION OF A CHLOROPRENE RUBBER
/COM,
/COM, REFERENCE:
/COM, HUSNU DAL, MICHAEL KALISKE, "BERGSTROM-BOYCE MODEL FOR
/COM, NONLINEAR FINITE RUBBER VISCOELASTICITY: THEORITICAL
/COM, ASPECTS AND ALGORITHMIC TREATMENT FOR THE FE METHOD
/COM,

/PREP7
ET,1,SOLID185                    ! 3D 8 NODE ELEMENT
KEYOPT,1,6,1

TB,BB,1,1,38,ISO                 ! DEFINE BERGSTROM-BOYCE MODEL
TBTEMP,0
TBDATA,1,0.6,8,0.96,8,7
TBDATA,6,-1,4

N,1,0,0,0                        ! NODES AND ELEMENTS
N,2,1,0,0
N,3,1,1,0
N,4,0,1,0
N,11,0,0,1
N,12,1,0,1
N,13,1,1,1
N,14,0,1,1
E,1,2,3,4,11,12,13,14
ALLSEL

NSEL,S,LOC,X,0                    ! BOUNDARY CONDITIONS
D,ALL,UX,0
NSEL,S,LOC,Y,0
D,ALL,UY,0
NSEL,S,LOC,Z,0
D,ALL,UZ,0
ALLSEL
FINISH


/SOLU
ANTYPE,0
NLGEOM,ON
DELTIM,2
OUTRES,ALL,LAST
TIME,100
NSEL,S,LOC,Z,1
D,ALL,UZ,-0.26                   ! TRUE STRAIN -0.3,Ln(1-0.26/1)
ALLSEL
LSWRITE,1

TIME,220
ALLSEL
LSWRITE,2                        ! RELAXATION 120S

TIME,320
NSEL,S,LOC,Z,1
D,ALL,UZ,-0.45                   ! TRUE STRAIN -0.6
ALLSEL
LSWRITE,3

TIME,440
ALLSEL
LSWRITE,4                        !RELAXATION 120S

TIME,540
NSEL,S,LOC,Z,1
```

```
D,ALL,UZ,-0.55                    ! TRUE STRAIN -0.8
ALLSEL
LSWRITE,5

TIME,640
NSEL,S,LOC,Z,1
D,ALL,UZ,-0.45                    ! TRUE STRAIN -0.6
ALLSEL
LSWRITE,6

TIME,760
ALLSEL
LSWRITE,7                         !RELAXATION 120S


TIME,860
NSEL,S,LOC,Z,1
D,ALL,UZ,-0.26                    ! TRUE STRAIN -0.3
ALLSEL
LSWRITE,8

TIME,980                          ! RELAXATION 120S
ALLSEL
LSWRITE,9

TIME,1080
NSEL,S,LOC,Z,1
D,ALL,UZ,0
ALLSEL
LSWRITE,10

ALLSEL
/OUT,SCRATCH
LSSOLVE,1,10,1
FINISH

/POST1
/OUT,
SET,FIRST
*GET,SZ1,NODE,NODE(1,1,1),S,Z
TS1=-0.65                          !TARGET
R1=SZ1/TS1
SET,3
*GET,SZ3,NODE,NODE(1,1,1),S,Z
TS3=-1.16                          !TARGET
R2=SZ3/TS3
SET,5
*GET,SZ5,NODE,NODE(1,1,1),S,Z
TS5=-1.58                          !TARGET
R3=SZ5/TS5
SET,6
*GET,SZ6,NODE,NODE(1,1,1),S,Z
TS6=-0.84                           !TARGET
R4=SZ6/TS6
SET,8
*GET,SZ8,NODE,NODE(1,1,1),S,Z
TS8=-0.40                           !TARGET
R5=SZ8/TS8

*DIM,LABEL,CHAR,5,1
*DIM,VALUE,,5,3
LABEL(1,1)='SET1','SET3','SET5','SET6','SET8'
*VFILL,VALUE(1,1),DATA,SZ1,SZ3,SZ5,SZ6,SZ8
*VFILL,VALUE(1,2),DATA,TS1,TS3,TS5,TS6,TS8
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5
/COM,
/OUT,vm189,vrt
/COM, ------------------VM189 RESULTS COMPARISON --------------------
/COM,
/COM,              |  Mechanical APDL  |   TARGET    |  RATIO
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
```

```
(1X,A8,'  ',F11.3,'   ',1F14.3,'  ',1F14.3)
/COM, ---------------------------------------------------------------
/OUT,
*LIST,vm189,vrt
FINISH
```

VM190 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM190
/PREP7
smrt,off
/TITLE, VM190, FERROMAGNETIC INDUCTOR
/COM,   CHAPMAN, "ELECTRIC MACHINERY FUNDAMENTALS", MCGRAW-HILL,
/COM,   1985, EXAMPLE 1-1, PG. 14
ET,1,SOLID98,10               ! 10-NODE TETRAHEDRAL, MAG OPTION
ET,2,INFIN47                  ! INFINITE ELEMENT
ET,3,SOURC36                  ! CURRENT ELEMENT
EMUNIT,MKS                    ! MKS UNITS
MP,MURX,1,1                   ! RELATIVE PERMEABILITY OF AIR
MP,MURX,2,2500                ! RELATIVE PERMEABILITY OF IRON
R,1,1,200,.02,.25             ! COIL DIMENSIONS AND CURRENT
LOCAL,11,0,-.325              ! SHIFT ORIGIN TO CENTER OF MODEL
WPCSYS,,11                    ! WORKING PLANE FOR SOLID MODELLING
N,1,.125,0,0                  ! CREATE NODES TO LOCATE COIL
N,2,.235,0,0
N,3,.235,.235,0
TYPE,3
E,2,3,1                       ! DEFINE COIL
BLOCK,.05,.20,0,.05,0,.45     ! CREATE SOLID MODEL OF IRON
BLOCK,.20,.50,0,.05,.30,.45
BLOCK,.50,.60,0,.05,0,.45
VGLUE,ALL
BLOCK,0,.65,0,.10,0,.50       ! CREATE SOLID MODEL OF AIR
VOVLAP,ALL                    ! OVERLAP AIR AND IRON
ASEL,S,AREA,,8,10
ASEL,A,AREA,,4
MSHK,0                        ! FREE MESH
MSHA,1,3D                     ! USING TETS
MSHA,1,2D                     ! USING TRIS
ESIZE,.10
TYPE,2
AMESH,ALL                     ! MESH EXTERIOR BOUNDARY WITH INFIN47
TYPE,1
MAT,2
VMESH,4,6                     ! MESH IRON
MAT,1
VMESH,2                       ! MESH AIR
NSEL,S,LOC,Z,0
D,ALL,MAG,0                   ! SET FLUX-NORMAL SYMMETRY CONDITION
NSEL,ALL
FINISH
/SOLU
ANTYPE,STATIC                 ! STATIC MAGNETIC FIELD ANALYSIS
MAGSOLV,4
FINISH
/POST1
PATH,IRON,7,,48               ! DEFINE PATH WITH NAME = "IRON"
PPATH,1,,-.2,0,0             ! DEFINE PATHS POINTS BY
PPATH,2,,-.2,0,.20
PPATH,3,,-.2,0,.375
PPATH,4,,.025,0,.375
PPATH,5,,.225,0,.375
PPATH,6,,.225,0,.20
PPATH,7,,.225,0,0
*CREATE,MAC                     ! CREATE MACRO FOR MMF CALCULATION
PDEF,HX,H,X                     ! INTERPOLATE H FIELD TO PATH
PDEF,HY,H,Y
```

```
PDEF,HZ,H,Z
PVECT,TANG,TX,TY,TZ               ! INTERPOLATE UNIT TANGENTS
PDOT,D,HX,HY,HZ,TX,TY,TZ          ! PERFORM DOT PRODUCT
PCALC,INTG,MMF,D,S                ! INTEGRATE OVER PATH
*GET,MMF,PATH,,LAST,MMF           ! GET MMF
MMF=MMF*2                         ! MULTIPLY BY 2 FOR SYMMETRY
*STATUS,MMF
*END
ESEL,S,MAT,,2                     ! SELECT IRON ELEMENTS
*USE,MAC                          ! USE MACRO TO CALCULATE MMF
/VIEW,,1,-3,1
/VUP,1,Z
/TRIAD,OFF
/PBC,PATH,1                       ! SHOW PATH ON DISPLAY
/AUTO
WPSTYL,,,,,,,OFF
NSLE,S                            ! SELECT NODES ATTACHED TO IRON
/COM                              *** THE FOLLOWING ANNOTATION COMMANDS ARE ***
/COM                              *** TYPICALLY GENERATED INTERACTIVELY ***
/ANUM,1,12,-.28056,.71310         ! ANNOTATION NUMBER, TYPE, AND HOT SPOT
/LSYMBOL,-.282,.511,269,4,1.0 ! ANNOTATION SYMBOL DEFINITION - ARROW
/LINE,-.282,.511,-.279,.915       ! ANNOTATION LINE DEFINITION
/ANUM,2,4,-.21690,.91150
/LINE,-.282,.911,-.151,.911
/ANUM,3,1.14734,.93021
/TLABEL,-.133,.930,CONTOUR PATH FOR  ! ANNOTATION LOCATION AND TEXT
/ANUM,4,1,.91097E-01,.87406
/TLABEL,-.136,.874,LINE INTEGRAL
/ANNOT,ON
/TITLE, VM190: MAGNETIC FLUX DENSITY
PLNSOL,B,SUM                      ! DISPLAY FLUX DENSITY IN IRON
FINISH
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'MMF DRP '
LABEL(1,2) = 'A-t'
*VFILL,VALUE(1,1),DATA,200
*VFILL,VALUE(1,2),DATA,MMF
*VFILL,VALUE(1,3),DATA,ABS(MMF/200),
/COM
/OUT,vm190,vrt
/COM,------------------- VM190 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F15.2,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
/DELETE,MAC
/DELETE,magsolv,out
*LIST,vm190,vrt
```

VM191 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM191
/TITLE, VM191, HERTZ CONTACT BETWEEN TWO CYLINDERS
/COM    "FINITE ELEMENT ANALYSIS OF HERTZ CONTACT PROBLEM"
/COM     N. CHANDRASEKARAN, W.E. HAISLER, R.E. GOFORTH,
/COM     FINITE ELEMENTS IN ANALYSIS AND DESIGN 3, 1987, PP 39-56.
/COM
/COM  2-D ANALYSIS USING PLANE182 AND CONTA175
/COM  CONTACT ALGORITHM: AUGMENTED LAGRANGIAN - KEYOPT(2) = 0
/COM
/PREP7
SMRT,OFF
```

```
ANTYPE,STATIC
ET,1,PLANE182          ! 2-D SOLID ELEMENTS
ET,2,TARGE169          ! 2-D TARGET ELEMENTS
ET,3,CONTA175          ! 2-D CONTACT ELEMENTS
MP,EX,1,30000          ! SMALLER CYLINDER PROPERTIES
MP,NUXY,1,0.25
MP,EX,2,29120          ! LARGER CYLINDER PROPERTIES
MP,NUXY,2,0.30
CSYS,1
K,1                    ! CREATE BIGGER CYLINDER
K,2,13
K,3,13,82
K,4,13,90
K,5,11,90
L,1,5
L,2,3
LESIZE,ALL,,,7
L,3,4                  ! TARGET SURFACE (LINE 3)
LOCAL,11,1,,13
L,3,5
CSYS,1
A,1,2,3,5
A,5,3,4,4
MAT,2
MSHK,1                    ! MAPPED AREA MESH
MSHA,0,2D                 ! USING QUADS
ESIZE,,4
AMESH,1,2
LOCAL,12,1,,23-1E-5,,-90  ! INTRODUCE SLIGHT INTERFERENCE
K,11                      ! CREATE SMALLER CYLINDER
K,12,10
K,13,10,8
K,14,10,90
K,15,8
L,11,15
L,13,14
LESIZE,7,,,6
LESIZE,8,,,6
L,12,13                ! CONTACT SURFACE (LINE 9)
CSYS,11
L,13,15
CSYS,12
MAT,1
A,12,13,15,15
A,15,13,14,11
ESIZE,,6
AMESH,3,4
LSEL,S,LINE,,9         ! SELECT CONTACT NODES ON SMALLER CYLINDER
NSLL,,1
CM,CYL1,NODE
REAL,1
TYPE,3
ESURF                  ! GENERATE COTAC175 ELEMENTS
LSEL,S,LINE,,3
NSLL,,1                ! SELECT TARGET NODES ON BIGGER CYLINDER
REAL,1
TYPE,2
ESURF                  ! GENERATE TARGE169 ELEMENTS
NSEL,ALL
CSYS,0
NSEL,S,LOC,Y,23        ! SELECT TOP EDGE OF MODEL
CP,1,UY,ALL            ! COUPLE NODES ON TOP EDGE
*GET,NC,NODE,,NUM,MIN  ! GET LOWEST NODE NUMBER (MASTER)
NSEL,S,LOC,X           ! SYMMETRY CONSTRAINTS
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
FINISH
SAVE,MODEL2D

*CREATE,SOLV2D,MAC     ! CREATE SOLUTION MACRO FOR 2-D CASE
```

```
/out,scratch
/SOLU
D,NC,UY,-0.005         ! APPLY SMALL DISPLACEMENT TO ENGAGE CONTACT
SOLVE                  ! SOLVE FIRST LOAD STEP
DDELE,NC,UY            ! DELETE IMPOSED DISPLACEMENT
F,NC,FY,-1600          ! APPLY HALF LOAD ON (SYMMETRY) MODEL
nsub,2,10,1
SOLVE                  ! SOLVE SECOND LOAD STEP
FINISH
/out
*END

SOLV2D                 ! EXECUTE SOLUTION MACRO FOR 2-D CASE

*CREATE,RES2D,MAC      ! CREATE RESULTS MACRO FOR 2-D CASE
/POST1
NSEL,,LOC,Y,23         ! SELECT TOP EDGE OF SMALLER CYLINDER
*GET,D,NODE,NC,U,Y     ! GET APPROACH DISTANCE (D)
ESEL,S,TYPE,,3         ! SELECT CONTACT ELEMENTS
ETABLE,NSTAT,CONT,STAT ! STORE CONTACT STATUS
ESEL,R,ETAB,NSTAT,2,2  ! SELECT ELEMENTS WITH CONTACT (STAT=2)
CMSEL,S,CYL1           ! SELECT CONTACT COMPONENT NODES
NSLE,R                 ! RESELECT NODES WITH CONTACT
NSORT,LOC,X,1          ! SORT CONTACT NODES BY ASCENDING X LOCATION
*GET,B,SORT,,MAX       ! GET SEMI-CONTACT LENGTH (B)
*STATUS,PARM
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'AP DIS ','S-CON LEN '
LABEL(1,2) = ' mm',' mm'
*VFILL,VALUE(1,1),DATA,-.4181,1.2
*VFILL,VALUE(1,2),DATA,D,B
*VFILL,VALUE(1,3),DATA,ABS(D/.4181),ABS(B/1.2)
FINISH
*END

RES2D                  ! EXECUTE POSTPROCESSING MACRO FOR 2-D CASE
SAVE,TABLE_1

/CLEAR, NOSTART
/COM
/COM  3-D ANALYSIS USING SOLID185 AND CONTA175
/COM  CONTACT ALGORITHM: AUGMENTED LAGRANGIAN - KEYOPT(2) = 0
/COM
/PREP7 $SMRT,OFF
ANTYPE,STATIC
ET,1,SOLID185          ! 3-D SOLID ELEMENTS
ET,2,170               ! 3-D TARGET ELEMENTS
ET,3,175               ! 3-D CONTACT ELEMENTS
MP,EX,1,30000          ! SMALLER CYLINDER PROPERTIES
MP,NUXY,1,0.25
MP,EX,2,29120          ! LARGER CYLINDER PROPERTIES
MP,NUXY,2,0.30
CSYS,1
K,1                    ! CREATE LOWER BIGGER CYLINDER
K,2,13
K,3,13,82
K,4,13,90
K,5,11,90
KGEN,2,1,5,1,,,1,100   ! UNIT THICKNESS SLICE
L,1,5
L,2,3
L,101,105
L,102,103
LESIZE,ALL,,,7
L,1,101
*REPEAT,5,1,1
LESIZE,5,,,1
*REPEAT,5,1
LOCAL,11,1,,13
L,3,5
L,103,105
```

```
CSYS,1
MAT,2
MSHK,1                  ! MAPPED VOLUME MESH
MSHA,0,3D               ! USING HEX
ESIZE,,4
V,1,2,3,5,101,102,103,105
V,5,3,4,4,105,103,104,104
VMESH,ALL
LOCAL,12,1,,23-1E-5,,-90 ! INTRODUCE SLIGHT INTERFERENCE
K,11                     ! CREATE UPPER SMALLER CYLINDER
K,12,10
K,13,10,8
K,14,10,90
K,15,8
KGEN,2,11,15,1,,,1,100
L,11,15
L,13,14
LESIZE,18,,,6
LESIZE,19,,,6
L,11,111
*REPEAT,5,1,1
LESIZE,20,,,1
*REPEAT,5,1
CSYS,11
L,13,15
L,113,115
CSYS,12
MAT,1
ESIZE,,6
V,12,13,15,15,112,113,115,115
V,15,13,14,11,115,113,114,111
VMESH,3,4
ASEL,S,AREA,,12
NSLA,,1                 ! SELECT CONTACT NODES ON SMALLER CYLINDER
CM,CYL1,NODE            ! CONTACT NODES COMPONENT
REAL,1
TYPE,3
ESURF                   ! GENERATE 3-D CONTA175 ELEMENTS
ASEL,S,AREA,,8
NSLA,,1                 ! SELECT TARGET NODES ON BIGGER CYLINDER
CM,CYL2,NODE            ! TARGET NODES COMPONENT
REAL,1
TYPE,2
ESURF                   ! GENERATE 3-D TARGE170 ELEMENTS
NSEL,ALL
CSYS,0
NSEL,S,LOC,Y,23         ! SELECT TOP EDGE OF MODEL
CP,1,UY,ALL             ! COUPLE NODES ON TOP EDGE
*GET,NC,NODE,,NUM,MIN   ! GET LOWEST NODE NUMBER (MASTER)
NSEL,S,LOC,X            ! SYMMETRY CONSTRAINTS
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,ALL
FINISH
SAVE,MODEL3D

*CREATE,SOLV3D,MAC      ! CREATE SOLUTION MACRO FOR 3-D CASE
/out,scratch
/SOLU
D,NC,UY,-0.001          ! APPLY SMALL DISPLACEMENT TO ENGAGE CONTACT
SOLVE                   ! SOLVE FIRST LOAD STEP
DDELE,NC,UY             ! DELETE IMPOSED DISPLACEMENT
F,NC,FY,-1600           ! APPLY HALF LOAD ON (SYMMETRY) MODEL
nsub,2,10,1
SOLVE                   ! SOLVE SECOND LOAD STEP
FINISH
/out
*END
```

```
SOLV3D                 ! EXECUTE SOLUTION MACRO FOR 3-D CASE

*CREATE,RES3D,MAC      ! CREATE RESULTS MACRO FOR 3D CASE
/POST1
NSEL,,LOC,Y,23         ! SELECT TOP EDGE OF SMALLER CYLINDER
*GET,D,NODE,NC,U,Y     ! GET APPROACH DISTANCE (D)
ESEL,S,TYPE,,3         ! SELECT CONTACT ELEMENTS
ETABLE,NSTAT,CONT,STAT ! STORE CONTACT STATUS
ESEL,R,ETAB,NSTAT,2,2  ! SELECT ELEMENTS WITH CONTACT (STAT=2)
CMSEL,S,CYL1           ! SELECT CONTACT COMPONENT NODES
NSLE,R                 ! RESELECT NODES WITH CONTACT
NSORT,LOC,X,1          ! SORT CONTACT NODES BY ASCENDING X LOCATION
*GET,B,SORT,,MAX       ! GET SEMI-CONTACT LENGTH (B)
*STATUS,PARM
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'AP DIS ','S-CON LEN '
LABEL(1,2) = ' mm',' mm'
*VFILL,VALUE(1,1),DATA,-.4181,1.2
*VFILL,VALUE(1,2),DATA,D,B
*VFILL,VALUE(1,3),DATA,ABS(D/.4181),ABS(B/1.2)
FINISH
*END

RES3D                  ! EXECUTE POSTPROCESSING MACRO FOR 3-D CASE
SAVE,TABLE_2

/CLEAR, NOSTART
/COM
/COM  2-D ANALYSIS USING PLANE182 AND CONTA175
/COM  CONTACT ALGORITHM: LAGRANGE MULTIPLIER - KEYOPT(2) = 3
/COM
RESUME,MODEL2D
/PREP7
KEYOPT,3,2,3           ! LAGRANGE MULTIPLIER ON CONTACT NORMAL AND PENALTY ON TANGENT
FINISH
SOLV2D
RES2D
SAVE,TABLE_3

/CLEAR, NOSTART
/COM
/COM  3-D ANALYSIS USING SOLID185 AND CONTA175
/COM  CONTACT ALGORITHM: LAGRANGE MULTIPLIER - KEYOPT(2) = 3
/COM
RESUME,MODEL3D
/PREP7
KEYOPT,3,2,3           ! LAGRANGE MULTIPLIER ON CONTACT NORMAL AND PENALTY ON TANGENT
FINISH
SOLV3D
RES3D
SAVE,TABLE_4


RESUME,TABLE_1
/COM
/OUT,vm191,vrt
/COM,=========== VM191 RESULTS COMPARISON =====================
/COM,
/COM,                    |  TARGET  |   Mechanical APDL  | RATIO
/COM,
/COM, 2-D ANALYSIS USING PLANE182 AND CONTA175:
/COM, CONTACT ALGORITHM: AUGMENTED LAGRANGIAN
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM, 3-D ANALYSIS USING SOLID185 AND CONTA175:
/COM, CONTACT ALGORITHM: AUGMENTED LAGRANGIAN
```

```
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM, 2-D ANALYSIS USING PLANE182 AND CONTA175:
/COM, CONTACT ALGORITHM: LAGRANGE MULTIPLIER
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_4
/GOPR
/COM,
/COM, 3-D ANALYSIS USING SOLID185 AND CONTA175:
/COM, CONTACT ALGORITHM: LAGRANGE MULTIPLIER
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,===========================================================
/OUT
FINISH
*LIST,vm191,vrt
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
/DELETE,TABLE_4
/DELETE,MODEL2D
/DELETE,MODEL3D
/DELETE,SOLV2D,MAC
/DELETE,SOLV3D,MAC
/DELETE,RES2D,MAC
/DELETE,RES3D,MAC
```

VM192 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM192
/PREP7
SMRT,OFF
/TITLE, VM192, COOLING OF A BILLET BY RADIATION
/COM    THERMAL RADIATION HEAT TRANSFER, SIEGEL AND HOWELL, 2ND EDITION,
/COM    PG. 229, PROBLEM NO. 21.
ET,1,SOLID70             ! 3-D THERMAL SOLID ELEMENT
ET,2,SURF152,,,,1,1      ! 3-D THERMAL SURFACE EFFECT ELEMENTS
KEYOPT,2,9,1             ! RADIATION OPTION
R,2,1,0.1712E-8          ! FORM FACTOR = 1, STEFAN-BOLTZMANN CONSTANT
MP,KXX,1,10000           ! ARBITRARY CONDUCTIVITY
MP,C,1,0.11
MP,DENS,1,487.5
MP,EMIS,2,1              ! BLACK BODY EMISSIVITY
BLOCK,,2,,2,,4
ESIZE,,1
VMESH,1                  ! MESH WITH A SINGLE SOLID70 ELEMENT
TYPE,2
REAL,2
MAT,2
N,100,5,5,5              ! EXTRA "SPACE" NODE FOR RADIATION
ESURF,100                ! GENERATE SURF152 ELEMENTS
FINISH

/SOLU
SOLCONTROL,0
ANTYPE,TRANS             ! TRANSIENT ANALYSIS
D,100,TEMP,530           ! SPECIFY SURROUNDING ABSOLUTE TEMPERATURE
TUNIF,2000               ! INITIAL BILLET ABSOLUTE TEMPERATURE
AUTOTS,ON
KBC,1                    ! STEP SURROUNDING TEMPERATURE IN FIRST TIME STEP
DELTIM,0.005             ! INITIAL (MINIMUM) INTEGRATION TIME STEP
```

```
OUTRES,,ALL
OUTPR,NSOL,LAST
TIME,3.7                ! TRANSIENT TIME SPAN
/OUT,SCRATCH
SOLVE
FINISH

/POST26
/OUT,
NSOL,2,1,TEMP,,TEMP
PRVAR,2                 ! PRINT TEMPERATURE HISTORY OF BILLET
*GET,T,VARI,2,RTIME,3.7
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,1,2
LABEL(1,1) = 'TEMP (B) '
LABEL(1,2) = 'DEG R'
*VFILL,VALUE(1,1),DATA,1000
*VFILL,VALUE(1,2),DATA,T
*VFILL,VALUE(1,3),DATA,ABS(T/1000)
/COM
/OUT,vm192,vrt
/COM,------------------- VM192 RESULTS COMPARISON --------------
/COM,
/COM,  LOAD STP 4      |   TARGET   |   Mechanical APDL    |   RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F15.1,'   ',1F18.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm192,vrt
```

VM193 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM193
/NOPR
/PREP7
SMRT,OFF
/TITLE, VM193, TWO DIMENSIONAL HEAT TRANSFER WITH CONVECTION
C***    "THE STANDARD NAFEMS BENCHMARKS", TEST NO. T4,
C***    NAFEMS, REV 3, OCTOBER 1990.
ANTYPE,STATIC
ET,1,PLANE55
MP,KXX,1,52.0
K,1
K,2,.6
K,3,.6,1.0
K,4,,1.0
K,5,.6,.2
L,1,2
L,2,5
L,5,3
L,3,4
L,4,1
AL,ALL
DK,1,TEMP,100,,1
DK,2,TEMP,100,,1
SFL,2,CONV,750.0,,0.0
SFL,3,CONV,750.0,,0.0
SFL,4,CONV,750.0,,0.0
FINISH
ADAPT,10,,5,0.2,1            ! FINAL PERCENT ERROR NEAR 5% WITHIN 10 LOOPS
/POST1
PLNSOL,TEMP                  ! DISPLAY TEMP CONTOURS IN FINAL MESH
*GET,TEPC,PRERR,,TEPC
KSEL,,,,5
```

```
NSLK
*GET,N1,NODE,,NUM,MAX
*GET,TEMP1,NODE,N1,TEMP
*status,parm
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,1,2
LABEL(1,1) = 'TEMP '
LABEL(1,2) = 'DEG C'
*VFILL,VALUE(1,1),DATA,18.3
*VFILL,VALUE(1,2),DATA,TEMP1
*VFILL,VALUE(1,3),DATA,ABS(TEMP1/18.3)
/COM
/OUT,vm193,vrt
/COM,------------------- VM193 RESULTS COMPARISON --------------
/COM,
/COM,  LOAD STP 4      |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F15.1,'   ',1F18.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm193,vrt
```

VM194 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM194
/PREP7
/TITLE, VM194, ELEMENT BIRTH/DEATH IN A FIXED BAR WITH THERMAL LOADING
/COM    ANY STANDARD MECHANICS OF MATERIALS TEXT
ET,1,LINK180         ! 3-D SPAR ELEMENTS
MP,EX,1,30E6         ! BAR MATERIAL PROPERTIES
MP,ALPX,1,.00005
MP,EX,2,30E6
MP,ALPX,2,.00005     ! MATERIAL PROPERTIES FOR RE-BORN ELEMENT
MP,REFT,2,100        ! REFERENCE TEMPERATURE FOR ELEMENT BIRTH
SECTYPE,1,LINK
SECDATA,1
N,1
N,4,10
FILL
E,1,2
EGEN,3,1,-1          ! GENERATE THREE ELEMENTS
FINISH

/SOLU
ANTYPE,STATIC
D,1,ALL,,,4,3        ! FIX BOTH ENDS OF THE BAR
D,ALL,UZ
TREF,0               ! ZERO REFERENCE TEMPERATURE
TUNIF,100            ! UNIFORM TEMPERATURE THERMAL LOAD
NROPT,FULL
OUTPR,BASIC,ALL
/OUT,SCRATCH
SOLVE
EKILL,2              ! KILL CENTER ELEMENT
SOLVE
EALIVE,2             ! RESURRECT CENTER ELEMENT
MPCHG,2,2            !  AND CHANGE TO MATERIAL 2 FOR STRAIN-FREE BIRTH
SOLVE
TUNIF,0              ! REMOVE THERMAL LOADING
SOLVE
FINISH

/POST1
SET,LAST
```

```
/OUT,
ESEL,S,ELEM,,1,2
ETABLE,FO,SMISC,1
ESORT,FO
*GET,F,SORT,,MAX
ETABLE,STR,LEPTH,1
ESORT,STR
*GET,S1,SORT,,MAX
*GET,S2,SORT,,MIN
*status,parm
*DIM,VALUE,,3,3
*DIM,LABEL,CHAR,3,2
LABEL(1,1) = 'PRESS ','MAX STRS ','MAX STRS '
LABEL(1,2) = 'psi','EL(1)','EL(2)'
*VFILL,VALUE(1,1),DATA,150000,0,-.005
*VFILL,VALUE(1,2),DATA,F,S1,S2
*VFILL,VALUE(1,3),DATA,ABS(F/150000),0,ABS(S2/.005)
/COM
/OUT,vm194,vrt
/COM,------------------- VM194 RESULTS COMPARISON --------------
/COM,
/COM,  LOAD STP 4      |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F15.3,'   ',1F18.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm194,vrt
```

VM195 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM195
/PREP7
MP,PRXY,,0.3
/TITLE, VM195, TOGGLE MECHANISM
C*** KINEMATICS AND DYNAMICS OF MACHINES, MARTIN, 2ND ED., P 56, FIG 3-22
ET,1,MPC184,6,,,1
ET,2,BEAM188,,,3
ET,3,COMBIN14
ET,4,LINK11
SECTYPE,1,JOINT,REVO               ! REVOLUTE JOINT
LOCAL,11,0,1.6,2.0
SECJOIN,,11,11
SECSTOP,6,-.6435,0.6435            !  ALLOW 37 DEG. ROTATION
SECT,2,BEAM,RECT                   ! BEAM PROPERTIES
SECD,0.1,0.1
R,3,166.6667                       ! SPRING STIFFNESS
SECTYPE,3,JOINT,REVO               ! REVOLUTE JOINT
LOCAL,12,0,1.6,1.2
SECJOIN,,12,12
SECLOCK,6,-1.287,1.287             ! ALLOW 74 DEG. ROTATION THEN LOCK-UP
DIST=(SQRT(12.2)-1)                ! DISTANCE TO MOVE ACTUATOR
R,4,(100/DIST)                     ! ACTUATOR STIFFNESS (F=100=KX)
MP,EX,1,1E9
N,1,,0.8
N,2,1.6,2.0
N,3,1.6,2.0
N,4,3.2,3.2
N,5
N,6,1.6,1.2
N,7,1.6,1.2
N,8,1.6,1.2
N,9,3.2
N,10,5
N,21,3.2,4.2
```

```
TYPE,1
SECN,1
E,2,3
CP,1,UX,6,7
CP,2,UY,6,7
SECN,3
E,7,8
TYPE,2
SECN,2
E,1,2
E,2,4
E,3,6
E,5,7
E,8,9
TYPE,3
REAL,3
E,9,10
TYPE,4
REAL,4
E,4,21
D,1,UX,,,5,4,UY,ROTX
D,9,UY
D,10,ALL,,,21,11
ESEL,S,TYPE,,1
NSLE,U
D,ALL,UZ
NSEL,ALL
ESEL,ALL
SFE,9,2,PRES,,102            ! ACTUATOR FORCE, INCREASE BY 2% TO ENSURE IMPACT
FINISH
/OUTPUT,SCRATCH
/SOLU
NLGEOM,ON
NSUBST,5
SOLVE
/POST1
*GET,UY,NODE,4,U,Y
*GET,UX,NODE,9,U,X
ESEL,S,ELEM,,8,8
ETABLE,FORCE,SMISC,1
ESORT,FORCE
*GET,F,SORT,,MIN
*STATUS,PARM
*DIM,VALUE,,3,3
*DIM,LABEL,CHAR,3,2
LABEL(1,1) = 'FORCE ','UY ','UX '
LABEL(1,2) = 'MAX','ND=4','ND=9'
*VFILL,VALUE(1,1),DATA,-133.33,-2.4,.8
*VFILL,VALUE(1,2),DATA,F,UY,UX
*VFILL,VALUE(1,3),DATA,ABS(F/133.33),ABS(UY/2.4),ABS(UX/.8)
/COM
/OUT,vm195,vrt
/COM,------------------- VM195 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F15.2,'   ',1F18.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm195,vrt
```

VM196 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM196
```

```
/PREP7
MP,PRXY,,0.3
SMRT,OFF
/TITLE, VM196, COUNTER-BALANCED LOADS ON A BLOCK
C***   ANY BASIC MECHANICS BOOK
C***   USING 3-D SOLID45
ET,1,SOLID45
MP,EX,1,70E9          ! ALUMINUM
MP,DENS,1,2712
MP,PRXY,1,0.3
WPOFFS,,,300          ! AXIS OF ROTATION 300 M
BLOCK,-1,1,-1,1,0,3   ! 3 M HIGH BY 2 M SQUARE
ESIZE,1
VMESH,ALL
DK,1,ALL              ! CONSTRAIN 6 DOF SUCH THAT NO ROTATIONS OCCUR
DK,4,UX
DK,6,UY
DK,7,UZ
SAVE                  ! SAVE DATABASE FOR SECOND SOLUTION
FINISH
*CREATE,SOLV3D,MAC    ! CREATE MACRO TO SOLVE AND RETRIEVE RESULTS
/SOLU
ANTYPE,STATIC
IRLF,1                ! INERTIA RELIEF CALCULATIONS
FK,5,FX,-2000
FK,5,FY,3000
OUTPR,RSOL,1          ! PRINT REACTION SOLUTION
SOLVE
IRLIST                ! LIST INERTIA RELIEF LOADS AND ACCELERATIONS
*GET,MX,ELEM,,MMOR,X
*GET,MY,ELEM,,MMOR,Y
*GET,MZ,ELEM,,MMOR,Z
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'MOM X ','MOM Y','MOM Z'
LABEL(1,2) = 'N-m','N-m','N-m'
*VFILL,VALUE(1,1),DATA,-909000,-606000,-5000
*VFILL,VALUE(1,2),DATA,MX,MY,MZ
*VFILL,VALUE(1,3),DATA,ABS(MX/909000),ABS(MY/606000),ABS(MZ/5000)
FINISH
*END

SOLV3D                ! EXECUTE MACRO TO SOLVE AND RETRIEVE RESULTS
SAVE,TABLE_1

/CLEAR, NOSTART       ! CLEAR DATABASE FOR 2ND SOLUTION
/TITLE, VM196, COUNTER-BALANCED LOADS ON A BLOCK
C***   USING 3-D SOLID185
/PREP7
SMRT,OFF
RESUME                ! RESUME DATABASE
ET,1,SOLID185         ! ANALYZE AGAIN USING 3-D SOLID185
FINISH

SOLV3D                ! EXECUTE MACRO TO SOLVE AND RETRIEVE RESULTS
SAVE,TABLE_2
/NOPR
RESUME,TABLE_1
/GOPR
/COM
/OUT,vm196,vrt
/COM,------------------- VM196 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM, SOLID45
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F15.0,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
```

```
/COM,
/COM, SOLID185
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F15.0,'   ',1F15.3)
/COM,----------------------------------------------------------
/COM,
/COM,----------------------------------------------------------
/COM,NOTE: THERE ARE VERIFIED RESULTS IN VM196  NOT CONTAINED IN
/COM,THIS TABLE
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm196,vrt
```

VM197 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM197
/PREP7
/TITLE, VM197, IGES WRITE/READ FOR THICK-WALLED CYLINDER WITH SPHERICAL END CAPS
/COM,   ANY BASIC GEOMETRY TEXT

RADIUS=20                                ! INSIDE RADIUS
THICK=10                                 ! WALL THICKNESS
LENGTH=50                                ! CYLINDER LENGTH (WITHOUT END CAPS)

CYLIND,RADIUS,RADIUS+THICK,0,LENGTH,90,270    ! CREATE HOLLOW CYLINDER
WPROTA,,90                      ! ROTATE WORKING PLANE FOR CREATION OF END CAPS
SPHERE,RADIUS,RADIUS+THICK,180,270      ! CREATE END CAP AT ONE END OF CYLINDER
WPOFFS,,LENGTH                          ! MOVE WORKING PLANE TO OTHER END OF CYL
SPHERE,RADIUS,RADIUS+THICK,90,180       ! CREATE END CAP AT OTHER END OF CYLINDER

/VIEW,1,1,1,1           ! SET VIEW DIRECTION FOR DISPLAY
/TYPE,1,4               ! SET TYPE OF DISPLAY TO PRECISE HIDDEN
/TRIAD,OFF              ! TURN OFF COORDINATE SYSTEM TRIAD ON DISPLAYS
WPSTYL,,,,,,,OFF        ! TURN OFF WORKING PLANE TRIAD ON DISPLAYS
VPLOT

IGESOUT,VM197,IGS            ! WRITE IGES FILE NAMED VM197.IGS
FINISH
PARSAV,ALL                   ! SAVE PARAMETERS (TO BE AVAILABLE AFTER CLEAR)
/CLEAR, NOSTART
/AUX15
IOPTN,IGES,SMOOTH            ! SELECT SMOOTH GEOMETRY IGES IMPORT
IOPTN,MERGE,YES
IOPTN,SOLID,YES
IGESIN,VM197,IGS             ! READ IN IGES FILE NAMED VM197.IGS
FINISH
/PREP7
/OUT,SCRATCH
VSUM                         ! PERFORM VSUM FOR SUBSEQUENT *GET OF TOT VOLUME

PARRES                       ! RESUME PARAMETERS SAVED PRIOR TO CLEAR
/OUT,
*GET,VOLUME,VOLU,,VOLU       ! VOLUME = TOTAL VOLUME OF GEOMETRY THAT WAS READ
                             ! IN FROM IGES FILE (FROM VSUM)

PI=(4.0)*ATAN(1.0)                      ! HAVE Mechanical APDL CALCULATE VALUE FOR PI
CAPVOL=2/3*PI*(((RADIUS+THICK)**3)-(RADIUS**3))  ! CALC VOL OF TWO END CAPS
CYLVOL=.5*LENGTH*PI*(((RADIUS+THICK)**2)-(RADIUS**2)) ! CALC VOL OF THE CYLINDER
CALCVOL=CAPVOL+CYLVOL        ! TOTAL CALC'D VOL = CYL VOL + END CAPS VOL

NORMVOL=VOLUME/CALCVOL       ! NORMALIZE Mechanical APDL'S VOLUME BY CALCULATED VOLUME

CAPVOL=                      ! DELETE PARAMETERS USED IN CALC. OF VOLUME
CYLVOL=
PI=
```

```
RADIUS=                      ! DELETE PARAMETERS USED IN MODEL GENERATION
THICK=
LENGTH=
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,1,2
LABEL(1,1) = 'VOLUME '
LABEL(1,2) = 'NO UNTS'
*VFILL,VALUE(1,1),DATA,79063
*VFILL,VALUE(1,2),DATA,VOLUME
*VFILL,VALUE(1,3),DATA,ABS(VOLUME/79063)
/COM
/OUT,vm197,vrt
/COM,------------------- VM197 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.0,'  ',F15.0,'   ',1F18.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
/NOPR
/DELETE,VM197,IGS
FINISH
*LIST,vm197,vrt
```

VM198 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM198
EL='PLANE182'
*DIM,A,CHAR,2              ! DEFINE AND DIMENSION THE CHARACTER PARAMETER A
A(1)='UX','UY'             ! SET CHARACTER STRINGS AS VALUES OF CHARACTER
!                            PARAMETER A
/PREP7
/TITLE, VM198, LARGE STRAIN IN-PLANE TORSION TEST (%EL%)
!       "SOME COMPUTATIONAL ASPECTS ....",NAGTEGAAL ET AL.
ET,1,PLANE182,,,2     ! 2-D 4 NODE PLANE ELEMENT
MP,EX,1,7200
MP,NUXY,1,0.33
TB,BISO,1                  ! BILINEAR ISOTROPIC HARDENING
TBDATA,1,10                ! YIELD STRESS
TBDATA,2,40                ! TANGENT MODULUS
SAVE                       ! SAVE DATABASE FOR LATER USE
CSYS,1
N,1,10
N,11,20
FILL
NGEN,2,100,1,11,1,,3
E,1,2,102,101
EGEN,10,1,1,1
!         APPLY BOUNDARY CONDITIONS
NSEL,S,LOC,X,20
D,ALL,ALL                  ! CLAMP OUTER SURFACE
NSEL,ALL
!         ROTATE APPROPRIATE NODES AND APPLY COUPLING
LOCAL,11,0,,,,3
NROTAT,101,111
CSYS,0
CP,1,A(1),2,102            ! USE A(1) VALUE FOR DOF LABEL
CP,2,A(2),2,102            ! USE A(2) VALUE FOR DOF LABEL
CPSGEN,9,1,1,2,1
FINISH
/OUTPUT,SCRATCH            ! DIVERT VOLUMINOUS SOLUTION OUTPUT
/SOLU
!     CREATE SOLUTION OPTIONS AND LOADING MACRO FOR MULTIPLE USE
*CREATE,SOLD,MAC
```

```
   SOLCONTROL,0
   ANTYPE,STATIC
   NLGEOM,ON                    ! LARGE STRAIN OPTION ACTIVATED
   NEQIT,100                    ! 100 EQUILIBRIUM ITERATIONS ALLOWED
  CUTC,PLSLIMIT,0.5            ! RESET MAXIMUM PLASTIC INCREMENTAL STRAIN
  NSUBS,100,1000,10
  D,ARG1,ARG2,,,ARG3,ARG4,ARG5
   SOLVE
   OUTRES,ESOL,1                ! STORE RESULTS FOR EVERY SUBSTEP
   NSTP = 10                    ! NO. OF LOAD STEPS USED
   T1   = 60/NSTP               ! ROTATION PER LOAD STEP
   T2   = 3.1415927/180         ! PARAMETER FOR FURTHER CALCULATIONS
   T33  = T1*T2                 ! DEGREES TO RADIANS CONVERSION
   *DO,I,1,NSTP                 ! USE DO LOOP FOR LOADING
       T3   = (I*T33)           ! CURRENT ANGLE
       T4   = (10*SIN(T3))      ! UY DISPLACEMENT
       T5   = (10*COS(T3))
       T5   = (T5-10)           ! UX DISPLACEMENT
       D,ARG1,ARG2,T5,,ARG3,ARG4
       D,ARG1,ARG5,T4,,ARG3,ARG4
       SOLVE
   *ENDDO
*END
SOLD,1,A(1),101,100,A(2)      ! USE A(1) AND A(2) AS ARG2 AND ARG5 VALUES FOR
FINISH                        !  DOF LABELS
/OUTPUT
!         CREATE POST PROCESSING MACRO FOR MULTIPLE USE
*CREATE,POSP,MAC
   !COM      PLOT THE FINAL DISPLACED GEOMETRY USING POST1
   /POST1
   SET,NSTP+1
   /DSCALE,1,1
   /DIST,1,13
   PLDISP,1
   /DIST,1
   FINISH
   !         OBTAIN MAXIMUM SHEAR STRESS USING POST26
   /POST26
   ESOL,2,1,1,S,1
   ESOL,3,1,1,S,3
   FILLDATA,5,1,,,0,6
   ADD,4,2,3,,SHEAR,,,-1/2,1/2         ! COMPUTE MAX. SHEAR USING
                                       !  PRINCIPAL STRESSES
   PRVAR,4,5
   /GRID,1
   /XRANGE,0,60
   /YRANGE,-60,0
   /AXLAB,X,ROTATION (DEGREES)
   /AXLAB,Y,SHEAR STRESS (PSI)
   XVAR,5
   PLVAR,4
   *GET,P1,VARI,4,RTIME,11
   *DIM,LABEL,CHAR,1,2
   *DIM,VALUE,,1,3
   LABEL(1,1) = 'PRS MAX '
   LABEL(1,2) = 'psi'
   *VFILL,VALUE(1,1),DATA,-48
   *VFILL,VALUE(1,2),DATA,P1
   *VFILL,VALUE(1,3),DATA,ABS(P1/48)
   FINISH
*END
POSP
SAVE,TABLE_1
/CLEAR, NOSTART

!         ANALYZE THE SAME PROBLEM WITH ELEMENT SOLID185
/PREP7
RESUME
EL='SOLID185'
/OUT,SCRATCH
/STATUS,TITLE              ! DISPLAY TITLE WITH NEW VALUE OF PARAMETER EL
/OUT,
```

```
ET,1,SOLID185            ! 3D 8 NODE SOLID ELEMENT
CSYS,1
N,1,10
N,11,20
FILL
NGEN,2,100,1,11,1,,3
NGEN,2,200,1,111,1,,,1
E,1,2,102,101,201,202,302,301
EGEN,10,1,1,1
!          APPLY BOUNDARY CONDITIONS
D,ALL,UZ
NSEL,S,LOC,X,20
D,ALL,ALL                  ! CLAMP OUTER SURFACE
NSEL,ALL
!          ROTATE APPROPRIATE NODES AND APPLY COUPLING
LOCAL,11,0,,,,3
NROTAT,101,111
NROTAT,301,311
CSYS,0
CP,1,A(1),2,102,202,302
CP,2,A(2),2,102,202,302
CPSGEN,9,1,1,2,1
FINISH
/OUTPUT,SCRATCH            ! DIVERT VOLUMINOUS SOLUTION OUTPUT
/SOLU
SOLD,1,A(1),301,100,A(2)
FINISH
/OUTPUT
POSP                       ! POSTPROCESS RESULTS USING POSP MACRO
SAVE,TABLE_2

!         ANALYZE THE SAME PROBLEM WITH ELEMENT PLANE183
/PREP7
RESUME
EL='PLANE183'
/OUT,SCRATCH
/STATUS,TITLE              ! DISPLAY TITLE WITH NEW VALUE OF PARAMETER EL
/OUT,
et,1,PLANE183,,,2
N,1,10
N,21,20
FILL
CSYS,1
NGEN,3,30,1,21,1,,1.5
E,1,3,63,61,2,33,62,31
EGEN,10,2,1,1,1
NSLE
NSEL,INVE
NDELE,ALL
!         APPLY BOUNDARY CONDITIONS
NSEL,S,LOC,X,20
D,ALL,ALL
!         ROTATE APPROPRIATE NODES AND APPLY COUPLING
NSEL,S,NODE,,61,81
LOCAL,11,0,,,,3
NROTAT,ALL
NSEL,S,NODE,,31,51,2
LOCAL,12,0,,,,1.5
NROTAT,ALL
NSEL,ALL
CSYS,0
CP,1,A(1),3,33,63
CP,2,A(2),3,33,63
CPSGEN,9,2,1,2,1
CP,21,A(1),2,62
CP,22,A(2),2,62
CPSGEN,10,2,21,22,1
FINISH

/OUT,SCRATCH
/SOLU
!     CREATE SOLUTION OPTIONS AND LOADING MACRO FOR MULTIPLE USE
```

```
*CREATE,SOLD1,MAC
   SOLCONTROL,0
   ANTYPE,STATIC
   NLGEOM,ON                  ! LARGE STRAIN OPTION ACTIVATED
   NEQIT,100                  ! 100 EQUILIBRIUM ITERATIONS ALLOWED
   CUTC,PLSLIMIT,0.5          ! RESET MAXIMUM PLASTIC INCREMENTAL STRAIN
   NSUBS,500,10000,100
   cnvtol,f,1,1.0e-3
   D,ARG1,ARG2,,,ARG3,ARG4,ARG5
   SOLVE
   OUTRES,ESOL,1              ! STORE RESULTS FOR EVERY SUBSTEP
   NSTP = 10                  ! NO. OF LOAD STEPS USED
   T1   = 60/NSTP             ! ROTATION PER LOAD STEP
   T2   = 3.1415927/180       ! PARAMETER FOR FURTHER CALCULATIONS
   T33  = T1*T2               ! DEGREES TO RADIANS CONVERSION
   *DO,I,1,NSTP               ! USE DO LOOP FOR LOADING
       T3   = (I*T33)         ! CURRENT ANGLE
       T4   = (10*SIN(T3))    ! UY DISPLACEMENT
       T5   = (10*COS(T3))
       T5   = (T5-10)         ! UX DISPLACEMENT
       D,ARG1,ARG2,T5,,ARG3,ARG4
       D,ARG1,ARG5,T4,,ARG3,ARG4
       SOLVE
   *ENDDO
*END
SOLD1,1,A(1),61,30,A(2)      ! USE A(1) AND A(2) AS ARG2 AND ARG5 VALUES FOR
FINISH

/OUTPUT
POSP                        ! POSTPROCESS RESULTS USING POSP MACRO
SAVE,TABLE_3
RESUME,TABLE_1
/COM
/OUT,vm198,vrt
/COM,------------------- VM198 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS USING PLANE182
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F15.1,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING SOLID185
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F15.1,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM,RESULTS USING PLANE183
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F15.1,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
/NOPR
/DELETE,POSP,MAC
/DELETE,SOLD,MAC
/DELETE,SOLD1,MAC
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
FINISH
*LIST,vm198,vrt
```

VM199 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM199
/PREP7
/TITLE, VM199, VISCOPLASTIC ANALYSIS OF A BODY UNDERGOING SHEAR DEFORMATION
!              " AN IMPLICIT STRESS UPDATE ....", LWO ET AL.
!           PLANE182 ELEMENT
ET,1,182                    ! 2-D, 4-NODE ELEMENT
KEYOPT,1,3,2     ! PLANE STRAIN
MP,EX,1,60.6E9
MP,NUXY,1,0.4999
TB,RATE,1,,9,ANAND              ! VISCOPLASTIC MODEL BY ANAND
TBDATA,1,29.7E6
TBDATA,2,21.08999E3
TBDATA,3,1.91E7
TBDATA,4,7.0
TBDATA,5,0.23348
TBDATA,6,1115.6E6
TBDATA,7,18.92E6
TBDATA,8,0.07049
TBDATA,9,1.3
SAVE                            ! SAVE DATABASE FOR LATER USE
N,1
N,2,1E-2
N,3,1E-2,1E-2
N,4,,1E-2
E,1,2,3,4
D,1,ALL,,,2
FINISH
/OUTPUT,SCRATCH                 ! DIVERT VOLUMINOUS SOLUTION OUTPUT
/SOLU
SOLCONTROL,0
ANTYPE,STATIC
NLGEOM,ON                       ! LARGE DEFORMATION ACTIVATED
OUTRES,RSOL,ALL                 ! STORE REACTION RESULTS FOR ALL SUBSTEPS
BFUNIF,TEMP,673                 ! UNIFORM TEMPERATURE OF 673 K
D,3,ALL,0.0,,4
TIME,0.000001                   ! NEAR ZERO TIME FOR FIRST LOAD STEP
SOLVE
NSUBST,20
D,3,UX,0.2E-2,,4
TIME,20
SOLVE
FINISH
/OUTPUT
/POST26
RFORCE,2,3,F,X
RFORCE,3,4,F,X
ADD,4,2,3,,LOAD,,,(1/100),(1/100)
!         THE FX FORCE IS DIVIDED BY 100 BECAUSE THE DEFAULT OUT-
!          OF-PLANE THICKNESS IS 1 METER WHILE PROBLEM CONSIDERED
!          HAS OUT-OF-PLANE THICKNESS OF 0.01 METER WHICH IS 100
!          TIMES LESS THAN 1 METER.
PRVAR,4
*GET,F1,VARI,4,RTIME,20
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'Fx '
LABEL(1,2) = 'N'
*VFILL,VALUE(1,1),DATA,845
*VFILL,VALUE(1,2),DATA,F1
*VFILL,VALUE(1,3),DATA,ABS(F1/845)
SAVE,TABLE1
FINISH
/CLEAR, NOSTART
!         PLANE183 ELEMENT TYPE
/PREP7
RESUME
```

```
ET,1,183                    ! 2-D, 8-NODE  ELEMENT
KEYOPT,1,3,2     ! PLANE STRAIN
N,1
N,2,1E-2
N,3,1E-2,1E-2
N,4,,1E-2
N,5,0.5E-2
N,6,1E-2,0.5E-2
N,7,0.5E-2,1E-2
N,8,,0.5E-2
E,1,2,3,4,5,6,7,8
D,1,ALL
D,2,ALL
D,5,ALL
FINISH
/OUTPUT,SCRATCH                  ! DIVERT VOLUMINOUS SOLUTION OUTPUT
/SOLU
SOLCONTROL,0
NLGEOM,ON                        ! LARGE DEFORMATION ACTIVATED
OUTRES,RSOL,ALL                  ! STORE REACTION RESULTS FOR ALL SUBSTEPS
BFUNIF,TEMP,673                  ! UNIFORM TEMPERATURE OF 673 K
D,3,ALL,0.0,,8
TIME,0.000001                    ! NEAR ZERO TIME FOR FIRST LOAD STEP
SOLVE
NSUBST,20
D,3,UX,0.2E-2,,4
D,7,UX,0.2E-2
D,6,UX,0.1E-2,,8,2
TIME,20
SOLVE
FINISH
/OUTPUT
/POST26
RFORCE,2,3,F,X
RFORCE,3,4,F,X
RFORCE,4,7,F,X
ADD,5,2,3,4,LOAD,,,(1/100),(1/100),(1/100)
PRVAR,5
*GET,F1,VARI,5,RTIME,20
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'Fx '
LABEL(1,2) = 'N'
*VFILL,VALUE(1,1),DATA,845
*VFILL,VALUE(1,2),DATA,F1
*VFILL,VALUE(1,3),DATA,ABS(F1/845)
SAVE,TABLE2
FINISH

/CLEAR, NOSTART
!         SOLID185 ELEMENT
/PREP7
RESUME
ET,1,SOLID185              !3-D, 8-NODE VISCOPLASTIC ELEMENT
N,1
N,2,1E-2
N,3,1E-2,1E-2
N,4,,1E-2
NGEN,2,4,1,4,1,,,1E-2
E,1,2,3,4,5,6,7,8
D,1,ALL,,,2
D,5,ALL,,,6
FINISH
/OUTPUT,SCRATCH                  ! DIVERT VOLUMINOUS SOLUTION OUTPUT
/SOLU
SOLCONTROL,0
NLGEOM,ON                        ! LARGE DEFORMATION ACTIVATED
OUTRES,RSOL,ALL                  ! STORE REACTION RESULTS FOR ALL SUBSTEPS
BFUNIF,TEMP,673                  ! UNIFORM TEMPERATURE OF 673 K
D,3,ALL,0.0,,8
TIME,0.000001                    ! NEAR ZERO TIME FOR FIRST LOAD STEP
SOLVE
```

```
NSUBST,20
D,3,UX,0.2E-2,,4
D,7,UX,0.2E-2,,8
TIME,20
SOLVE
FINISH
/OUTPUT
/POST26
RFORCE,2,3,F,X
RFORCE,3,4,F,X
RFORCE,4,7,F,X
RFORCE,5,8,F,X
ADD,6,2,3,4
ADD,7,6,5,,LOAD
PRVAR,7
*GET,F1,VARI,7,RTIME,20
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'Fx '
LABEL(1,2) = 'N'
*VFILL,VALUE(1,1),DATA,845
*VFILL,VALUE(1,2),DATA,F1
*VFILL,VALUE(1,3),DATA,ABS(F1/845)
/COM
/OUT,vm199,vrt
/COM,------------------- VM199 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,PLANE182 RESULTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F15.2,'   ',1F18.3)
/NOPR
RESUME,TABLE1
/GOPR
/COM,
/COM,PLANE183 RESULTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F15.2,'   ',1F18.3)
/NOPR
RESUME,TABLE2
/GOPR
/COM,
/COM,SOLID185 RESULTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F15.2,'   ',1F18.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm199,vrt
```

VM200 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM200
/PREP7
/TITLE, VM200, VISCOELASTIC SANDWICH SEAL ANALYSIS
/COM,    ----- 2-D ANALYSIS -----
/COM,    "FE CALCULATIONS OF RESIDUAL STRESSES ....",SOULES ET AL.
ET,1,PLANE183,,,1            ! AXISYMMETRIC 2-D QUADRATIC ELEMENT
KEYOPT,1,6,0     !U-P formulation; 1= mixed, 0=U only
*CREATE,MAC1
/COM,    MATERIAL ONE IS G-11 GLASS AND MATERIAL TWO IS ALUMINA
/COM,    NOTE THAT ALUMINA IS AN ELASTIC MATERIAL THEREFORE IT
/COM,     DOES NOT HAVE VISCOELASTICITY AND STRUCTURAL RELAXATION
```

```
/COM,    MATERIAL PROPERTIES OF ALUMINA
MP,EX,  2, 3.73113E5
MP,PRXY,2, 0.3
TB,PRONY,2,1,1,SHEAR
TBDATA,1,0.0,1E-7
TB,SHIFT,2,1,1,FICT
TBDATA, 1,    618,      0.0,     1.0 ! SHIFT FUNCTION PARAMETERS
TBDATA, 4,    618,      1.0,     0.0 ! FICTIVE TEMP PARAMETERS, TFI, CFI, TAUFI
TBDATA, 7,52.6E-7, 0.119E-7, -1.0E-11 ! GLASS CTE COEFFICIENTS
TBDATA,12,52.6E-7, 0.119E-7, -1.0E-11 ! LIQUID CTE COEFFICIENTS
/COM,    MATERIAL PROPERTIES OF G-11 GLASS
MP,EX,  1, 7.2548E4
MP,PRXY,1, 0.3
TB,PRONY,1,1,3,SHEAR         ! DEVIATORIC VISCOELASTIC PROPERTIES
TBDATA,1,0.422,0.0689
TBDATA,3,0.423,0.0065
TBDATA,5,0.155,0.0001
TB,SHIFT,1,1,6,FICT           ! TN TTS W/ FICTIVE TEMPERATURE
TBDATA, 1, 618, 6.45E4, 0.53  ! SHIFT FUNCTION PARAMETERS
TBDATA, 4, 618,  0.108, 3.0   ! 1ST FICTIVE TEMP
TBDATA, 7, 618,  0.443, 0.671 ! 2ND FICTIVE TEMP
TBDATA,10, 618,  0.166, 0.247 ! 3RD FICTIVE TEMP
TBDATA,13, 618,  0.161, 0.091 ! 4TH FICTIVE TEMP
TBDATA,16, 618,  0.046, 0.033 ! 5TH FICTIVE TEMP
TBDATA,19, 618,  0.076, 0.008 ! 6TH FICTIVE TEMP
TBDATA,22, 64.7E-7, 0.02E-7,  ! GLASS CTE COEFFICIENTS
TBDATA,27, 3.43E-5,           ! LIQUID  CTE COEFFICIENTS
*END
*USE,MAC1                    ! EXECUTE MACRO FOR MATERIAL PROPERTIES
/COM,   CREATE FINITE ELEMENT MODEL
N,1,
N,3,,0.00025
FILL
N,5,0,(0.00025+0.00325)
FILL
NGEN,3,10,1,5,1,.001
MAT,2
E,1,21,23,3,11,22,13,2
MAT,1
E,3,23,25,5,13,24,15,4
/COM,    APPLY BOUNDARY CONDITIONS AND COUPLING
NSEL,S,LOC,Y
DSYM,SYMM,Y
NSEL,S,LOC,X
DSYM,SYMM,X
NSEL,ALL
D,1,ALL
CP,1,UX,21,22,23,24,25
CP,2,UY,2,22
CP,3,UY,3,13,23
CPSGEN,2,2,2,3,1
FINISH
/COM    SINCE THE SOLUTION OUTPUT IS VOLUMINOUS IT IS DIVERTED TO A
/COM     SCRATCH FILE
/OUTPUT,SCRATCH
*CREATE,MAC2                   ! CREATE MACRO FOR ANALYSIS TYPE AND LOADING
/SOLU
SOLCONTROL,0
ANTYPE,STATIC
/COM,    TEMPERATURE SET UP
TREF,618
TOFFST,273
TUNIF,618
TIME,1E-5
CNVTOL,F,,,,.001             ! VERY SMALL MINIMUM ENFORCED
                               !  FOR CONVERGENCE
SOLVE
OUTRES,ESOL,1                  ! STORE RESULTS FOR EVERY SUBSTEP
NSUBST,200
TUNIF,460                      ! COOLING
TIME,3160
SOLVE
```

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TIME,(14400+3160)               ! ISOTHERMAL HOLD
SOLVE
TUNIF,18                        ! FURTHER COOLING
TIME,(14400+12000)
SOLVE
*END
FINISH
*USE,MAC2                       ! EXECUTE ANALYSIS AND LOADING MACRO
/OUTPUT
/POST26
ESOL,2,2,,BFE,TEMP
ESOL,3,2,3,S,X,STRESS
*CREATE,MAC3                    ! MACRO FOR PROCESSING RESULTS
XVAR,2
/GRID,1
/AXLAB,X,TEMPERATURE
/AXLAB,Y,IN-PLANE STRESS (MPA)
PLVAR,3
*GET,MXSX,VARI,3,EXTREM,VMAX    ! MAXIMUM IN-PLANE STRESS
NSTORE,20                       ! STORE EVERY 20TH TIME POINT RESULTS
PRVAR,2,3
*END
*USE,MAC3                       ! EXECUTE POSTPROCESSING MACRO
*SET,P1,(MXSX)
*GET,T1,VARI,3,EXTREM,TMAX
*GET,TE,VARI,2,RTIME,T1
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'PRES MX ','TEMP '
LABEL(1,2) = 'MPa','DEG C'
*VFILL,VALUE(1,1),DATA,12.5,460
*VFILL,VALUE(1,2),DATA,P1,TE
*VFILL,VALUE(1,3),DATA,ABS(P1/12.5),ABS(TE/460)
SAVE,TABLE_1
FINISH
/CLEAR,NOSTART                  ! CLEAR THE DATABASE
/PREP7
/TITLE, VM200, VISCOELASTIC SANDWICH SEAL ANALYSIS
/COM,    ----- 3-D ANALYSIS -----
ET,1,SOLID186
KEYOPT,1,2,1
KEYOPT,1,6,1     !U-P formulation; 1= mixed, 0=U only
*USE,MAC1                       ! EXECUTE MACRO FOR MATERIAL PROPERTIES
/COM,   CREATE FINITE ELEMENT MODEL
N,1,
N,3,0.00025
FILL
N,5,(0.00025+0.00325)
FILL
NGEN,3,10,1,5,1,,.001
NGEN,3,100,1,25,1,,,0.001
MAT,2
E,1,3,23,21,201,203,223,221
EMORE,2,13,22,11,202,213,222,211
EMORE,101,103,123,121
EGEN,2,2,1,1,1,-1
NSLE,S
NSEL,INVE
NDELE,ALL
NSLE,S
/COM,    APPLY BOUNDARY CONDITIONS AND COUPLING
NSEL,S,LOC,Y
DSYM,SYMM,Y
NSEL,S,LOC,X
DSYM,SYMM,X
NSEL,S,LOC,Z
DSYM,SYMM,Z
NSEL,S,LOC,Y,0.002
CP,1,UY,ALL
NSEL,S,LOC,Z,0.002
CP,2,UZ,ALL
NSEL,S,LOC,X,0.00025
```

```
CP,3,UX,ALL
NSEL,S,LOC,X,0.0035
CP,4,UX,ALL
NSEL,ALL
FINISH
/COM,    SINCE THE SOLUTION OUTPUT IS VOLUMINOUS IT IS DIVERTED TO A
/COM,     SCRATCH FILE
/OUTPUT,SCRATCH
*USE,MAC2                      ! EXECUTE ANALYSIS AND LOADING MACRO
/OUTPUT
/POST26
ESOL,2,2,,BFE,TEMP
ESOL,3,2,3,S,Y,STRESS
*USE,MAC3                      ! EXECUTE POSTPROCESSING MACRO
*SET,P2,(MXSX)
*GET,T2,VARI,3,EXTREM,TMAX
*GET,TE2,VARI,2,RTIME,T2
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'PRES MX ','TEMP '
LABEL(1,2) = 'MPa','DEG C'
*VFILL,VALUE(1,1),DATA,12.5,460
*VFILL,VALUE(1,2),DATA,P2,TE2
*VFILL,VALUE(1,3),DATA,ABS(P2/12.5),ABS(TE2/460)
SAVE,TABLE_2
RESUME,TABLE_1
/COM
/OUT,vm200,vrt
/COM,------------------- VM200 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS USING VISCO88
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING VISCO89
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
/NOPR
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,MAC1
/DELETE,MAC2
/DELETE,MAC3
FINISH
*LIST,vm200,vrt
```

VM201 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM201
R = 200                       ! RADIUS OF CYLINDER (mm)
/PREP7
smrt,off
/TITLE, VM201, RUBBER CYLINDER PRESSED BETWEEN TWO PLATES
/COM    REF: T. SUSSMAN, K.J. BATHE, "A FE FORMULATION FOR NONLINEAR ..."
/COM         COMPUTERS & STRUCTURES, VOL. 26, NOS. 1/2, 1987
ET,1,PLANE182, , ,2           ! 2-D PLANE-STRAIN 4-NODE STRUCTURAL SOLID
KEYOPT,1,6,1
ET,2,CONTA175                 ! 2-D 1-NODE NODE-TO-SURFACE CONTACT ELEMENT
R,2, , ,-2000                 ! SET SURFACE STIFFNESS
```

```
ET,3,TARGE169                  ! 2-D TARGET ELEMENT
C10 = 0.293
C01 = 0.177
NU1 = 0.49967
DD  = (1-2*NU1)/(C10+C01)
TB,HYPER,1,1,2,MOONEY
TBDATA,1,C10,C01,DD
CSYS,1                         ! SWITCH TO CYLINDRICAL C.S.
K,1                            ! DEFINE KEYPOINTS
K,2,R,-90
K,3,R
K,4,(0.5*R),-90
K,5,(0.6*R),-45
K,6,(0.5*R)
K,7,R,-45
L,2,7
L,7,3
CSYS,0                         ! SWITCH TO CARTESIAN C.S.
A,2,7,5,4
A,7,3,6,5
A,4,5,6,1
ESIZE,,4                       ! SET ELEMENT DIVISION SIZE
AMESH,ALL                      ! MESH ALL AREAS
SAVE                           ! SAVE MODEL FOR MORE ANALYSIS
N,1001,(-2*R),-R               ! TARGET SURFACE NODES
N,1002,(2*R) ,-R
NSEL,S,NODE,,1001,1002
TYPE,3
REAL,2
TSHAP,LINE                     ! SET TARGET SHAPE TO LINE
E,1002,1001                    ! GENERATE RIGID TARGET
D,ALL,ALL,0                    ! FIX TARGET
NSEL,S,LOC,X                   ! SELECT LEFT EDGE
D,ALL,UX                       ! CONSTRAIN LEFT EDGE IN UX
NSEL,S,LOC,Y                   ! SELECT TOP EDGE
CP,1,UY,ALL                    ! COUPLE TOP EDGE IN UY
*GET,NCEN,NODE,,NUM,MIN        ! GET MINIMUM NODE NUMBER FROM SELECTED SET
NSEL,ALL
CSYS,1                         ! SWITCH TO CYLINDRICAL C.S.
ESEL,S,TYPE,,1
NSLE
NSEL,R,LOC,X,R
TYPE,2
REAL,2
ESURF                          ! DEFINE CONTACT ELEMENTS
ALLSEL,ALL
CSYS,0
SAVE,CONT2D                    ! SAVE 2D CONTACT MODEL FOR SECOND ANALYSIS
FINISH

*CREATE,SOLVIT,MAC             ! MACRO TO SOLVE MODEL
 /SOLU
 ANTYPE,STATIC
 CNVTOL,F,,,,-1
 NLGEOM,ON                     ! INCLUDE LARGE DEFORMATION EFFECTS
 NSUBST,6                      ! SPECIFY NUMBER OF SUBSTEPS IN LOAD STEP
 OUTRES,,1                     ! WRITE SOLUTION FOR EVERY SUBSTEP
 D,NCEN,UY,-100                ! APPLY DISPLACEMENT UY = -100 TO COUPLED NODES
 SOLVE
 FINISH
*END
SOLVIT                         ! USE MACRO SOLVIT

*CREATE,PLOTS,MAC              ! MACRO FOR POST-PROCESSING
 /POST1
 /DSCALE,1,1
 PLDISP,1                      ! PLOT DISPLACED SHAPE
 FINISH
 /POST26
 /AXLAB,Y,FORCE
 /AXLAB,X,DISPLACEMENT
 NSOL,2,NCEN,U,Y
```

```
 RFORCE,3,NCEN,F,Y
 PROD,2,2,,,,,,-2
 PROD,3,3,,,,,,-2
 XVAR,2
 PLVAR,3                       ! PLOT DISPLACEMENT VS FORCE
 PRVAR,2,3                     ! PRINT DISPLACEMENT, FORCE
 *GET,F1,VARI,3,RTIME,.5
 *GET,F2,VARI,3,RTIME,1
 *DIM,LABEL,CHAR,2,2
 *DIM,VALUE,,2,3
 LABEL(1,1) = 'F (N) @ ','F (N) @ '
 LABEL(1,2) = '.1','.2'
 *VFILL,VALUE(1,1),DATA,250,1400
 *VFILL,VALUE(1,2),DATA,F1,F2
 *VFILL,VALUE(1,3),DATA,ABS(F1/250),ABS(F2/1400)
 FINISH
*END
PLOTS                          ! USE MACRO PLOTS
SAVE,TABLE_1

RESUME
/PREP7
SMRT,OFF
ET,5,SOLID185                  ! 3-D 8-NODE STRUCTURAL SOLID
KEYOPT,5,6,1
ET,6,CONTA175                  ! 3-D 1-NODE NODE-TO-SURFACE CONTACT ELEMENT
R,6, , ,-2000,-0.1,
ET,7,TARGE170                  ! 3-D TARGET ELEMENT
ET,8,MESH200,6                 ! 2-D 4-NODED QUAD
R,8,0.05
ALLSEL
TYPE,5
ESIZE,,1
VEXT,ALL,,,,,1
N,1001,,-R                     ! CREATE TARGET PLANE OF NODES
N,1002,2*R,-R
N,1003,2*R,-R,8*R
N,1004,,-R,8*R
TYPE,8
REAL,8
E,1002,1001,1004,1003
NSEL,S,NODE,,1001,1004
TYPE,7
REAL,6
ESURF                          ! GENERATE TARGET ELEMENTS
D,ALL,ALL,0
CSYS,1                         ! SWITCH TO CYLINDRICAL C.S.
ESEL,S,TYPE,,5
NSLE
NSEL,R,LOC,X,R
ESEL,S,TYPE,,5,7
TYPE,6
REAL,6
ESURF
CSYS,0                         ! SWITCH TO CARTESIAN C.S.
NSEL,ALL
D,ALL,UZ                       ! CONSTRAIN ALL NODES IN Z (PLANE STRAIN)
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
CP,1,UY,ALL                    ! COUPLE TOP NODES IN Y
*GET,NCEN,NODE,,NUM,MIN
ESEL,S,TYPE,,5,7
NSLE
SAVE,CONT3D                    ! SAVE 3D CONTACT MODEL FOR SECOND ANALYSIS
FINISH
/OUT,SCRATCH
SOLVIT                         ! USE MACRO TO OBTAIN SOLUTION
PLOTS                          ! USE MACRO TO POSTPROCESS
SAVE,TABLE_2

RESUME,CONT2D                  ! RESUME CONT175 -2D MODEL
```

```
/OUT,
/PREP7
R,2                             ! CONTACT STIFFNESS IS NOT REQUIRED
KEYOPT,2,2,3                    ! LAGRANGE MULTIPLIER ON CONTACT NORMAL AND PENALTY ON TANGENT
FINISH
/OUT,SCRATCH
SOLVIT                          ! USE MACRO TO OBTAIN SOLUTION
PLOTS                           ! USE MACRO TO POSTPROCESS
SAVE,TABLE_3

RESUME,CONT3D                   ! RESUME CONT175 -3D MODEL
/OUT,
/PREP7
R,6                             ! CONTACT STIFFNESS IS NOT REQUIRED
KEYOPT,6,2,4                    ! PURE LAGRANGE MULTIPLIER ON CONTACT NORMAL AND TANGENT
FINISH
/OUT,SCRATCH
SOLVIT                          ! USE MACRO TO OBTAIN SOLUTION
PLOTS                           ! USE MACRO TO POSTPROCESS
SAVE,TABLE_4

RESUME,TABLE_1
/OUT,
/COM
/OUT,vm201,vrt
/COM,------------------- VM201 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS USING PLANE182 AND 2D-CONTA175:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING SOLID185 AND 3D-CONTA175:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM,RESULTS USING PLANE182 AND 2D-CONTA175 WITH K(2)=3:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_4
/GOPR
/COM,
/COM,RESULTS USING SOLID185 AND 3D-CONTA175 WITH K(2)=4:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,----------------------------------------------------------
/COM,
/OUT
FINISH
*LIST,vm201,vrt
/DELETE,PLOTS,MAC
/DELETE,SOLVIT,MAC
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
/DELETE,TABLE_4
```

VM202 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
```

```
/VERIFY,VM202
/PREP7
/TITLE, VM202, TRANSVERSE VIBRATIONS OF A SHEAR BEAM
/COM, REF:  R. BLEVINS, FORMULAS FOR NATURAL FREQUENCY AND MODE SHAPE, 1979.
ANTYPE,MODAL
ET,1,SHELL28
R,1,0.1                 ! DEFINE REAL CONSTANT SET 1; THICKNESS OF SHELL
MP,EX,  1,200E9
MP,NUXY,1,0.27
MP,DENS,1,7860.0
N,1                     ! DEFINE NODES
N,2,10
N,3,10,10
N,4,  ,10
NGEN,9,4,1,4,1,,,3.75
E,1,2,6,5               ! DEFINE ELEMENTS
EGEN,3,1,-1
E,4,1,5,8
EGEN,8,4,-4
D,ALL,UZ                ! DEFINE BOUNDARY CONDITIONS
D,1,UX,,,4,1,UY
NSEL,S,LOC,Z,3.75       ! SELECT NODES AT COMMON Z LOCATION
CP,1,UX,ALL             ! COUPLE NODES IN X AND Y DOF
CP,2,UY,ALL
NSEL,S,LOC,Z,7.5
CP,3,UX,ALL
CP,4,UY,ALL
NSEL,S,LOC,Z,11.25
CP,5,UX,ALL
CP,6,UY,ALL
NSEL,S,LOC,Z,15
CP,7,UX,ALL
CP,8,UY,ALL
NSEL,S,LOC,Z,18.75
CP,9,UX,ALL
CP,10,UY,ALL
NSEL,S,LOC,Z,22.5
CP,11,UX,ALL
CP,12,UY,ALL
NSEL,S,LOC,Z,26.25
CP,13,UX,ALL
CP,14,UY,ALL
NSEL,S,LOC,Z,30
CP,15,UX,ALL
CP,16,UY,ALL
NSEL,ALL
FINISH
/out,scratch
/SOLU
MXPAND,4                ! EXPAND FIRST TWO REPEATED MODES
MODOPT,LANB,8
SOLVE
*GET,F1,MODE,1,FREQ
*GET,F2,MODE,3,FREQ
FINISH
/out
/POST1
SET,1,1
/VUP,,Z
/VIEW,,,1
PLDISP,1                ! DISPLAY DISPLACEMENTS (FIRST MODE)
SET,1,3
PLDISP,1                ! DISPLAY DISPLACEMENTS (SECOND MODE)
*status,parm
*DIM,VALUE,,2,3
*DIM,LABEL,CHAR,2,2
LABEL(1,1) = 'F1 ','F2 '
LABEL(1,2) = 'Hz ','Hz '
*VFILL,VALUE(1,1),DATA,17.375,52.176
*VFILL,VALUE(1,2),DATA,F1,F2
*VFILL,VALUE(1,3),DATA,ABS(F1/17.375),ABS(F2/52.176)
/COM
```

```
/OUT,vm202,vrt
/COM,------------------- VM202 RESULTS COMPARISON -------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F18.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm202,vrt
```

VM203 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM203
/PREP7
/TITLE, VM203, DYNAMIC LOAD EFFECT ON SIMPLY-SUPPORTED THICK SQUARE PLATE
/COM REFERENCE: NAFEMS FORCED VIBRATION BENCHMARKS, TEST 21R
C***          USING SHELL281 ELEMENTS
ET,1,SHELL281            ! DEFINE ELEMENT TYPE
SECTYPE,1,SHELL
SECDATA,1,1,0,5       ! THICKNESS
MP,EX,1,200E9                ! DEFINE MATERIAL PROPERTIES
MP,NUXY,1,0.3
MP,ALPX,1,0.1E-5
MP,DENS,1,8000
N,1,0,0,0                    ! DEFINE MODEL
N,9,0,10,0
FILL
NGEN,5,40,1,9,1,2.5
N,21,1.25,0,0
N,29,1.25,10,0
FILL,21,29,3
NGEN,4,40,21,29,2,2.5
EN,1,1,41,43,3,21,42,23,2
EGEN,4,2,1
EGEN,4,40,1,4
FINISH
SAVE,MODEL
*CREATE,SOLVIT,MAC
/out,scratch
/SOLU
ANTYPE,MODAL                 ! DEFINE ANALYSIS TYPE AS MODAL VIBRATION
MODOPT,LANPCG,16
MXPAND,16,,,YES
SFE,ALL,,PRES,,-1E6          ! PRESS LOAD OF 1000,000 N/M**2
D,ALL,UX,0,,,,UY,ROTZ        ! APPLY CONSTRAINTS
D,1,UZ,0,0,9,1,ROTX
D,161,UZ,0,0,169,1,ROTX
D,1,UZ,0,0,161,20,ROTY
D,9,UZ,0,0,169,20,ROTY
SOLVE
*GET,F,MODE,1,FREQ
/out
FINISH
/SOLU
/TITLE, VM203, RANDOM VIBRATION , RESPONSE TO UNIFORM PSD FORCE
ANTYPE,SPECTR                 ! DEFINE ANALYSIS TYPE
SPOPT,PSD,2,ON                ! USE FIRST 2 MODES, CALC ELEM. STRESSES
PSDUNIT,1,PRES                ! DEFINE TYPE OF PSD AS A PRESSURE SPECTRUM
DMPRAT,0.02
PSDFRQ,1,1,1.0,80.0
PSDVAL,1,1.0,1.0              ! IN N**2/HZ
SFEDELE,ALL,,PRES,,
LVSCALE,1                     ! USE AND SCALE THE LOAD VECTOR GENERATED AT MODAL ANALYSIS
PFACT,1,NODE
```

```
PSDRES,DISP,REL
PSDCOM
SOLVE
FINISH
/POST1
SET,3,1                       ! ONE SIGMA DISPLACEMENT SOLUTION RESULTS
/VIEW,1,2,3,4
PLNSOL,U,Z
PRNSOL,U,Z
L2=NODE(2,8,0)
*GET,SIGEL2,NODE,L2,S,EQV
NSEL,,NODE,,L2
PRNSOL,S,COMP
NSEL,ALL
FINISH
/SOLUTION
ANTYPE,HARMIC                ! REDEFINE ANALYSIS TYPE AND SOLVE AGAIN
HROPT,MSUP                   ! USING MODE SUPERPOSITION HARMONIC ANALYSIS
HROUT,OFF,ON                 ! PRINT AMPLITUDE & PHASE, CLUSTER FREQUENCIES
KBC,1
HARFRQ,1,80
DMPRAT,0.02
NSUBSTEP,10
SOLVE
FINISH
/POST26
FILE,,rfrq
PRCPLX,1
NSOL,2,85,U,Z
PSDDAT,6,1,1.0,80,1.0
PSDTYP,2
PSDCAL,7,2
PSDPRT
PRVAR,2,7
*GET,P,VARI,7,EXTREM,VMAX
*STATUS,PARM
/AXLAB,Y,PSD  (M^2/HZ)
PLVAR,7
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'f ','PSD '
LABEL(1,2) = 'Hz','SQmmS/Hz'
*VFILL,VALUE(1,1),DATA,45.9,3.4018E-3
*VFILL,VALUE(1,2),DATA,F,P
*VFILL,VALUE(1,3),DATA,ABS(F/45.9),ABS(P/(3.4018E-3))
FINISH
*END
SOLVIT
SAVE,TABLE_1
/NOPR
RESUME,TABLE_1
/COM
/OUT,vm203,vrt
/COM,------------------- VM203 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM, SHELL281
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F11.6,'  ',F15.6,'   ',1F16.3)
/COM,
/COM,
/COM,-----------------------------------------------------------
/COM,
/OUT
FINISH
*LIST,vm203,vrt
/DELETE,MODEL
/DELETE,SOLVIT,MAC
/DELETE,TABLE_1
```

VM204 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM204
/UNITS,BIN
/PREP7
/TITLE, VM204, SOLID MODEL OF AN AXIAL BEARING
/COM    ANY BASIC GEOMETRY TEXT
BASEWD=8.0                                        ! BASE WIDTH
BASEDP=4.0                                        ! BASE DEPTH
BASEHT=1.0                                        ! BASE HEIGHT
BRNGWD=4.0                                        ! BEARING HOUSING WIDTH
BRNGDP=3.0                                        ! BEARING HOUSING DEPTH
BRNGHT=2.0                                        ! BEARING HOUSING HEIGHT
GRVDIA=3.5                                        ! GROOVE DIAMETER
BRCKWD=2.0                                        ! BRACKET WIDTH
BRCKDP=0.5                                        ! BRACKET DEPTH
SPRTHT=BRNGHT/2                                   ! SUPPORT HOLE HEIGHT
SPRTRAD=0.5                                       ! SUPPORT HOLE RADIUS
BLOCK,-BASEWD/2,BASEWD/2,0,-BASEHT,0,BASEDP       ! BASE
BLOCK,-BRNGWD/2,BRNGWD/2,0,BRNGHT,0,BRNGDP        ! BEARING HOUSING
WPAVE,BRNGWD/2,0,0                                ! MOVE WORKING PLANE ORIGIN
BLOCK,0,BRCKWD,0,BRNGHT,0,BRCKDP                  ! RIGHT BRACKET
WPAVE,-BRNGWD/2,0,0
BLOCK,0,-BRCKWD,0,BRNGHT,0,BRCKDP                 ! LEFT BRACKET
WPAVE,0,BRNGHT,0
CYLIND,0,GRVDIA/2,0,BRNGWD
VSBV,2,5                                          ! GROOVE
LOCAL,11,1,BRNGWD/2+(BASEWD-BRNGWD)/4,SPRTHT      ! LOCAL COORD SYSTEM
WPCSYS,1,11                                       ! MOVE WP TO LOCAL CS
CYLIND,0,SPRTRAD,0,1
VSBV,3,2                                          ! SUPPORT HOLE
LOCAL,12,1,-BRNGWD/2-(BASEWD-BRNGWD)/4,SPRTHT
WPCSYS,1,12
CYLIND,0,SPRTRAD,0,1
VSBV,4,2                                          ! SUPPORT HOLE
CSYS,0                                            ! CARTESIAN COORD SYSTEM
WPAVE,BRNGWD/2+(BASEWD-BRNGWD)/4,,BASEDP*0.75
WPROTA,,90
CYLIND,0,SPRTRAD,0,1
VSBV,1,2                                          ! SUPPORT HOLE
WPOFFS,-BRNGWD-(BASEWD-BRNGWD)/2                  ! OFFSET WORKING PLANE
CYLIND,0,SPRTRAD,0,1
VSBV,4,1                                          ! SUPPORT HOLE
CSYS,11
K,100,(BASEWD-BRNGWD)/4,0,0
K,101,(BASEWD-BRNGWD)/4,90,0
K,102,(BASEWD-BRNGWD)/4,90,1
K,103,(BASEWD-BRNGWD)/4,0,1
A,100,101,102,103                                 ! CUTTING AREA
VSBA,5,3,SEPO                                     ! ROUND
VDELE,1,,,1
CSYS,12
K,105,(BASEWD-BRNGWD)/4,180,0
K,106,(BASEWD-BRNGWD)/4,90,0
K,107,(BASEWD-BRNGWD)/4,90,1
K,108,(BASEWD-BRNGWD)/4,180,1
A,105,106,107,108                                 ! CUTTING AREA
VSBA,3,3,SEPO                                     ! ROUND
VDELE,1,,,1
VGLUE,ALL                                         ! GLUE VOLUMES - CONTINUITY
/TYPE,1,4
/VIEW,1,1,2,3                                     ! VIEWING ANGLE
/AUTO,1
/TRIAD,OFF
VPLOT                                             ! DISPLAY VOLUMES
VSUM                                              ! CALCULATE TOTAL VOLUME
*GET,TVOL,VOLU,,VOLU
*status,parm
```

```
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,1,2
LABEL(1,1) = 'VOLUME '
LABEL(1,2) = 'NO UNTS '
*VFILL,VALUE(1,1),DATA,42.997
*VFILL,VALUE(1,2),DATA,TVOL
*VFILL,VALUE(1,3),DATA,ABS(TVOL/42.997)
/COM
/OUT,vm204,vrt
/COM,------------------- VM204 RESULTS COMPARISON--------------
/COM,
/COM,                    |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F18.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm204,vrt
```

VM205 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM205
/PREP7
SMRT,OFF
/TITLE, VM205, ELLIPTIC MEMBRANE UNDER A UNIFORMLY-DISTRIBUTED LOAD
/COM,   NAFEMS (REF.58), TEST NO. LE1 (MODIFIED)
/COM,   USING 2-D STRUCTURAL SOLID, PLANE182
ANTYPE,STATIC
ET,1,PLANE182,3,,3           ! DEFINE ELEMENT AS PLANE182 FOR PLANE STRESS
                             !  WITH THICKNESS
MP,EX,1,210E9                ! DEFINE MATERIAL PROPERTIES
MP,NUXY,1,.3
R,1,0.1                      ! SET THICKNESS
LOCAL,11,1,,,,,,,0.5         ! DEFINE ELLIPTICAL COORD. SYSTEM
K,1,2,90                     ! CREATE MODEL GEOMETRY
K,2,2,0                      ! DEFINE KEYPOINTS
L,1,2                        ! DEFINE LINE SEGMENTS
LOCAL,12,1,,,,,,,0.8461585
K,3,3.25,90
K,4,3.25,0.0
L,3,4
CSYS,0
L,2,4
L,1,3
AL,2,4,1,3                   ! DEFINE AREA
DL,4,1,SYMM                  ! APPLY BOUNDARY CONDITIONS
DL,3,1,SYMM
SFL,2,PRES,-10E6             ! APPLY LINE PRESSURE LOAD
MSHK,2                     ! MAPPED AREA MESH IF POSSIBLE
MSHA,0,2D                  ! USING QUADS
SAVE                         ! SAVE DATABASE
FINISH
ADAPT,4,7,,,1                ! USE Mechanical APDL PREDEFINED MACRO FOR ADAPTIVE MESHING
                             !  AND SOLUTION WITH NSOLN=3, STARGT=7, AND FACMX=1
*CREATE,MAC                  ! CREATE MACRO FOR POST PROCESSING
/POST1
EPLOT                        ! PLOT ELEMENTS
PRERR                        ! PRINT THE ENERGY NORM PERCENT ERROR (SEPC)
NSEL,S,LOC,Y,0.0
NSEL,R,LOC,X,2.0
*GET,MNODE,NODE,,NUM,MAX
*GET,SY_D,NODE,MNODE,S,Y     ! GET DESIRED STRESS SY VALUE
NSEL,ALL
ESEL,ALL
*status,parm                      ! SHOW STATUS OF PARAMETERS
```

```
*END
*USE,MAC                    ! USE POST PROCESSING MACRO
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'TAN STR '
LABEL(1,2) = 'MPa'
*VFILL,VALUE(1,1),DATA,92.70
*VFILL,VALUE(1,2),DATA,(SY_D/1000000)
*VFILL,VALUE(1,3),DATA,ABS((SY_D/1000000)/92.7)
SAVE,TABLE1
FINISH
/CLEAR, NOSTART ! CLEAR DATABASE BEFORE STARTING PART 2
/COM,        USING 2-D 8-NODE STRUCTURAL SOLID, PLANE82
/PREP7
SMRT,OFF
RESUME                      ! RESUME DATABASE
ET,1,PLANE183,,,3            ! DEFINE ELEMENT AS PLANE82 FOR PLANE STRESS
                            !  WITH THICKNESS
FINISH
ADAPT,2,5,,,1               ! USE Mechanical APDL PREDEFINED MACRO FOR ADAPTIVE MESHING
                            !  AND SOLUTION WITH NSOLN=2, STARGT=5, AND FACMX=1
*USE,MAC                    ! USE POST PROCESSING MACRO
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,1,2
LABEL(1,1) = 'TAN STR '
LABEL(1,2) = 'MPa'
*VFILL,VALUE(1,1),DATA,92.70
*VFILL,VALUE(1,2),DATA,(SY_D/1000000)
*VFILL,VALUE(1,3),DATA,ABS((SY_D/1000000)/92.7)
SAVE,TABLE2
RESUME,TABLE1
/COM
/OUT,vm205,vrt
/COM,------------------- VM205 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,PLANE182 RESULTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F18.3)
/NOPR
RESUME,TABLE2
/GOPR
/COM,
/COM,PLANE183 RESULTS:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F18.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm205,vrt
```

VM206 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM206
/PREP7
SMRT,OFF
/TITLE,VM206,STRANDED COIL MODEL, WITH VOLTAGE EXCITATION
/COM,   REF: BOAST "ELECTRIC AND MAGNETIC FIELDS", PG. 247, EQN. 12.18
ET,1,53,,,1         ! AIR
ET,2,53,2,,1        ! VOLTAGE FORCED COIL
ET,3,110,,,1        ! FAR-FIELD

EMUNIT,MKS
MP,MURX,1,1
```

```
MP,MURX,2,1
MP,RSVX,2,3.00E-8   ! RESISTIVITY OF COIL

S=.02      ! COIL WIDTH AND HEIGHT
N=500      ! NUMBER OF TURNS
R=3*S/2      ! COIL MIDSPAN RADIUS

RECTNG,S,2*S,0,S/2
PCIRC,0,6*S,0,90
PCIRC,0,12*S,0,90
AOVLAP,ALL
ASEL,S,AREA,,1
AATT,2,1,2
ASUM
*GET,A,AREA,,AREA        ! AREA OF 1/2 COIL CROSS-SECTION
ASEL,S,AREA,,5
AATT,1,1,1
ASEL,S,AREA,,4
AATT,1,1,3
ASEL,ALL
CSYS,1
LSEL,S,LOC,X,9*S
LESIZE,ALL,,,1
ESIZE,,8
AMESH,4

*GET,A,AREA,,AREA        ! AREA OF 1/2 COIL CROSS-SECTION
R,1,2*A,500,,1,1  ! COIL CONSTANTS
ASEL,S,AREA,,1
LSLA,S
LESIZE,ALL,,,5
LSEL,ALL
ASEL,ALL
CSYS,0
KSEL,S,LOC,X,0
KSEL,R,LOC,Y,0
KESIZE,ALL,S/5
AMESH,ALL

NSEL,ALL

N1=NODE(S,0,0)           ! GET A NODE ON THE COIL
N2=NODE(0,0,0)           ! GET NODE AT ORIGIN

ESEL,S,MAT,,2            ! GET COIL ELEMENTS
NSLE,S
CP,1,CURR,ALL            ! COUPLE CURR DOF IN COIL
*GET,ELM,ELEM,,NUM,MIN   ! GET AN ELEMENT NUMBER IN THE COIL REGION
NSEL,ALL
ESEL,ALL
CSYS,1
NSEL,S,LOC,X,12*S
SF,ALL,INF
NSEL,S,LOC,X,0
D,ALL,AZ,0
NSEL,ALL
FINISH

/SOLU
ANTYPE,STATIC
ESEL,S,MAT,,2
BFE,ALL,VLTG,,12         ! 12 VOLT LOAD
ESEL,ALL
SOLVE
FINISH

/POST1
SET,LAST
ESEL,S,MAT,,2            ! SELECT COIL ELEMENTS
ETABLE,RES,NMISC,8       ! STORE ELEMENT RESISTANCE
ETABLE,IND,NMISC,9       ! STORE ELEMENT INDUCTANCE
SSUM
```

```
*GET,CRES,SSUM,,ITEM,RES ! GET COIL RESISTANCE
*GET,CIND,SSUM,,ITEM,IND ! GET COIL INDUCTANCE
 CRES=2*CRES             ! COIL RESISTANCE
 CIND=2*CIND             ! COIL INDUCTANCE
ICUR=12/CRES             ! CALCULATE COIL CURRENT
*GET,NCUR,NODE,N1,CURR   ! GET SOLUTION CURRENT
ESEL,ALL
FINISH
PI=4*ATAN(1)
W=2*PI*60
IMAG=12/SQRT(CRES**2+W**2*CIND**2)
ANG=-ATAN(W*CIND/CRES)
REALCURR=IMAG*COS(ANG)              ! TARGET REAL CURRENT
IMAGCURR=IMAG*SIN(ANG)              ! TARGET IMAGINARY CURRENT
/SOLU
ESEL,ALL
ANTYPE,HARM
HARFRQ,60
SOLVE
FINISH

/POST1
SET,1
*GET,CURREAL,NODE,N1,CURR        ! COMPARE TO REALCURR
SET,1,1,,1
*GET,CURIMAG,NODE,N1,CURR        ! COMPARE TO IMAGCURR
*DIM,LABEL,CHAR,5,2
*DIM,VALUE,,5,3
LABEL(1,1) = 'INDUCTAN','RESISTAN','COIL CUR','REAL SOL','IMAG SOL'
LABEL(1,2) = 'CE,HENRY','CE, OHM ','RENT    ','UTION   ','UTION   '
*VFILL,VALUE(1,1),DATA,.01274,3.534,3.395,1.192,-1.621
*VFILL,VALUE(1,2),DATA,CIND,CRES,ICUR,CURREAL,CURIMAG
V1 = ABS(CIND/.01274)
V2 = ABS(CRES/3.534)
V3 = ABS(ICUR/3.395)
V4 = ABS(CURREAL/1.192)
V5 = ABS(CURIMAG/1.621)
*VFILL,VALUE(1,3),DATA,V1,V2,V3,V4,V5
/COM
/OUT,vm206,vrt
/COM,------------------- VM206 RESULTS COMPARISON -------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,PLANE53
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/OUT
FINISH
!

/CLEAR,NOSTART
/NOPR
/PREP7
SMRT,OFF
ET,1,233,,,1        ! AIR
ET,2,233,2,,1       ! STRANDED COIL
ET,3,110,,,1        ! FAR-FIELD

EMUNIT,MKS
MP,MURX,1,1
MP,MURX,2,1
MP,RSVX,2,3.00E-8   ! RESISTIVITY OF COIL

S=.02      ! COIL WIDTH AND HEIGHT
SC=S**2             ! COIL CROSS-SECTIONAL AREA
N=500      ! NUMBER OF TURNS
RMID=3*S/2     ! COIL MIDSPAN RADIUS
R=3.534             ! COIL RESISTANCE


R,1,1.0,SC,N,RMID,1,R
```

```
RMORE,2

RECTNG,S,2*S,0,S/2
PCIRC,0,6*S,0,90
PCIRC,0,12*S,0,90
AOVLAP,ALL
ASEL,S,AREA,,1
AATT,2,1,2
ASUM
*GET,A,AREA,,AREA         ! AREA OF 1/2 COIL CROSS-SECTION
ASEL,S,AREA,,5
AATT,1,2,1
ASEL,S,AREA,,4
AATT,1,3,3
ASEL,ALL
CSYS,1
LSEL,S,LOC,X,9*S
LESIZE,ALL,,,1
ESIZE,,8
AMESH,4


ASEL,S,AREA,,1
LSLA,S
LESIZE,ALL,,,5
LSEL,ALL
ASEL,ALL
CSYS,0
KSEL,S,LOC,X,0
KSEL,R,LOC,Y,0
KESIZE,ALL,S/5
AMESH,ALL

NSEL,ALL

N1=NODE(S,0,0)            ! GET A NODE ON THE COIL

ESEL,S,MAT,,2             ! GET COIL ELEMENTS
NSLE,S
CP,1,VOLT,ALL             ! COUPLE VOLT DOF IN COIL
CP,2,EMF,ALL              ! COUPLE EMF DOF IN COIL
*GET,ELM,ELEM,,NUM,MIN    ! GET AN ELEMENT NUMBER IN THE COIL REGION
NSEL,ALL
ESEL,ALL
CSYS,1
NSEL,S,LOC,X,12*S
SF,ALL,INF
NSEL,S,LOC,X,0
D,ALL,AZ,0
NSEL,ALL
FINISH

/SOLU
ANTYPE,STATIC
D,N1,VOLT,12              ! 12 VOLT LOAD
SOLVE
FINISH
*GET,ICOIL,NODE,N1,RF,AMPS         ! GET COIL CURRENT
/COM,
/COM,

FINISH

/SOLU
ANTYPE,HARM
HARFRQ,60
SOLVE
FINISH

/COM,
/COM,
/POST1
```

```
SET,1
*GET,CURREAL,NODE,N1,RF,AMPS
SET,1,1,,1
*GET,CURIMAG,NODE,N1,RF,AMPS

*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'COIL CUR','REAL SOL','IMAG SOL'
LABEL(1,2) = 'RENT    ','UTION   ','UTION   '
*VFILL,VALUE(1,1),DATA,3.395,1.192,-1.621
*VFILL,VALUE(1,2),DATA,ICOIL,CURREAL,CURIMAG
V1 = ABS(ICOIL/3.395)
V2 = ABS(CURREAL/1.192)
V3 = ABS(CURIMAG/1.621)
*VFILL,VALUE(1,3),DATA,V1,V2,V3
/COM
/OUT,vm206,vrt,,APPEND
/COM,PLANE233
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm206,vrt
```

VM207 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM207
/PREP7
SMRT,OFF
/TITLE,VM207,  STRANDED COIL MODEL, CIRCUIT-FED OPTION
/COM,   REF: BOAST "ELECTRIC AND MAGNETIC FIELDS", PG. 247, EQN. 12.18
ET,1,53,,,1         ! AIR
ET,2,53,3,,1        ! CIRCUIT-COUPLED STRANDED COIL
ET,3,110,,,1        ! FAR-FIELD
ET,4,124,0          ! EXTERNAL RESISTOR
ET,5,124,4,4        ! INDEPENDENT VOLTAGE SOURCE, PIECEWISE LINEAR LOAD
ET,6,124,5          ! STRANDED COIL (TO FEA DOMAIN)
R,2,2               ! 2 OHM RESISTOR
R,3,1               ! SYMMETRY FACTOR FOR COIL
EMUNIT,MKS
MP,MURX,1,1
MP,MURX,2,1
MP,RSVX,2,3.04878E-8  ! RESISTIVITY OF COIL
S=.02
N=500
R=3*S/2
N,1                   ! CREATE NODES FOR CIRCUIT ELEMENTS
*REPEAT,4,1
RECTNG,S,2*S,0,S/2
PCIRC,0,6*S,0,90
PCIRC,0,12*S,0,90
AOVLAP,ALL
ASEL,S,AREA,,1
AATT,2,1,2
ASUM
*GET,A,AREA,,AREA        ! AREA OF 1/2 COIL CROSS-SECTION
ASEL,S,AREA,,5
AATT,1,1,1
ASEL,S,AREA,,4
AATT,1,1,3
ASEL,ALL
CSYS,1
LSEL,S,LOC,X,9*S
LESIZE,ALL,,,1
ESIZE,,8
AMESH,4
```

```
*GET,A,AREA,,AREA         ! AREA OF 1/2 COIL CROSS-SECTION
R,1,2*A,500,,1,.9
ASEL,S,AREA,,1
LSLA,S
LESIZE,ALL,,,5
LSEL,ALL
ASEL,ALL
CSYS,0
KSEL,S,LOC,X,0
KSEL,R,LOC,Y,0
KESIZE,ALL,S/5
AMESH,ALL
N1=NODE(S,0,0)            ! GET A NODE ON THE COIL
TYPE,5                    ! VOLTAGE SOURCE
R,4,0,12,.01,12,.010001,0 ! PIECEWISE LINEAR LOAD
REAL,4
E,2,1,4                   ! VOLTAGE SOURCE ELEMENT
TYPE,4                    ! RESISTOR
REAL,2
E,2,3                     ! EXTERNAL RESISTOR ELEMENT
TYPE,6                    ! STRANDED COIL (TO FEA DOMAIN)
REAL,3
E,3,1,N1                  ! STRANDED COIL "ELEMENT"
ESEL,S,MAT,,2             ! GET COIL ELEMENTS
NSLE,S
CP,1,CURR,ALL             ! COUPLE CURR DOF IN COIL
CP,2,EMF,ALL              ! COUPLE EMF DOF IN COIL
*GET,ELM,ELEM,,NUM,MIN    ! GET AN ELEMENT NUMBER IN THE COIL REGION
NSEL,ALL
ESEL,ALL
FINISH
/SOLU
ANTYPE,STATIC
TIME,1E-9
CSYS,1
NSEL,S,LOC,X,12*S
SF,ALL,INF                ! APPLY INFINITE SURFACE FLAG
CSYS,0
NSEL,S,LOC,X,0
D,ALL,AZ,0
NSEL,ALL
D,1,VOLT,0                ! GROUND
SOLVE
FINISH
/POST1
SET,LAST
ESEL,S,MAT,,2             ! SELECT COIL ELEMENTS
ETABLE,RES,NMISC,8        ! STORE ELEMENT RESISTANCE
ETABLE,IND,NMISC,9        ! STORE ELEMENT INDUCTANCE
SSUM
*GET,CRES,SSUM,,ITEM,RES ! GET COIL RESISTANCE
*GET,CIND,SSUM,,ITEM,IND ! GET COIL INDUCTANCE
 CRES=2*CRES
 CIND=2*CIND
ESEL,ALL
FINISH
/SOLU
ANTYPE,TRANS
OUTRES,ALL,ALL            ! STORE EVERY SUBSTEP
DELTIM,.0004
TIME,.01
SOLVE
FINISH
/POST26
NSOL,2,N1,CURR            ! GET CURRENT IN COIL
RES=CRES+2
I01=(12/RES)*(1-(EXP(-RES*.01/CIND)))
PRVAR,2
*GET,ICUR,VARI,2,RTIME,.01
/AXLAB,X,TIME
/AXLAB,Y,CURRENT IN COIL (AMPS)
/SHOW
```

```
PLVAR,2                  ! PLOT COIL CURRENT VS TIME.
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'INDUCTAN','RESISTAN','CURRENT,'
LABEL(1,2) = 'CE,HENRY','CE, OHM ',' AMPS   '
*VFILL,VALUE(1,1),DATA,.01274,3.9908,1.9849
*VFILL,VALUE(1,2),DATA,CIND,CRES,ICUR
*VFILL,VALUE(1,3),DATA,ABS(CIND/.01274),ABS(CRES/3.9908),ABS(ICUR/1.9849)
/COM
/OUT,vm207,vrt
/COM,------------------- VM207 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,PLANE53
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/OUT
FINISH

/CLEAR,NOSTART
/NOPR
/PREP7
SMRT,OFF
/TITLE,VM207,  STRANDED COIL MODEL, CIRCUIT-FED OPTION
ET,1,233,,,1        ! AIR
ET,2,233,2,,1       ! STRANDED COIL
ET,3,110,,,1        ! FAR-FIELD
ET,4,124,0          ! EXTERNAL RESISTOR
ET,5,124,4,4        ! INDEPENDENT VOLTAGE SOURCE, PIECEWISE LINEAR LOAD
R,2,2               ! 2 OHM RESISTOR
R,4,0,12,.01,12,.010001,0 ! PIECEWISE LINEAR LOAD

EMUNIT,MKS
MP,MURX,1,1
MP,MURX,2,1

S=.02      ! COIL WIDTH AND HEIGHT
SC=S**2             ! COIL CROSS-SECTIONAL AREA
N=500      ! NUMBER OF TURNS
RMID=3*S/2     ! BROOKS COIL MIDSPAN RADIUS
R=3.991             ! COIL RESISTANCE

N,1                 ! CREATE NODES FOR CIRCUIT ELEMENTS
*REPEAT,3,1

R,3,1.0,SC,N,RMID,1,R
RMORE,2

RECTNG,S,2*S,0,S/2
PCIRC,0,6*S,0,90
PCIRC,0,12*S,0,90
AOVLAP,ALL
ASEL,S,AREA,,1
AATT,2,3,2
ASUM
*GET,A,AREA,,AREA        ! AREA OF 1/2 COIL CROSS-SECTION
ASEL,S,AREA,,5
AATT,1,1,1
ASEL,S,AREA,,4
AATT,1,1,3
ASEL,ALL
CSYS,1
LSEL,S,LOC,X,9*S
LESIZE,ALL,,,1
ESIZE,,8
AMESH,4

ASEL,S,AREA,,1
LSLA,S
LESIZE,ALL,,,5
LSEL,ALL
ASEL,ALL
```

```
CSYS,0
KSEL,S,LOC,X,0
KSEL,R,LOC,Y,0
KESIZE,ALL,S/5
AMESH,ALL

NSEL,ALL

N1=NODE(S,0,0)            ! GET A NODE ON THE COIL

TYPE,5                    ! VOLTAGE SOURCE
REAL,4
E,2,1,3                   ! VOLTAGE SOURCE ELEMENT
TYPE,4                    ! RESISTOR
REAL,2
E,2,N1                    ! EXTERNAL RESISTOR ELEMENT, DIRECTLY CONNECTED TO THE COIL

ESEL,S,MAT,,2             ! GET COIL ELEMENTS
NSLE,S
CP,1,VOLT,ALL             ! COUPLE VOLT DOF IN COIL
CP,2,EMF,ALL              ! COUPLE EMF DOF IN COIL
*GET,ELM,ELEM,,NUM,MIN    ! GET AN ELEMENT NUMBER IN THE COIL REGION
NSEL,ALL
ESEL,ALL
CSYS,1
NSEL,S,LOC,X,12*S
SF,ALL,INF
CSYS,0
NSEL,S,LOC,X,0
D,ALL,AZ,0
NSEL,ALL
FINISH

/SOLU
ANTYPE,STATIC
TIME,1E-9
D,1,VOLT,0                ! GROUND
SOLVE
FINISH

/POST1
*GET,IC,NODE,1,RF,AMPS    ! GET COIL CURRENT
ETABLE,_SENE,SENE         ! SUM UP MAGNETIC ENERGY STORED
SSUM
*GET,W,SSUM,,ITEM,_SENE
W=2*W                     ! SYMMETRY FACTOR
LCOIL=2*W/IC**2           ! CALCULATE INDUCTANCE VIA MAGNETIC ENERGY
FINISH

/SOLU
ANTYPE,TRANS
OUTRES,ALL,ALL            ! STORE EVERY SUBSTEP
DELTIM,.0004
TIME,.01
SOLVE
FINISH

/POST26
RFOR,2,1,AMPS            ! GET CURRENT IN COIL
/AXLAB,X,TIME
/AXLAB,Y,CURRENT IN COIL (AMPS)
/YRANGE,0,2,.2
/SHOW
PLVAR,2                   ! PLOT COIL CURRENT VS TIME.
PRVAR,2                   ! PRINT COIL CURRENT VS TIME.
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'INDUCTAN','CURRENT,'
LABEL(1,2) = 'CE,HENRY',' AMPS   '
*VFILL,VALUE(1,1),DATA,.01274,1.9849
*VFILL,VALUE(1,2),DATA,LCOIL,IC
*VFILL,VALUE(1,3),DATA,ABS(LCOIL/.01274),ABS(IC/1.9849)
```

```
/COM
/OUT,vm207,vrt,,APPEND
/COM,PLANE233
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm207,vrt
```

VM208 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM208
/PREP7
/TITLE, VM208, TEST CIRCUIT COMPONENT CCCS IN HARMONIC ANALYSIS
/COM  REV.5.2  SDS-98
/COM,   SEE SCHAUMS OUTLINE "BASIC CIRCUIT ANALYSIS", 2ND ED, 1992,
/COM,   PROBLEM 14.23, FIGURE 14-25.
/NOPR
ET,1,CIRCU124,4    ! VOLTAGE SOURCE
ET,2,CIRCU124,3    ! CURRENT SOURCE
ET,3,CIRCU124,0    ! RESISTOR
ET,4,CIRCU124,1    ! INDUCTOR
ET,5,CIRCU124,12   ! CURRENT CONTROLLED CURRENT SOURCE

R,1,15,30          ! VOLTAGE SOURCE
R,2,5,-45          ! CURRENT SOURCE
R,3,3              ! R1
R,4,2              ! R2
R,5,4              ! L1
R,6,-3              ! CCCS GAIN

N,1
NGEN,10,1,1,1,1

TYPE,1
REAL,1
E,2,1,7            ! V1
TYPE,3
REAL,3
E,2,3              ! R1
TYPE,4
REAL,5
E,3,1              ! L1
TYPE,3
REAL,4
E,3,4              ! R2
TYPE,5
REAL,6
E,3,4,5,2,1,7      ! CCCS
TYPE,2
REAL,2
E,1,4              ! C1

FINISH
/SOLU
ANTYP,HARM
D,1,VOLT,0
PI=4*ATAN(1)
HARFRQ,1/(2*PI)
OUTPR,ALL,ALL
HROUT,OFF
SOLVE
FINISH

/POST1
SET,1,1                 ! READ IN REAL SOLUTION
```

```
PRESOL,ELEM              ! PRINT CIRCUIT SOLUTION PER ELEMENT
SET,1,1,,1               ! READ IN IMAGINARY SOLUTION
PRESOL,ELEM              ! PRINT CIRCUIT SOLUTION PER ELEMENT
FINISH
/POST26
NSOL,2,4,VOLT
PRVAR,2
*GET,REAL,VARI,2,RTIME,15915
*GET,IMAG,VARI,2,ITIME,15915
FINISH
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'REAL VOL','IMAG VOL'
LABEL(1,2) = 'TAGE, V ','TAGE, V '
*VFILL,VALUE(1,1),DATA,16.44,-1.41
*VFILL,VALUE(1,2),DATA,REAL,IMAG
*VFILL,VALUE(1,3),DATA,ABS(REAL/16.44),ABS(IMAG/1.41)
/COM
/OUT,vm208,vrt
/COM,------------------- VM208 RESULTS COMPARISON -------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm208,vrt
```

VM209 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM209
/TITLE,VM209,DOUBLE BELLOWS AIR SPRING
/COM, REFERENCE: BERRY,DALE T. AND YANG,HENRY T.Y.,"FORMULATION AND EXPERIMENTAL
/COM, VERIFICATION OF A PNEUMATIC FINITE ELEMENT" - IJNME, VOL. 39, PG:1097-1114 (1996)
/COM,
/PREP7
ET,1,208    !AXISYMMETRIC SHELL
MP,EX,1,1000    !YOUNG'S MODULUS (PSI)
MP,NUXY,1,0.49    !POISSON'S RATIO

ET,2,241    !2D HYDROSTATIC FLUID ELEMENT
KEYOPT,2,3,1    !AXISYMMETRIC KEY OPTION
TB,FLUID,2,1,1,GAS
TBDATA,1,4.4256E-5   !DENSITY IN LB/IN^3 FOR AIR

MP,EX,3,400000    !YOUNG'S MODULUS FOR POLYESTER CORDS (PSI)
MP,NUXY,3,0.37    !POISSON'S RATIO FOR POLYESTER CORDS

MP,EX,4,3.046E7    !YOUNG'S MODULUS (PSI) FOR RIGID PLATE
MP,NUXY,4,0.3    !POISSON'S RATIO FOR RIGID PLATE

MP,REFT,2,20
TOFFST,274

SECT,1,SHELL          !SECTION DEFINITION FOR BELLOW SHELL
SECD,0.1

RB=2.2                    !RADIUS OF THE BELLOW (IN)
RP=4                      !RADIUS OF THE PLATE (IN)
H=9.6/4                   !TOTAL HEIGHT (IN)
HP=0.2                    !PLATE HEIGHT (IN)
F=1000
PI=3.14159           !VALUE OF PI

N,1,0,0        !PRESSURE NODE LOCATION
```

```
K,1,0,0
K,2,RP,0
K,3,RP+RB,0
K,4,RP,RB
K,5,RP,RB+HP
K,6,0,H

LARC,3,4,2,2.2,
L,4,5
L,5,6

TYPE,1
SECN,1
MAT,1
LESIZE,1,,,10
LMESH,1     !MESH THE BELLOWS

TYPE,1
SECN,1
MAT,4
LESIZE,2,,,1
LMESH,2     !MESH RIGID PLATE
LESIZE,3,,,1
LMESH,3     !MESH RIGID PLATE
ALLSEL,ALL

TYPE,2
REAL,2
R,2,,14.7    !INITIAL AIR PRESSURE (ATMOSPHERIC)=14.7 PSI
MAT,2

LSEL,S,LINE,,1,3
NSLL,S,1
ESURF,1     !GENERATE HYDROSTATIC FLUID ELEMENTS
ALLSEL,ALL

SECTYPE,11,REINF,SMEAR
SECDATA,3,1.96E-3,0.05,,,EDGO,1,0.5 !CROSS-SECTIONAL AREA/PLACEMENT (IN) OF CORDS
LSEL,S,LINE,,1
ESLL,S
ESEL,R,TYPE,,1
SECN,11
EREINF     !REINFORCE BELLOWS WITH POLYESTER CORDS
ALLSEL,ALL

NSEL,S,LOC,Y,H    !SET BOUNDARY CONDITIONS
D,ALL,ALL
NSEL,S,LOC,X,0.
D,ALL,UX,0.
NSEL,S,LOC,Y,0
D,ALL,UY,0
ALLSEL,ALL
FINISH

/SOLU
NLGEOM,ON
TIME,1
CNVTOL,F,1
CNVTOL,M,1
CNVTOL,DVOL,1
CNVTOL,U,1
CNVTOL,ROT,1
CNVTOL,HDSP,1
OUTRES,ALL,ALL
NSUB,1,100,1
BF,1,TEMP,20    !BRING EVERYTHING TO REFERENCE TEMPERATURE
KBC,1
/OUT,SCRATCH
SOLVE
TIME,2
KBC,0
```

```
D,1,HDSP,20    !INCREASE THE PRESSURE TO DESIRED
NSUB,10,100,1
SOLVE
DDEL,1,HDSP
NSEL,S,LOC,Y,H
D,ALL,UY,-1.5    !MOVE THE RIGID PLATE DOWNWARD
ALLSEL,ALL
NSUB,30,30,30
TIME,3
SOLVE
FINISH

/POST26
/OUT,
NSOL,2,1,HDSP,,PRES
NSOL,3,14,U,Y,UY
RFOR,4,13,F,Y,FY13
RFOR,5,14,F,Y,FY14
ADD,6,4,5,,RFOR,,,-1,-1   !SWITCH THE SIGNS OF RFOR RESULTS

/OUT
/RESET
AA=
*DIM,AA,TABLE,7,6
AA(1,0) = 10,9,8,7,6,5   !VALUES FOR DISPLACEMENT
AA(0,1) = 0,990,1231,1692,2230,2769,3384,4230
AA(0,2) = 0,869.659,1226.55,1609.8,2050.35,2581.33,3246.09,4109.82
AA(0,3) = 0, 1850,2640,3350,4050,5000,6000,7333
AA(0,4) = 0,1750.69,2405.88,3089.12,3849.41,4738.9,5825.32,7209.64
AA(0,5) = 0,2667,3875,4650,6000,7200,8750
AA(0,6) = 0,2644.49,3596.3,4578.78,5658.43,6906.07,8413.2
/TITLE,ANALYSIS OF DOUBLE BELLOWS AIR SPRING
/GCOLUMN,1,EXP 20 PSI   !ASSIGNS AA(0,1) AS EXPERIMENTAL DATA AT 20 PSI
/GMARKER,1,1
/GCOLUMN,2,ANS 20 PSI   !ASSIGNS AA(0,2) AS Mechanical APDL DATA AT 20 PSI (GAS)
/GMARKER,2,2
/GCOLUMN,3,EXP 40 PSI   !ASSIGNS AA(0,3) AS EXPERIMENTAL DATA AT 40 PSI
/GMARKER,3,1
/GCOLUMN,4,ANS 40 PSI   !ASSIGNS AA(0,4) AS Mechanical APDL DATA AT 40 PSI (GAS)
/GMARKER,4,2
/GCOLUMN,5,EXP 60 PSI   !ASSIGNS AA(0,5) AS EXPERIMENTAL DATA AT 60 PSI
/GMARKER,5,1
/GCOLUMN,6,ANS 60 PSI   !ASSIGNS AA(0,6) AS Mechanical APDL DATA AT 60 PSI (GAS)
/GMARKER,6,2
/XRANGE,5,10
/YRANGE,0,10000
/GROPT,DIVX,5    !5 DIVISIONS ALONG THE X AXIS
/GROPT,REVX,1    !PLOTS X AXIS VALUES IN REVERSE ORDER
/AXLAB,X,HEIGHT BETWEEN END PLATES (IN) !X AXIS LABEL
/AXLAB,Y,COMPRESSIVE LOAD (LBS)  !Y AXIS LABEL
*VPLOT,AA(1,0),AA(1),2,3,4,5,6  !COMPARE THIS PLOT WITH FIGURE 8 IN REFERENCE

*DIM,LABEL2,CHAR,6,6
*DIM,VALUE2,,6,6
LABEL2(1,1) ='0.25','0.50','0.75','1.00','1.25','1.50'
*VFILL,VALUE2(1,1),DATA,1231,1692,2230,2769,3384,4230
*VFILL,VALUE2(1,2),DATA,1226.55,1609.8,2050.35,2581.33,3246.09,4109.82
*VFILL,VALUE2(1,3),DATA,ABS(1226.55/1231),ABS(1609.8/1692),ABS(2050.35/2230),ABS(2581.33/2769),ABS(3246.09/3384)

*DIM,LABEL,CHAR,6,6
*DIM,VALUE,,6,6
LABEL(1,1) ='0.25','0.50','0.75','1.00','1.25','1.50'
*VFILL,VALUE(1,1),DATA,2640,3350,4050,5000,6000,7333
*VFILL,VALUE(1,2),DATA,2405.88,3089.12,3849.41,4738.9,5825.32,7209.64
*VFILL,VALUE(1,3),DATA,ABS(2405.88/2640),ABS(3089.12/3350),ABS(3849.41/4050),ABS(4738.9/5000),ABS(5825.32/6000),

*DIM,LABEL3,CHAR,5,5
*DIM,VALUE3,,5,5
LABEL3(1,1) ='0.25','0.50','0.75','1.00','1.25'
*VFILL,VALUE3(1,1),DATA,3875,4650,6000,7200,8750
*VFILL,VALUE3(1,2),DATA,3596.3,4578.78,5658.43,6906.07,8413.20
*VFILL,VALUE3(1,3),DATA,ABS(3596.3/3875),ABS(4578.78/4650),ABS(5658.43/6000),ABS(6906.07/7200),ABS(8413.20/8750)
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```
FINISH
SAVE,TABLE_1
/CLEAR,NOSTART
C***  PERFORM ANALYSIS USING PVDATA
/PREP7
ET,1,208    !AXISYMMETRIC SHELL
MP,EX,1,1000    !YOUNG'S MODULUS (PSI)
MP,NUXY,1,0.49    !POISSON'S RATIO

ET,2,241    !2D HYDROSTATIC FLUID ELEMENT
KEYOPT,2,3,1    !AXISYMMETRIC KEY OPTION

TB,FLUID,2,1,7,PVDATA
TBTEMP,20
TBPT,,34.7,238.931   !PV POINTS FOR 20 PSI
TBPT,,44.7,185.4788747
TBPT,,54.7,151.5704881
TBPT,,74.7,110.9893668
TBPT,,94.7,87.54916262
TBPT,,414.7,19.99253846
TBPT,,1014.7,8.170795013

TB,FLUID,5,1,12,PVDATA
TBTEMP,20
TBPT,,34.7,377.9675418   !PV POINTS FOR 40 PSI
TBPT,,44.7,293.4110447
TBPT,,54.7,239.771
TBPT,,74.7,175.5752838
TBPT,,94.7,138.4949704
TBPT,,114.7,114.345891
TBPT,,314.7,41.67611598
TBPT,,414.7,31.62641355
TBPT,,514.7,25.48178298
TBPT,,714.7,18.35101959
TBPT,,914.7,14.3385522
TBPT,,1014.7,12.9254693

TB,FLUID,6,1,25,PVDATA
TBTEMP,20
TBPT,,34.7,517.9960634   !PV POINTS FOR 60 PSI
TBPT,,44.7,402.7732752
TBPT,,54.7,328.6007934
TBPT,,74.7,240.622
TBPT,,84.7,212.2132633
TBPT,,94.7,189.8042598
TBPT,,104.7,171.6758682
TBPT,,164.7,109.1345683
TBPT,,214.7,83.71897252
TBPT,,264.7,67.9050374
TBPT,,314.7,57.11618494
TBPT,,364.7,49.28561393
TBPT,,414.7,43.3432925
TBPT,,464.7,38.67971465
TBPT,,514.7,34.92221372
TBPT,,564.7,31.8301105
TBPT,,614.7,29.24103367
TBPT,,664.7,27.04146743
TBPT,,714.7,25.14966196
TBPT,,764.7,23.50524833
TBPT,,814.7,22.06267755
TBPT,,864.7,20.78693852
TBPT,,914.7,19.65066514
TBPT,,964.7,18.63217933
TBPT,,1014.7,17.71406662

MP,EX,3,400000    !YOUNG'S MODULUS FOR POLYESTER CORDS (PSI)
MP,NUXY,3,0.37    !POISSON'S RATIO FOR POLYESTER CORDS

MP,EX,4,3.046E7    !YOUNG'S MODULUS (PSI) FOR RIGID PLATE
MP,NUXY,4,0.3    !POISSON'S RATIO FOR RIGID PLATE

MP,REFT,2,20
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TOFFST,274

SECT,1,SHELL          !SECTION DEFINITION FOR BELLOW SHELL
SECD,0.1

RB=2.2                    !RADIUS OF THE BELLOW (IN)
RP=4                      !RADIUS OF THE PLATE (IN)
H=9.6/4                   !TOTAL HEIGHT (IN)
HP=0.2                    !PLATE HEIGHT (IN)
F=1000
PI=3.14159           !VALUE OF PI

N,1,0,0        !PRESSURE NODE LOCATION

K,1,0,0
K,2,RP,0
K,3,RP+RB,0
K,4,RP,RB
K,5,RP,RB+HP
K,6,0,H

LARC,3,4,2,2.2,
L,4,5
L,5,6

TYPE,1
SECN,1
MAT,1
LESIZE,1,,,10
LMESH,1     !MESH THE BELLOWS

TYPE,1
SECN,1
MAT,4
LESIZE,2,,,1
LMESH,2     !MESH RIGID PLATE
LESIZE,3,,,1
LMESH,3     !MESH RIGID PLATE
ALLSEL,ALL

TYPE,2
REAL,2
R,2,,14.7    !INITIAL AIR PRESSURE (ATMOSPHERIC)=14.7 PSI
MAT,2       !CHANGE MATERIAL TO USE DESIRED PRESSURE AND PV POINTS

LSEL,S,LINE,,1,3
NSLL,S,1
ESURF,1     !GENERATE HYDROSTATIC FLUID ELEMENTS
ALLSEL,ALL

SECTYPE,11,REINF,SMEAR
SECDATA,3,1.96E-3,0.05,,,EDGO,1,0.5 !CROSS-SECTIONAL AREA/PLACEMENT (IN) OF CORDS
LSEL,S,LINE,,1
ESLL,S
ESEL,R,TYPE,,1
SECN,11
EREINF     !REINFORCE BELLOWS WITH POLYESTER CORDS
ALLSEL,ALL

NSEL,S,LOC,Y,H    !SET BOUNDARY CONDITIONS
D,ALL,ALL
NSEL,S,LOC,X,0.
D,ALL,UX,0.
NSEL,S,LOC,Y,0
D,ALL,UY,0
ALLSEL,ALL
FINISH

/SOLU
NLGEOM,ON
TIME,1
CNVTOL,F,1
```

```
CNVTOL,DVOL,1
CNVTOL,U,1
CNVTOL,HDSP,1
OUTRES,ALL,ALL
NSUB,1,100,1
BF,1,TEMP,20    !BRING EVERYTHING TO REFERENCE TEMPERATURE
KBC,1
/OUT,SCRATCH
SOLVE
TIME,2
KBC,0
D,1,HDSP,20    !INCREASE THE PRESSURE TO DESIRED PSI
NSUB,10,100,1
SOLVE
DDEL,1,HDSP
NSEL,S,LOC,Y,H
D,ALL,UY,-1.5    !MOVE THE RIGID PLATE DOWNWARD
ALLSEL,ALL
NSUB,30,30,30
TIME,3
SOLVE
FINISH

/POST26
/OUT,
NSOL,2,1,HDSP,,PRES
NSOL,3,14,U,Y,UY
RFOR,4,13,F,Y,FY13
RFOR,5,14,F,Y,FY14
ADD,6,4,5,,RFOR,,,-1,-1   !SWITCH THE SIGNS OF RFOR RESULTS

/OUT
/RESET
AA=
*DIM,AA,TABLE,7,6
AA(1,0) = 10,9,8,7,6,5   !VALUES FOR DISPLACEMENT
AA(0,1) = 0,990,1231,1692,2230,2769,3384,4230
AA(0,2) = 0,869.659,1249.79,1650.75,2077.76,2613.12,3263.09,4238.18
AA(0,3) = 0, 1850,2640,3350,4050,5000,6000,7333
AA(0,4) = 0,1750.69,2455.05,3185.58,3950.18,4742.42,5923.76,7251.99
AA(0,5) = 0,2667,3875,4650,6000,7200,8750
AA(0,6) = 0,2644.49,3613.49,4580.66,5674.34,6922.04,8780.85
/TITLE,ANALYSIS OF DOUBLE BELLOWS AIR SPRING
/GCOLUMN,1,EXP 20 PSI   !ASSIGNS AA(0,1) AS EXPERIMENTAL DATA AT 20 PSI
/GMARKER,1,1
/GCOLUMN,2,ANS 20 PSI   !ASSIGNS AA(0,2) AS Mechanical APDL DATA AT 20 PSI (PVDATA)
/GMARKER,2,2
/GCOLUMN,3,EXP 40 PSI   !ASSIGNS AA(0,3) AS EXPERIMENTAL DATA AT 40 PSI
/GMARKER,3,1
/GCOLUMN,4,ANS 40 PSI   !ASSIGNS AA(0,4) AS Mechanical APDL DATA AT 40 PSI (PVDATA)
/GMARKER,4,2
/GCOLUMN,5,EXP 60 PSI   !ASSIGNS AA(0,5) AS EXPERIMENTAL DATA AT 60 PSI
/GMARKER,5,1
/GCOLUMN,6,ANS 60 PSI   !ASSIGNS AA(0,6) AS Mechanical APDL DATA AT 60 PSI (PVDATA)
/GMARKER,6,2
/XRANGE,5,10
/YRANGE,0,10000
/GROPT,DIVX,5    !5 DIVISIONS ALONG THE X AXIS
/GROPT,REVX,1    !PLOTS X AXIS VALUES IN REVERSE ORDER
/AXLAB,X,HEIGHT BETWEEN END PLATES (IN) !X AXIS LABEL
/AXLAB,Y,COMPRESSIVE LOAD (LBS)  !Y AXIS LABEL
*VPLOT,AA(1,0),AA(1),2,3,4,5,6  !COMPARE THIS PLOT WITH FIGURE 8 IN REFERENCE

*DIM,LABEL2,CHAR,6,6
*DIM,VALUE2,,6,6
LABEL2(1,1) ='0.25','0.50','0.75','1.00','1.25','1.50'
*VFILL,VALUE2(1,1),DATA,1231,1692,2230,2769,3384,4230
*VFILL,VALUE2(1,2),DATA,1249.79,1650.75,2077.76,2613.12,3263.09,4238.18
*VFILL,VALUE2(1,3),DATA,ABS(1249.79/1231),ABS(1650.75/1692),ABS(2077.76/2230),ABS(2613.12/2769),ABS(3263.09/3384),ABS(4

*DIM,LABEL,CHAR,6,6
*DIM,VALUE,,6,6
```

```
LABEL(1,1) ='0.25','0.50','0.75','1.00','1.25','1.50'
*VFILL,VALUE(1,1),DATA,2640,3350,4050,5000,6000,7333
*VFILL,VALUE(1,2),DATA,2455.05,3185.58,3950.18,4742.42,5923.76,7251.99
*VFILL,VALUE(1,3),DATA,ABS(2455.05/2640),ABS(3185.58/3350),ABS(3950.18/4050),ABS(4742.42/5000),ABS(5923.76/6000)

*DIM,LABEL3,CHAR,5,5
*DIM,VALUE3,,5,5
LABEL3(1,1) ='0.25','0.50','0.75','1.00','1.25'
*VFILL,VALUE3(1,1),DATA,3875,4650,6000,7200,8750
*VFILL,VALUE3(1,2),DATA,3613.49,4580.66,5674.34,6922.04,8780.85
*VFILL,VALUE3(1,3),DATA,ABS(3613.49/3875),ABS(4580.66/4650),ABS(5674.34/6000),ABS(6922.04/7200),ABS(8780.85/8750
FINISH
SAVE,TABLE_2
RESUME, TABLE_1
/COM
/OUT,vm209,vrt
/COM,----------------- VM209 RESULTS COMPARISON -------------------
/COM,
/COM,
/COM,20 PSI         |  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL2(1,1),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(6X,A8,' ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM,
/COM,40 PSI         |  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(6X,A8,' ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM,
/COM,60 PSI         |  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL3(1,1),VALUE3(1,1),VALUE3(1,2),VALUE3(1,3)
(6X,A8,' ',F10.4,'  ',F14.4,'   ',F15.3)
/NOPR
RESUME,TABLE_2
/GOPR/COM,
/COM,20 PSI (PVDATA)|  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL2(1,1),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(6X,A8,' ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM,
/COM,40 PSI (PVDATA)|  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(6X,A8,' ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM,
/COM,60 PSI (PVDATA)|  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL3(1,1),VALUE3(1,1),VALUE3(1,2),VALUE3(1,3)
(6X,A8,' ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vm209,vrt
/DELETE,TABLE_1
/DELETE,TABLE_2
```

VM210 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM210
/TITLE,VM210, BENDING OF HEX-TO-TET INTERFACE, FORMATION OF PYRAMIDS
/COM,   ****** USING 3-D SOLID95 ******
/PREP7
```

```
SMRT,OFF
ET,1,95                                   ! ELEMENT TYPE SOLID95
ET,2,95                                   ! ELEMENT TYPE SOLID95

*CREATE,MSHGEN3D,MAC                      ! CREATE MACRO TO GENERATE MESH
MP,EX,1,30E6                              ! ELASTIC MODULUS
MP,NUXY,1,0.3                             ! POISSON RATIO
P = 200                                   ! FORCE
W = 31.071                                ! WIDTH
H = 33.917                                ! HEIGHT
L = 37.264                                ! LENGTH
I = 1/12*(W)*(H**3)                       ! MOMENT OF INERTIA
SURF = P/(W*H)                            ! SURFACE FORCE
BLOCK,-W/2, 0  , 0  , H/2, 0  ,  L
BLOCK, 0  , W/2, 0  , H/2, 0  ,  L        ! CREATE BLOCKS
BLOCK, 0  , W/2,-H/2, 0  , 0  ,  L        ! FORMING MIDPLANES
BLOCK,-W/2, 0  ,-H/2, 0  , 0  ,  L
WPOFF,,,L/2                               ! OFFSET WORKPLANE
WPLANE,-1,0,0,18.632,.87653,.402592,18.896,-.437455,.894952,18.72
WPLANE,-1,0,0,18.632,.890222,.338091,18.937,-.405661,.893273,18.826
VSBW,ALL,,
VGLUE,ALL
NUMCMP,ALL
/VIEW, 1, 0.9227    , 0.3132    ,-0.2246
/ANG,  1,  4.473
/PNUM,LINE,1
/NUM,-1
LPLO
/PNUM,LINE,0
/NUM,0
LESIZE,ALL,,,2
MOPT,PYRA,ON                               ! MESH SET TO TRANSITIONAL PYRAMID
MSHK,1
MSHA,0
MSHM,0
TYPE,1
VSEL,S,VOLU,,1,2,1
VSEL,A,VOLU,,5,7,2
VMESH,ALL                                  ! VMESH ELEMENT TYPE 1
MSHK,0
MSHA,1,3D
MSHM,0
TYPE,2
VSEL,S,VOLU,,3,4,1
VSEL,A,VOLU,,6,8,2
VMESH,ALL                                 ! VMESH ELEMENT TYPE 2
VSEL,ALL
CSYS,4                                    ! USE WP AS LOCAL COOR. SYS
NSEL,S,LOC,Z,0                            ! SELECT ALL NODES ON WP
CSYS,0                                    ! REVERT COOR. SYS TO CART.
ESLN                                      ! ALL ELEMENTS ATTACHED TO WP NODES
NSLE                                      ! AND ALL NODES ATT. TO ELEMS
/SHRINK,0.5
/VIEW,1,  0.51440  , -0.35450 ,  -0.78090
/ANG,1 ,1.41
EPLO                                      ! ADJUST VIEW AND CAPTURE INTERFACE
/SHRINK,0
*END

MSHGEN3D                                  ! READ MACRO TO GENERATE MESH

*CREATE,SOLV3D,MAC                        ! CREATE MACRO TO PERFORM SOLUTION
! THIS IS THE SECTION CONTAINING THE LOADING.  THE MOMENT
! USED IN THE VERIFICATION EQUATION IS THE SUM OF ALL
! OF THE MOMENTS ON THE AREA LOCATED AT Z=0 OR Z=L.  NOTE
! THAT THE LOADS ON EITHER AREA FORM A COUPLE.
SFGRAD,PRES,,Y,H/2,2*SURF/H                 ! APPLY GRADIENT SURFACE LOADS
ASEL,S,LOC,Z,0
ASEL,A,LOC,Z,L
SFA,ALL,1,PRES,SURF,
ALLS
SFTRAN                                      ! LOADS END
```

```
NSEL,S,LOC,X,W/2                          ! DEFINE DOF CONSTRAINTS
NSEL,R,LOC,Y,0                            ! SIMILAR TO PATCH TEST
NSEL,R,LOC,Z,0                            ! CONSTRAINTS
D,ALL, UX ,
D,ALL, UY ,
D,ALL, UZ ,
NSEL,S,LOC,X,-W/2
NSEL,R,LOC,Y,0
NSEL,R,LOC,Z,0
D,ALL, UY ,
D,ALL, UZ ,
NSEL,S,LOC,X,W/2
NSEL,R,LOC,Y,0
NSEL,R,LOC,Z,L
D,ALL, UY ,                               ! CONSTRAINTS END
ALLSEL
FINISH
/SOLU
/OUT,SCRATCH
SOLVE                                     ! SOLVE
FINISH
*END

SOLV3D                                    ! READ MACRO TO PERFORM SOLUTION

*CREATE,RES3D,MAC
/POST1
SET,LAST
/OUT,
PRRSOL                                    ! PRINT REACTION SOLUTIONS
/GRA,OFF
/VIEW,1,1,0,0
/GLINE,1,0
/DEV,VECT,ON
PLNSOL,S,Z                                ! Z-STRESS CONTOUR
/NUM,0

MST1=0                                    ! INIT PARAMETERS
NDE1=0
MST2=0
NDE2=0
MST3=0
NDE3=0
*DIM,RESULTS,ARRAY,3                      ! DEFINE ARRAY PARAMETER RESULTS
                                          ! CALCULATION : TOP AVERAGE OF STRESS
NSEL,S,LOC,Y,H/2                          ! SELECT NODES IN TOP AREA
*GET,NUMNOD1,NODE,,COUNT                  ! OBTAIN NUMBER OF TOP SURFACE NODES

ZSTR1=0
TOTAL=0
COUNT=0

*DO,J,1,NUMNOD1,1
   NDE1=NDNEXT(NDE1)
   NSEL,,,,NDE1
   ESLN
   *GET,NUMELM,ELEM,0,COUNT              ! GET NUMBER OF ELEMS CONNECTED TO NDE1
   ELNUM=0
   TRIP=0
   *DO,K,1,NUMELM,1                      ! LOOP ON ELEMS CONNECTED TO NDE1
      ELNUM=ELNEXT(ELNUM)
      *DO,L,1,8,1                        ! VOLUME : SOLID95 CORNER NODES
         POS=NELEM(ELNUM,L)              ! CHECK POS 1-8 ON SOLID95 FOR
                                         ! NODE NUMBER
         *IF,POS,EQ,NDE1,THEN
            TRIP=1                       ! SET TRIP IF OUR CURRENTLY SELECTED
                                         ! NODE IS CORNER OF ELEMENT ELNUM
         *ENDIF
         *IF,TRIP,EQ,1,EXIT
      *ENDDO
      *IF,TRIP,EQ,1,EXIT
   *ENDDO
```

```
   *IF,TRIP,NE,1,THEN
      NSEL,S,LOC,Y,H/2                    ! IF ENTRY IS GAINED TO HERE
      ESEL,ALL                            ! THEN IT MUST BE THAT NDE1 IS A
      *CYCLE                              ! MIDNODE : NO STRESS CALC WANTED!
   *ENDIF

   ALLSEL
   *GET,ZSTR1,NODE,NDE1,S,Z               ! IF ENTRY GAINED TO THIS POINT OF
   TOTAL=TOTAL+ZSTR1                      ! THE LOOP, THEN GRAB Z-STRESS AT
   COUNT=COUNT+1                          ! NODE NDE1 AND ADD IT TO TOTAL.
   NSEL,S,LOC,Y,H/2                       ! RESET SELECTED SETS TO WHAT IS
   ESEL,ALL                               ! NEEDED.
*ENDDO

MST1=(TOTAL/COUNT)                        ! AVERAGE OF Z-STRESS ON TOP SURFACE
RESULTS(1)=MST1

NSEL,S,LOC,Y,0                            ! SELECT NODES ALONG Z AXIS
NSEL,R,LOC,X,0                            ! ( THE NURTRAL AXIS )
*GET,NUMNOD2,NODE,,COUNT                  ! OBTAIN NUMBER OF TOP SURFACE NODES

ZSTR2=0
COUNT=0
TOTAL=0

*DO,J,1,NUMNOD2,1                         ! LOGIC IS SIMILAR TO ABOVE *DO LOOP!
   NDE2=NDNEXT(NDE2)
   NSEL,,,,NDE2
   ESLN
   *GET,NUMELM,ELEM,0,COUNT
   ELNUM=0
   TRIP=0
   *DO,K,1,NUMELM,1
      ELNUM=ELNEXT(ELNUM)
      *DO,L,1,8,1                         ! VOLUME : SOLID95 CORNER NODES
         POS=NELEM(ELNUM,L)
         *IF,POS,EQ,NDE2,THEN
            TRIP=1
         *ENDIF
         *IF,TRIP,EQ,1,EXIT
      *ENDDO
      *IF,TRIP,EQ,1,EXIT
   *ENDDO

   *IF,TRIP,NE,1,THEN
      NSEL,S,LOC,Y,0
      NSEL,R,LOC,X,0
      ESEL,ALL
      *CYCLE
   *ENDIF

   ALLSEL

   *GET,ZSTR2,NODE,NDE2,S,Z
   TOTAL=TOTAL+ZSTR2
   COUNT=COUNT+1
   NSEL,S,LOC,Y,0
   NSEL,R,LOC,X,0
   ESEL,ALL
*ENDDO

MST2=TOTAL/COUNT                         ! AVERAGE STRESS OF NEURTRAL AXIS
RESULTS(2)=MST2

NSEL,S,LOC,Y,-H/2                        ! SELECT NODES IN BOTTOM AREA
*GET,NUMNOD3,NODE,,COUNT

ZSTR3=0
COUNT=0
TOTAL=0
```

```
*DO,J,1,NUMNOD3,1                        !  LOGIC IS SIMILAR TO ABOVE *DO LOOP!
   NDE3=NDNEXT(NDE3)
   NSEL,,,,NDE3
   ESLN
   *GET,NUMELM,ELEM,0,COUNT
   ELNUM=0
   TRIP=0
   *DO,K,1,NUMELM,1
      ELNUM=ELNEXT(ELNUM)
      *DO,L,1,8,1                        ! VOLUME : SOLID CORNER NODES
         POS=NELEM(ELNUM,L)
         *IF,POS,EQ,NDE3,THEN
            TRIP=1
         *ENDIF
         *IF,TRIP,EQ,1,EXIT
      *ENDDO
      *IF,TRIP,EQ,1,EXIT
   *ENDDO

   *IF,TRIP,NE,1,THEN
      NSEL,S,LOC,Y,-H/2
      ESEL,ALL
      *CYCLE
   *ENDIF
   ALLSEL

   *GET,ZSTR3,NODE,NDE3,S,Z
   TOTAL=TOTAL+ZSTR3
   COUNT=COUNT+1
   NSEL,S,LOC,Y,-H/2
   ESEL,ALL
*ENDDO

MST3=TOTAL/COUNT                         ! AVERAGE STRESS ON BOTTOM NODES
RESULTS(3)=MST3
                                         ! CALCULATE THE RATIOS
RAT1=MST1/(-SURF)

!* EXPECTED VALUE FOR MST2 = 0.0
*if,MST2,le,1E-3,then
   RAT2=1
*else
   RAT2=MST2
*endif

RAT3=MST3/SURF

*DIM,RATIO,ARRAY,3                       ! DEFINE ARRAY PARAMETER RATIO
*VFILL,RATIO(1),DATA,RAT1,RAT2,RAT3      ! DEFINE ARRAY PARAMETER TAR

*DIM,TAR,ARRAY,3
*VFILL,TAR(1),DATA,(-SURF),0,SURF

*DIM,LABEL,CHAR,3,2
LABEL(1,1) = 'TOP'
LABEL(1,2) = 'STRESS'

LABEL(2,1) = 'MIDDLE'
LABEL(2,2) = 'STRESS'

LABEL(3,1) = 'BOTTOM'
LABEL(3,2) = 'STRESS'
FINISH
*END

RES3D                             ! READ MACRO TO RETRIEVE RESULTS
SAVE,TABLE_1

/CLEAR, NOSTART ! CLEAR DATABASE FOR 2ND SOLUTION
/PREP7
SMRT,OFF
/TITLE, VM210, BENDING OF HEX-TO-TET INTERFACE, FORMATION OF PYRAMIDS
```

```
/COM,    ****** USING 3-D SOLID186 ******
ET,1,186                                  ! ELEMENT TYPE SOLID186
ET,2,186                                  ! ELEMENT TYPE SOLID186

MSHGEN3D                                  ! READ MACRO TO GENERATE MESH

/OUT,SCRATCH
SOLV3D                                    ! READ MACRO TO PERFORM SOLUTION

RES3D                                     ! READ MACRO TO RETRIEVE RESULTS
/OUT,

SAVE,TABLE_2

/COM
/OUT,vm210,vrt
/NOPR
RESUME,TABLE_1
/GOPR
/COM,------------------- VM210 RESULTS COMPARISON ---------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS USING SOLID95:
*VWRITE,LABEL(1,1),LABEL(1,2),TAR(1),RESULTS(1),RATIO(1)
(1X,A8,A8,'   ',F12.4,'  ',F13.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING SOLID186:
*VWRITE,LABEL(1,1),LABEL(1,2),TAR(1),RESULTS(1),RATIO(1)
(1X,A8,A8,'   ',F12.4,'  ',F13.4,'   ',1F15.3)
/COM,----------------------------------------------------------------
/COM,
/OUT
FINISH
*LIST,vm210,vrt
/DELETE,MSHGEN3D,MAC
/DELETE,SOLV3D,MAC
/DELETE,RES3D,MAC
```

VM211 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM211
/config,nproc,1
R = 200                       ! RADIUS OF CYLINDER (mm)
/PREP7
SMRT,OFF
/TITLE, VM211, RUBBER CYLINDER PRESSED BETWEEN TWO PLATES
/COM    REF: T. SUSSMAN, K.J. BATHE, "A FE FORMULATION FOR NONLINEAR ..."
/COM         COMPUTERS & STRUCTURES, VOL. 26, NOS. 1/2, 1987
ET,1,PLANE182, , ,2           ! 2-D PLANE-STRAIN 4-NODE STRUCTURAL SOLID
KEYOPT,1,6,1                  ! Mixed U-P FORMULATION
ET,2,TARGE169                 ! 2-D TARGET ELEMENT
ET,3,CONTA171                 ! 2-D CONTACT ELEMENT
KEYOPT,3,5,4
KEYOPT,3,10,2
C10 = 0.293
C01 = 0.177
NU1 = 0.49967
DD  = (1-2*NU1)/(C10+C01)
TB,HYPER,1,1,2,MOONEY
TBDATA,1,C10,C01,DD
CSYS,1                        ! SWITCH TO CYLINDRICAL C.S.
K,1                           ! DEFINE KEYPOINTS
K,2,R,-90
```

```
K,3,R
K,4,(0.5*R),-90
K,5,(0.6*R),-45
K,6,(0.5*R)
K,7,R,-45
L,2,7
L,7,3
CSYS,0                         ! SWITCH TO CARTESIAN C.S.
A,2,7,5,4
A,7,3,6,5
A,4,5,6,1
TSHAPE,LINE
K,1001,-2*R,-R
K,1002,2*R,-R
L,1002,1001
SAVE,temp,db                    ! SAVE MODEL FOR SECOND ANALYSIS
TYPE,1
AMESH,ALL                         ! MESH ALL AREAS
REAL,2
TYPE,2
LMESH,10
LSEL,S,LINE,,1,2,1
TYPE,3
LMESH,ALL
save,cont171,db
FINI

*CREATE,SOLV2D,MAC             ! MACRO TO SOLVE MODEL
/SOLU
!SOLCONTROL,0
ANTYPE,STATIC
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
CP,1,UY,ALL
*GET,NCEN,NODE,,NUM,MIN
ALLSEL
!CNVTOL,F,,,,-1
NLGEOM,ON                     ! INCLUDE LARGE DEFORMATION EFFECTS
NSUBST,20,1000,10             ! SPECIFY NUMBER OF SUBSTEPS IN LOAD STEP
OUTRES,,1                     ! WRITE SOLUTION FOR EVERY SUBSTEP
D,NCEN,UY,-100                ! APPLY DISPLACEMENT UY = -100 TO COUPLED NODES
!NROPT,FULL,,OFF
SOLVE
FINISH
*END
/OUT,SCRATCH
SOLV2D                         ! USE MACRO SOLVE2D
/OUT,
*CREATE,PLOTS,MAC              ! MACRO FOR POST-PROCESSING
/POST1
/DSCALE,1,1
PLDISP,1                      ! PLOT DISPLACED SHAPE
FINISH
/POST26
/AXLAB,Y,FORCE
/AXLAB,X,DISPLACEMENT
NSOL,2,NCEN,U,Y
RFORCE,3,NCEN,F,Y
PROD,2,2,,,,,,-2
PROD,3,3,,,,,,-2
XVAR,2
PLVAR,3                       ! PLOT DISPLACEMENT VS FORCE
PRVAR,2,3                     ! PRINT DISPLACEMENT, FORCE
*GET,F1,VARI,3,RTIME,.5
*GET,F2,VARI,3,RTIME,1
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
 LABEL(1,1) = 'F (N) @ ','F (N) @ '
LABEL(1,2) = '.1','.2'
*VFILL,VALUE(1,1),DATA,250,1400
*VFILL,VALUE(1,2),DATA,F1,F2
```

```
*VFILL,VALUE(1,3),DATA,ABS(F1/250),ABS(F2/1400)
FINISH
*END

PLOTS                          ! USE MACRO PLOTS
SAVE,TABLE_1

RESUME,temp,db
/PREP7
ALLSEL
ET,1,PLANE183, , ,2            ! 2-D PLANE-STRAIN 8-NODE STRUCTURAL SOLID
KEYOPT,1,6,1                   ! Mixed U-P FORMULATION
ET,2,TARGE169                  ! 2-D TARGET ELEMENT
ET,3,CONTA172                  ! 2-D CONTACT ELEMENT
KEYOPT,3,5,4
KEYOPT,3,10,2
TYPE,1
AMESH,ALL
REAL,2
TYPE,2
LMESH,10
LSEL,S,LINE,,1,2,1
TYPE,3
LMESH,ALL
save,cont172,db
FINISH
/OUT,SCRATCH
SOLV2D                         ! USE MACRO TO OBTAIN SOLUTION
PLOTS                          ! USE MACRO TO POSTPROCESS
/OUT,
SAVE,TABLE_2

/PREP7
RESUME,temp,db
ET,5,SOLID185                  ! 3-D 8-NODE STRUCTURAL SOLID
KEYOPT,5,6,1                   ! Mixed U-P FORMULATION
ET,2,TARGE170
ET,3,CONTA173                  ! 3-D 4 NODE CONTACT ELEMENT
KEYOPT,3,10,2
KEYOPT,3,5,4
ET,4,200,6                     ! 2-D 4 NODED MESH200
LDELETE,10,,,1
ALLSEL
CSYS,0
K,1001,-.1*R,-R,-.1*R
K,1002,2*R,-R,-.1*R
K,1003,2*R,-R,8*R
K,1004,-.1*R,-R,8*R
A,1004,1003,1002,1001
TSHAPE,TRI
SAVE,temp3d,db
ESIZE,,1
REAL,2
TYPE,2
AMESH,4
REAL,1
TYPE,4
ESIZE,,4
AMESH,1,3,1
TYPE,1
ESIZE,,4
VEXT,1,3,1,,,1
CSYS,1
ASEL,S,LOC,X,R
TYPE,3
REAL,2
AMESH,ALL
LSEL,ALL
NSEL,ALL
CSYS,0
save,cont173,db
FINISH
```

```
*CREATE,SOLV3D,MAC             ! MACRO TO SOLVE MODEL
/SOLUTION
ANTYPE,STATIC
D,ALL,UZ                       ! CONSTRAIN ALL IN Z (PLANE STRAIN)
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
CP,1,UY,ALL
*GET,NCEN,NODE,,NUM,MIN
NSEL,ALL
!CNVTOL,F,1
NLGEOM,ON                      ! INCLUDE LARGE DEFORMATION EFFECTS
NSUBST,20,1000,10              ! SPECIFY NUMBER OF SUBSTEPS IN LOAD STEP
!NROPT,FULL,,OFF
OUTRES,,1                      ! WRITE SOLUTION FOR EVERY SUBSTEP
D,NCEN,UY,-100                 ! APPLY DISPLACEMENT UY = -100 TO COUPLED NODES
SOLVE
FINISH
*END
/OUT,SCRATCH
SOLV3D                          ! USE MACRO TO OBTAIN SOLUTION
/OUT,
PLOTS                           ! USE MACRO TO POSTPROCESS
SAVE,TABLE_3

/PREP7
RESUME,temp3d,db
ET,1,SOLID186                   ! 3-D 20-NODE STRUCTURAL SOLID
KEYOPT,1,6,1                    ! Mixed U-P FORMULATION
ET,2,TARGE170
ET,3,CONTA174
KEYOPT,3,10,2
KEYOPT,3,5,4
KEYOPT,3,7,1
VEXT,1,3,1,,,1
TYPE,1
VMESH,ALL
REAL,2
TYPE,3
CSYS,1
ASEL,S,LOC,X,R
AMESH,ALL
ESIZE,,1
TYPE,2
ASEL,ALL
AMESH,4
ALLSEL
CSYS,0
save,cont174,db
FINI
/OUT,SCRATCH
SOLV3D
/OUT,
PLOTS
SAVE,TABLE_4

!* THE INPUT BELOW IS SAME AS INPUT ABOVE BUT WITH K(2)=3 OF CONTAC171-174 ELEMENTS...
RESUME,cont171,db
/PREP7
KEYOPT,3,4,2                    ! ON NODAL POINT - NORMAL TO TARGET SURFACE
KEYOPT,3,2,3                    ! LAGRANGE MULTIPLIER ON CONTACT NORMAL AND PENALTY ON TANGENT
FINISH
/OUT,SCRATCH
SOLV2D                          ! USE MACRO TO OBTAIN SOLUTION
/OUT,
PLOTS                           ! USE MACRO TO POSTPROCESS
SAVE,TABLE_5

RESUME,cont172,db
/PREP7
KEYOPT,3,4,2                    ! ON NODAL POINT - NORMAL TO TARGET SURFACE
```

```
KEYOPT,3,2,3                   ! LAGRANGE MULTIPLIER ON CONTACT NORMAL AND PENALTY ON TANGENT
FINISH
/OUT,SCRATCH
SOLV2D                         ! USE MACRO TO OBTAIN SOLUTION
/OUT,
PLOTS                          ! USE MACRO TO POSTPROCESS
SAVE,TABLE_6

RESUME,cont173,db
/PREP7
KEYOPT,3,4,2                   ! ON NODAL POINT - NORMAL TO TARGET SURFACE
KEYOPT,3,2,3                   ! LAGRANGE MULTIPLIER ON CONTACT NORMAL AND PENALTY ON TANGENT
FINISH
/OUT,SCRATCH
SOLV3D                         ! USE MACRO TO OBTAIN SOLUTION
/OUT,
PLOTS                          ! USE MACRO TO POSTPROCESS
SAVE,TABLE_7

RESUME,cont174,db
/PREP7
KEYOPT,3,4,2                   ! ON NODAL POINT - NORMAL TO TARGET SURFACE
KEYOPT,3,2,3                   ! LAGRANGE MULTIPLIER ON CONTACT NORMAL AND PENALTY ON TANGENT
FINISH
/OUT,SCRATCH
SOLV3D
/OUT,
PLOTS
SAVE,TABLE_8

/COM
/OUT,vm211,vrt
RESUME,TABLE_1
/COM,------------------- VM211 RESULTS COMPARISON --------------
/COM,
/COM,                |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS USING PLANE182:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING PLANE183:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM,RESULTS USING SOLID185:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_4
/GOPR
/COM,
/COM,RESULTS USING SOLID186:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_5
/GOPR
/COM,
/COM,RESULTS USING PLANE182 WITH KEYOPT(2)=3 OF CONTAC171:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_6
/GOPR
/COM,
```

```
/COM,RESULTS USING PLANE183 WITH KEYOPT(2)=3 OF CONTAC172:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_7
/GOPR
/COM,
/COM,RESULTS USING SOLID185 WITH KEYOPT(2)=3 OF CONTAC173:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/NOPR
RESUME,TABLE_8
/GOPR
/COM,
/COM,RESULTS USING SOLID186 WITH KEYOPT(2)=3 OF CONTAC174:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.2,'  ',F14.2,'   ',1F15.3)
/COM,-----------------------------------------------------------
/COM,
/OUT
FINISH
*LIST,vm211,vrt
/DELETE,PLOTS,MAC
/DELETE,SOLV2D,MAC
/DELETE,SOLV3D,MAC
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
/DELETE,TABLE_4
/DELETE,TABLE_5
/DELETE,TABLE_6
/DELETE,TABLE_7
/DELETE,TABLE_8
/DELETE,temp,db
/DELETE,temp3d,db
/DELETE,cont171,db
/DELETE,cont172,db
/DELETE,cont173,db
/DELETE,cont174,db
```

VM212 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM212
/TITLE,VM212,DDAM ANALYSIS OF FOUNDATION SYSTEM (2-DOF SYSTEM)
/COM, -------------------------------------------------------------------
/COM  REFERENCE:
/COM, INTERIM DESIGN VALUES FOR SHOCK DESIGN OF SHIPBOARD EQUIPMENT
/COM  NRL MEMORANDUM REPORT 1396, G. J. O'HARA, FEBRUARY 1963, P10.
/COM, -------------------------------------------------------------------
/COM, SHOCK INPUT DESCRIPTION:
/COM,
/COM, SHIP TYPE        - SURFACE
/COM, EQUIPMENT LOCATION     - DECK MOUNTED
/COM, CATEGORY OF SHOCK DESIGN VALUE  - ELASTIC-PLASTIC
/COM, SHOCK DIRECTION      - ARTHWARTSHIPS
/COM,
/COM, SHOCK DESIGN VALUES AS PER NRL-1396:
/COM, Aa = 0.4 * Ao AND Va = 0.2 * Vo,
/COM, WHERE,
/COM, Ao  = 10 * ((37.5 + Wa) * (12 + Wa) / (6 + Wa)**2) * (g)
/COM, Vo  = 30 * ((12 + Wa) / (6 + Wa))
/COM, g  = ACCELERATION DUE TO GRAVITY
/COM, Wa = MODAL EFFECTIVE WEIGHT (KIPS) FOR MODE 'a'
/COM,
/COM, BASED ON THE ABOVE EQUATIONS ACCELERATION AND VELOCITY COMPUTATION
/COM, CONSTANTS ARE DEFINED AS:
/COM, AF = 1.0, AA = 10, AB = 37.5, AC = 12, AD = 6
```

```
/COM, VF = 0.5, VA = 30, VB = 12, VC = 6
/COM, -----------------------------------------------------------------
/OUT,SCRATCH
/PREP7
_PI = 4*ATAN(1)
!*** MATERIAL PROPERTIES FOR SPRING ELEMENT IN POUNDS AND INCH ***
!-----------------------------------------------------------------
MP,PRXY,,0.3
MP,EX,1,1
! *** FE MODEL ***
! ---------------
N,1,0,0
N,2,144,0
N,10,0,0,20
N,20,54,0,20
N,30,114,0,20
N,40,144,0,20
!*** ELEMENT TYPES ***
!--------------------
ET,1,COMBIN40,0,,3                  ! SPRING ELEMENT
! *** REAL CONSTANTS ***
! ---------------------
R,1,1.3E6       ! SPRING CONSTANT # 1
E,1,10
! *** REAL CONSTANTS ***
! ---------------------
R,2,3.9E6                        ! SPRING CONSTANT # 2
REAL,2
E,2,40
!*** ELEMENT TYPES ***
!--------------------
ET, 3, BEAM188      ! BEAM188 ELEMENT MODEL
KEYOPT,3,3,2
!*** SECTION DATA ***
!-------------------
SECTYPE,3,BEAM,ASEC
SECDATA,100,833,,833,,1,,,,,10,10
!*** MATERIAL PROPERTIES FOR RIGID BEAM IN POUNDS AND INCH ***
!-------------------------------------------------------------
MP,EX,3,1
MP,GXY,3,1/2.6
TYPE,3
MAT,3
REAL,3
SECNUM,3
E,10,20
E,20,30
E,30,40
!*** ELEMENT TYPES ***
!--------------------
ET,4,MASS21,,,2                   ! MASS ELEMENTS
! *** REAL CONSTANTS ***
! ---------------------
R,4,10E3/386.      ! MASS
TYPE,4
REAL,4
E,20
E,30
! *** BOUNDARY CONDITIONS ***
! --------------------------
D,1,ALL,0.0,,2,1
D,40,UY,0.0,,,,ROTX,ROTZ
D,40,UX
ALLSEL,ALL,ALL

CERIG,10,20,All
CERIG,30,20,All
CERIG,30,40,All

SAVE
FINISH
! *** SOLUTION CONTROLS FOR MODAL ANALYSIS ***
```

```
! ---------------------------------------------
/SOLUTION
ANTYPE,MODAL
MXPAND,2,,,NO                      ! DO NOT OBTAIN FORCES AND STRESSES
MODOPT,LANB,2,,,,OFF              ! 2 MODES EXTRACTED
                                   ! MODE SHAPE NORMALIZE OFF
SOLVE
*GET,FREQ_1,MODE,1,FREQ
*GET,FREQ_2,MODE,2,FREQ
FINISH

/POST1
SET,1,1
*GET,UZ1_20,NODE,20,U,Z
*GET,UZ1_30,NODE,30,U,Z
SET,1,2
*GET,UZ2_20,NODE,20,U,Z
*GET,UZ2_30,NODE,30,U,Z
FINISH

/SOLUTION
ANTYPE,SPECTRUM
SPOPT,DDAM
ADDAM,0.4,10.0,37.5,12.0,6.0     ! INPUT SPECTRAL ACCELERATION
VDDAM,0.2,30.0,12.0,6.0          ! INPUT SPECTRAL VELOCITY
SED,0,0,1                        ! ATHWARTSHIPS = Z, DIRECTION
NRLSUM,,DISP
OUTRES,ALL,ALL
/OUT,
SOLVE
/OUT,SCRATCH
*GET,MODC_1,MODE,1,MCOEF
*GET,MODC_2,MODE,2,MCOEF
*GET,PFAC_1,MODE,1,PFACT
*GET,PFAC_2,MODE,2,PFACT
FINISH

/OUT,
/COM, ----------------------------
/COM, FREQUENCY VALUES
/COM, ----------------------------
*STATUS,FREQ_1
*STATUS,FREQ_2
/COM, ----------------------------
/COM, MODE COEFFICIENT VALUES
/COM, ----------------------------
*STATUS,MODC_1
*STATUS,MODC_2
/COM, ----------------------------
/COM, PARTICIPATION FACTOR VALUES
/COM, ----------------------------
*STATUS,PFAC_1
*STATUS,PFAC_2
/COM, ----------------------------
/COM, DISPLACEMENT VALUES
/COM, ----------------------------
/COM, ----------
/COM, MODE 1
/COM, ----------
*STATUS,UZ1_20
*STATUS,UZ1_30
/COM, ----------
/COM, MODE 2
/COM, ----------
*STATUS,UZ2_20
*STATUS,UZ2_30
/COM, ----------------------------
/COM, SHOCK DESIGN VALUES
/COM, ----------------------------
DA_1 = MODC_1*(2*_PI*FREQ_1)**2/PFAC_1
DA_2 = MODC_2*(2*_PI*FREQ_2)**2/PFAC_2
/COM
```

```
/OUT,SCRATCH
*DIM,LABEL,CHAR,2,3
*DIM,VALUE,,2,3
LABEL(1,1) = 'FREQ(f1),      ','FREQ(f2)  '
LABEL(1,2) = '     Hz','     Hz'
*VFILL,VALUE(1,1),DATA,46.30,114.0
*VFILL,VALUE(1,2),DATA,FREQ_1,FREQ_2
*VFILL,VALUE(1,3),DATA,FREQ_1/46.3,FREQ_2/114

*DIM,LAB1,CHAR,5,2
*DIM,VALUE1,,5,3
LAB1(1,1) = 'DEF.(20), ','DEF.(30)  ','MCOEF  ','PFACT ','SHOCK,D1  '
LAB1(1,2) = '  INCH','  INCH','','','  IN/S^2'
*VFILL,VALUE1(1,1),DATA,0.1629,0.1099,0.1931,7.0659,2316
*VFILL,VALUE1(1,2),DATA,UZ1_20,UZ1_30,MODC_1,PFAC_1,DA_1
*VFILL,VALUE1(1,3),DATA,ABS(UZ1_20)/0.1629,ABS(UZ1_30)/0.1099,ABS(MODC_1)/0.1932,ABS(PFAC_1)/7.060,ABS(DA_1)/2316

*DIM,LAB2,CHAR,5,2
*DIM,VALUE2,,5,3
LAB2(1,1) = 'DEF.(20), ','DEF.(30)  ','MCOEF  ','PFACT ','SHOCK,D2  '
LAB2(1,2) = '  INCH','  INCH','','','  IN/S^2'
*VFILL,VALUE2(1,1),DATA,-0.1099,0.1629,0.2175E-01,1.373,8133
*VFILL,VALUE2(1,2),DATA,UZ2_20,UZ2_30,MODC_2,PFAC_2,DA_2
*VFILL,VALUE2(1,3),DATA,ABS(UZ2_20)/0.1099,ABS(UZ2_30)/0.1629,ABS(MODC_2)/0.2176E-01,ABS(PFAC_2)/1.373,ABS(DA_2)/8133
/COM
/OUT,vm212,vrt
/COM,------------------- VM212 RESULTS COMPARISON --------------
/COM,
/COM,                   |   TARGET   |   Mechanical APDL      |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F12.4,'  ',F16.4,'   ',1F15.3)
/COM,
/COM,MODE # 1
/COM,
*VWRITE,LAB1(1,1),LAB1(1,2),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A8,A8,'   ',F12.4,'  ',F16.4,'   ',1F15.3)
/COM,
/COM,MODE # 2
/COM,
*VWRITE,LAB2(1,1),LAB2(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F12.4,'  ',F16.4,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT,
*LIST,vm212,vrt
FINISH
```

VM213 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM213
/TITLE,VM213, DIFFERENTIAL INDUCTANCE OF A TRANSFORMER
/NOPR
/COM
/COM  REFERENCE:
/COM  M.GYIMESI,D.OSTERGAARD,"INDUCTANCE COMPUTATION BY
/COM  INCREMENTAL FINITE ELEMENT ANALYSIS", IEEE
/COM  TRANSACTION ON MAGNETICS, VOL.35, NO.3 (1998),
/COM  PP.1119-1122
/COM
/COM
/COM      ^ y axis             : symmetry plane
/COM      :                    : core center
/COM      :<.x1.>.<.x2.>.<.x..>:
/COM      :      :      :      :
/COM  --------------------------:
/COM !                         : nonlin core:
/COM !     yoke ideal iron     : H = Hs (B/Bs)^2; BS=2T;HS=100A/m
```

```
/COM !                          :
/COM !      -------------       :....
/COM !leg  !      :      !nonlin:  ^
/COM !ideal!coil1 :coil2 ! iron :  y
/COM !iron !      :      ! core :  :
/COM !      -------------       :..v..> x axis
/COM !                          :
/COM !     yoke ideal iron      :
/COM !                          :
/COM  --------------------------:
/COM
/COM target
/COM
/COM nominal
/COM    magnetic field in the core    : Hn  = (N1 I1 + N2 I2) / y    = 25
/COM    flux density   in the core    : Bn  = Bs sqrt(H/Hs)          = 1
/COM    tangent reluctivity           : dH/dB = 2 Hs/Bs B/Bs         = 50
/COM    magnetic energy in the core   : nlene = Hs/Bs^2 Bn^3/3 2xyz  = 0.0166
/COM    magnetic coenergy in the core : nlcene = Bn Hn 2xyz - nlene  = 0.0333
/COM
/COM inductances
/COM    self coil 1                   : L11 ~ 2 N1^2  x z / (y nui)  = 0.4
/COM    self coil 2                   : L22 ~ 2 N2^2  x z / (y nui)  = 1.6
/COM    mutual between coil 1 and 2   : L12 ~ 2 N1 N2 x z / (y nui)  = 0.8
/COM
/COM flux linkages
/COM    coil 1                        : psi1 = 2 N1 x z B0           = 0.2
/COM    coil 2                        : psi2 = 2 N2 x z B0           = 0.4



!       GEOMETRY DATA

N=1                     ! MESHING PARAMETER
X1=0.1                  ! WIDTH (X SIZE) OF COIL 1
X2=0.1                  ! WIDTH (X SIZE) OF COIL 2
X=0.1                   ! WIDTH (X SIZE) OF CORE
Y=0.1                   ! HIGHT OF CORE, Y SIZE OF WINDOW
Z=0.1                   ! THICKNESS OF IRON IN Z DIRECTION
NUI=50                  ! ABSOLUTE RELUCTIVITY OF IRON
N1=10                   ! NUMBER OF TURNS IN COIL1
N2=20                   ! NUMBER OF TURNS IN COIL2

!      EXCITATION DATA

SYMFAC=2                ! SYMMETRIC FACTOR FOR INDUCTANCE COMPUTATION
NC=2                    ! NUMBER OF COILS
*DIM,CUR,ARRAY,NC       ! NOMINAL CURRENTS OF COILS
CUR(1)=0.2              ! NOMINAL CURRENT OF 1ST COIL
CUR(2)=0.025            ! TINY NOMINAL CURRENT OF 2ND COIL

!      DERIVED AUXILIARY PARAMETERS

MU0=3.1415926*4.0E-7
MURI=1/NUI/MU0          ! RELATIVE PERMEABILITY OF IRON
X3=X1+X2                ! X COORDINATE OF THE RIGHT OF COIL2
X4=X3+X                 ! X COORDINATE OF MIDDLE OF CORE (SYMMETRY PLANE)
JS1=CUR(1)*N1/(X1*Y)    ! NOMINAL CURRENT DENSITY OF COIL1
JS2=CUR(2)*N2/(X2*Y)    ! NOMINAL CURRENT DENSITY OF COIL2


/PREP7
SMRT,OFF
ET,1,SOLID236

MP,MURX,1,1             ! AIR/COIL
BS=2                    ! SATURATION FLUX DENSITY
HS=100                  ! SATURATION MAGNETIC FIELD
TB,BH,2                 ! CORE: H = Hs (B/Bs)^2; Bs=2T;Hs=100A/m
TBPT,,  1, 0.2
TBPT,,  4, 0.4
TBPT,,  9, 0.6
```

```
TBPT,, 16, 0.8
TBPT,, 25, 1.0
TBPT,, 36, 1.2
TBPT,, 49, 1.4
TBPT,, 64, 1.6
TBPT,, 81, 1.8
TBPT,,100, 2.0
TBPT,,121, 2.2
TBPT,,144, 2.4
TBPT,,169, 2.6
TBPT,,176, 2.8
TBPT,,225, 3.0
TBPT,,256, 3.2
TBPT,,289, 3.4
TBPT,,324, 3.6
TBPT,,361, 3.8
TBPT,,400, 4.0
TBPLOT,BH,2   !PLOT BH CURVE


BLOCK, 0,X1,0,Y,0,Z     ! COIL1
BLOCK,X1,X3,0,Y,0,Z     ! COIL2
BLOCK,X3,X4,0,Y,0,Z     ! CORE

VGLUE,ALL

VSEL,S,LOC,X,X1/2
VATT,1,1,1               ! COIL 1 VOLUME ATTRIBUTE
VSEL,S,LOC,X,X1+X2/2
VATT,1,2,1               ! COIL 2 VOLUME ATTRIBUTE
VSEL,S,LOC,X,X3+X/2
VATT,2,3,1               ! IRON VOLUME ATTRIBUTE
VSEL,ALL

ESIZE,,N
VMESH,ALL

NSEL,S,LOC,X,X4         ! FLUX PARALLEL DIRICHLET AT SYMMETRY PLAIN, X=X4,Z=0,Z=Z
NSEL,A,LOC,Z,0
NSEL,A,LOC,Z,Z
D,ALL,AZ,0
!                       ! HOMOGENEOUS NEUMANN FLUX NORMAL AT YOKE, X=0, Y=0, Y=Y
NSEL,ALL

ESEL,S,ELEM,,1          ! COIL 1 COMPONENT
BFE,ALL,JS,,,,JS1       ! CURRENT DENSITY IN COIL 1

ESEL,S,ELEM,,2          ! COIL 2 COMPONENT
BFE,ALL,JS,,,,JS2       ! UNITE CURRENT DENSITY IN COIL 2

ALLSEL
FINISH

/COM
/COM OBTAIN OPERATING SOLUTION
/COM
/SOLUTION
ANTYPE,STATIC
CNVTOL,CSG,1,1.0E-3
SOLVE
FINISH

/POST1
SET,LAST
/COM
/COM COMPUTE STORED ENERGY AND CO-ENERGY
/COM
ETABLE,_mene,MENE
ETABLE,_coen,COEN
ETABLE,_aene,AENE

SSUM
```

```
*get,STORENG,ssum,,item,_mene
*get,STORCOE,ssum,,item,_coen
*get,STORAEN,ssum,,item,_aene
/com,
/com, Energy = %STORENG*SYMFAC%
/com, Co-energy = %STORCOE*SYMFAC%
/com, Apparent energy = %STORAEN*SYMFAC%
/com
FINISH

*DIM,LABENG,CHAR,2
*DIM,VALENG,,2,2
*DIM,RESENG,,2,1
LABENG(1)='ENERGY','CO-ENERGY'
*VFILL,VALENG(1,1),DATA,0.0166,0.0333
*VFILL,RESENG(1,1),DATA,2*STORENG,2*STORCOE
*VFILL,VALENG(1,2),DATA,ABS(2*STORENG/0.0166),ABS(2*STORCOE/0.0333)
PARSAVE,all
/COM,
/COM, ***  COMPUTE INDUCTANCE AND FLUX USING THE LINEAR PERTURBATION PROCEDURE
/COM,
ALLSEL

/SOLUTION
ANTYPE,STATIC,RESTART,,,PERTURB
PERTURB,STATIC,,CURRENT,ALLKEEP
SOLVE,ELFORM

! Apply CUR(1) only to determine L11
BFE,1,JS,,,,JS1
BFEDELE,2,JS
SOLVE

! Apply CUR(2) only to determine L12
BFEDELE,1,JS
BFE,2,JS,,,,JS2
SOLVE

! Apply CUR(1) and CUR(2) together to determine L12
BFE,1,JS,,,,JS1
BFE,2,JS,,,,JS2
SOLVE
FINISH

PARRES
! define arrays for inductance, flux linkage, and energy
*DIM,INDI,ARRAY,2,2  ! incremental inductance matrix

*DIM,IENE,ARRAY,2,2  ! incremental energy
*DIM,COEN,ARRAY,2,2  ! coenergy energy

*DIM,FLX,ARRAY,2     ! flux

/POST1
FILE,,rstp
SET,1,LAST
ETABLE,_iene,IENE
ETABLE,_coen,COEN
SSUM
*GET,IENE(1,1),ssum,,item,_iene
*GET,COEN(1,1),ssum,,item,_coen

SET,2,LAST
ETABLE,_iene,IENE
ETABLE,_coen,COEN
SSUM
*GET,IENE(2,2),ssum,,item,_iene
*GET,COEN(2,2),ssum,,item,_coen

SET,3,LAST
ETABLE,_iene,IENE
ETABLE,_coen,COEN
```

```
SSUM
*GET,IENE(1,2),ssum,,item,_iene
*GET,COEN(1,2),ssum,,item,_coen

FINISH

! COMPUTE INCREMENTAL INDUCTANCE
INDI(1,1)=2*IENE(1,1)/CUR(1)**2*SYMFAC
INDI(2,2)=2*IENE(2,2)/CUR(2)**2*SYMFAC
INDI(1,2)=(IENE(1,2)-IENE(1,1)-IENE(2,2))/(CUR(1)*CUR(2))*SYMFAC
INDI(2,1)=INDI(1,2)

! COMPUTE FLUX
FLX(1)=COEN(1,1)/CUR(1)*SYMFAC
FLX(2)=COEN(2,2)/CUR(2)*SYMFAC

!SET UP AND FILL VM RATIO TABLE
RAT_1 = ABS(INDI(1,1)/0.40)
RAT_2 = ABS(INDI(2,2)/1.60)
RAT_3 = ABS(INDI(1,2)/0.80)
*DIM,LABEL,CHAR,3
*DIM,VALUE,,3,2
*DIM,RESULTS,,3,1
LABEL(1) = 'COIL1','COIL2','MUTUAL'
*VFILL,VALUE(1,1),DATA,0.40,1.60,0.80
!
!FILL RESULTS VECTOR WITH INDUCTANCE MATRIX VALUES
!
*VFILL,RESULTS(1,1),DATA,INDI(1,1),INDI(2,2),INDI(1,2)
*VFILL,VALUE(1,2),DATA,RAT_1,RAT_2,RAT_3

*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,2
*DIM,RESULT1,,2,1
LABEL1(1)= 'COIL1','COIL2'
*VFILL,VALUE1(1,1),DATA,0.2,0.4
!
! FILL RESULTS VECTOR WITH FLUX ARRAY VALUES
!
*VFILL,RESULT1(1,1),DATA,FLX(1),FLX(2)
*VFILL,VALUE1(1,2),DATA,ABS(FLX(1)/0.2),ABS(FLX(2)/0.4)

/COM
/OUT,vm213,vrt
/COM,------------------- VM213  RESULTS COMPARISON ---------------------
/COM
/COM,   ENERGY (J)    |    TARGET    |  Mechanical APDL  |    RATIO
/COM
*VWRITE,LABENG(1),VALENG(1,1),RESENG(1,1),VALENG(1,2)
(1X,A10,'     ',F10.4,'    ',F10.4,'     ',1F13.3)
/COM
/COM,  FLUX (Weber)  |    TARGET    |  Mechanical APDL  |    RATIO
/COM,
*VWRITE,LABEL1(1),VALUE1(1,1),RESULT1(1,1),VALUE1(1,2)
(1X,A10,'     ',F10.4,'    ',F10.4,'     ',1F13.3)
/COM,
/COM, INDUCTANCE (H) |    TARGET    |  Mechanical APDL  |    RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),RESULTS(1,1),VALUE(1,2)
(1X,A10,'     ',F10.4,'    ',F10.4,'     ',1F13.3)
/COM,-----------------------------------------------------------------
/OUT,
*LIST,vm213,vrt
FINISH
```

VM214 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
```

```
/VERIFY,VM214
/TITLE, VM214, ROD ROTATING IN UNIFORM MAGNETIC FIELD
/com,
/com,  Problem description:
/com,  A conducting rod of length L and radius R is rotating in a uniform
/com,  magnetic field Bz with angular velocity OMEGAZ. Determine the EMF
/com,  induced in the rod.
/com,
/com,  Reference: Any basic electromagnetic text book
/com,

/PREP7

PI=ACOS(-1)

L_ROD=0.06      ! LENGTH OF ROD
R_ROD=L_ROD/10  ! RADIUS OF ROD

D_DMN=L_ROD/2  ! DEPTH OF SURROUNDING DOMAIN (EXTENDING BEYOND ROD)

BZ_EXT=0.1      ! EXTERNAL FIELD

OMG_ROD=60*2*PI  ! ROD ANGULAR VELOCITY (RAD/S)

BLOC,-D_DMN,L_ROD+D_DMN,-D_DMN,D_DMN,-D_DMN,D_DMN
WPRO,,,90
CYLI,R_ROD,,0,L_ROD

VSBV,1,2,,DELE,KEEP
VSEL,S,VOLU,,2
VATT,2,2,2
VSEL,INVE
VATT,1,1,1
ALLSEL,ALL

ET,1,SOLID236       ! 3D 20 NODE ELECTROMAGNETIC SOLID ELEMENTS
MP,MURX,1,1

ET,2,SOLID236,1
MP,MURX,2,1
MP,RSVX,2,1

VSEL,S,MAT,,2
VSWE,ALL
VSEL,S,MAT,,1
/OUT,SCRATCH
MSHA,1
MSHMID,1              ! STRAIGHT EDGES
VMES,ALL

BF,ALL,VELO,,,,,,OMG_ROD ! OMEGAZ (RAD/S)

DFLX,ALL,,,BZ_EXT     ! UNIFORM MAGNETIC FIELD

VSEL,S,MAT,,2
ALLS,BELO,VOLU
NSEL,R,LOC,X
D,ALL,VOLT            ! ELECTRICALLY GROUND ONE END
ALLSEL,ALL
FINISH

/SOLU
ANTYPE,STATIC         ! ELECTROMAGNETIC STATIC ANALYSIS
TIME,1.0
SOLVE
FINISH

/POST1
SET,LAST
ESEL,S,TYPE,,2
PLNSOL,VOLT
ALLSEL,ALL
```

```
/OUT,
V_END=VOLT(NODE(L_ROD,0,0))
V_END_TAR=0.5*OMG_ROD*BZ_EXT*L_ROD**2   ! V=B*OMEGA*L^2/2

*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,1,3
LABEL(1,1) = 'VOLTAGE',
LABEL(1,2) = '  (V)      '
*VFILL,VALUE(1,1),DATA,v_end_tar,
*VFILL,VALUE(1,2),DATA,v_end,
*VFILL,VALUE(1,3),DATA,ABS(v_end/v_end_tar),
/COM
/OUT,vm214,vrt
/COM,------------------- VM214 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F9.5,'  ',F13.5,'   ',1F15.3)
/COM,
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm214,vrt
```

VM215 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM215
/PREP7
/TITLE,VM215, CONDUCTING SPHERE
ET,1,157
R,1,0.2                ! THICKNESS = 0.2
MP,RSVX,,7             ! DEFINE ELECTRICAL RESISTIVITIES PROPERTY
MP,KXX,,3              ! DEFINE THERMAL CONDUCTIVITIES PROPERTY
CSYS,2                 ! SPHERICAL COORDINATE SYSTEM
N,1,10                 ! 10 UNIT RADIUS SPHERE
N,21,10,,80            ! 10 DEGREE HOLE AT THE TOP
FILL,,, ,,, ,,0.1      ! SHIFT ELEMENTS TOWARD HOLE
NGEN,2,30,1,21,1,,3    ! ANALYSE A 3 DEGREE SECTOR
E,1,2,32,31            ! DEFINE ELEMENT
EGEN,20,1,-1           ! USE 20 ELEMENTS
CP,1,VOLT,1,31
CP,2,TEMP,1,31
CP,3,VOLT,21,51
CP,4,TEMP,21,51
FINISH
/SOLU
OUTPR,,1
D,21,ALL               ! SET ALL VOLTAGES AND TEMPERATURES AT THE HOLE TO ZERO
D,1,VOLT,100           ! SET VOLTAGE AT THE EQUATOR TO 100
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
PRRSOL,AMPS            ! PRINTS THE CONSTRAINED NODE REACTION AT CURRENT FLOW
PRRSOL,HEAT            ! PRINTS THE CONSTRAINED NODE REACTION AT HEAT FLOW
NSEL,S,NODE,,21,51,30
FSUM
*GET,I21,FSUM,0,ITEM,AMPS
*GET,H21,FSUM,0,ITEM,HEAT
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'I AMPS ','Q WATT'
LABEL(1,2) = 'NODE 21','NODE 21'
*VFILL,VALUE(1,1),DATA,0.0614,6.14058
```

```
*VFILL,VALUE(1,2),DATA,I21,H21
*VFILL,VALUE(1,3),DATA,(I21/0.0614),(H21/6.14058)
/COM
/OUT,vm215,vrt
/COM,------------------- VM215 RESULTS COMPARISON --------------------------
/COM,
/COM,      SHELL157    |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A9,A8,'     ',F7.5,'     ',F14.5,'     ',1F15.3)
/COM,-----------------------------------------------------------------------
/OUT
FINISH
*LIST,vm215,vrt
```

VM216 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM216
/TITLE,VM216, LATERAL BUCKLING OF RIGHT-ANGLE FRAME
!  J.C. SIMO, L. VU-QUOC, "THREE-DIMENSIONAL FINITE-STRAIN ROD
!  MODEL",PART II CMAME, VOL 58, 1986, PP 79-116

/PREP7
N,1 ,   ,240  !DEFINE NODES
N,21,240,240
N,41,240,0
FILL,1,21
FILL,21,41
N,101,120,360
N,201,360,120
SECNUM,1
ET,1,188  !USE BEAM188 ELEMENT TYPE
KEYOPT,1,3,2
*DO,I,1,20,1
 E,I,I+1,101
*ENDDO
*DO,I,21,40,1
 E,I,I+1,201
*ENDDO
SECTYPE,1,BEAM,ASEC
SECDATA,18.0,1350.0,0.0,0.54,0.0,2.16
MP,EX,1,71240
MP,NUXY,1,0.31
D,1,ALL
FINISH

/SOLU
NLGEOM,ON
NSUBST,2
F,41,FZ,1.0E-3  !APPLY PERTURBATION FORCE
/OUT,SCRATCH,  !SUPPRESS SOLUTION DATA
SOLVE
OUTRES,ALL,ALL
ARCLEN,ON
ARCTRM,U,60,41,UZ
F,41,FX,1.485  !APPLY END FORCE
NSUBST,10
SOLVE
FINISH

/POST26
/AXLAB,X,TIP DISPLACEMENT
/AXLAB,Y,END FORCE
NSOL,2,41,U,Z,DISP
RFORCE,3,1,F,X,FORCE
PROD,4,3, , ,FORCE , , ,-1.0,1,1,
XVAR,2
```

```
/COM,   THE LOAD DEFLECTION CURVE SHOWN IN VM216.GRPH
/COM,   SHOW A CRITICAL LOAD OF APPROX. 1.09
!PRVAR,2,4
PLVAR,4
FINISH

/POST1
SET,2,7,1
NSEL,S,LOC,X,0
FSUM
*GET,CP1,FSUM,,ITEM,FX
*DIM,LABEL1,CHAR,1
*DIM,VALUE1,,1,3
LABEL1(1) = 'FX_CRLD'
*VFILL,VALUE1(1,1),DATA,1.09
*VFILL,VALUE1(1,2),DATA,ABS(CP1)
*VFILL,VALUE1(1,3),DATA,ABS(CP1 / 1.09)
FINISH
SAVE,TABLE_1

/CLEAR,NOSTART   !PERFORM SAME ANALYSIS WITH BEAM189
/OUT
/PREP7
N,1 ,   ,240
N,21,240,240
N,41,240,0
FILL,1,21
FILL,21,41
N,101,120,360
N,201,360,120
SECNUM,1
ET,1,BEAM189                    ! 3-D QUADRATIC BEAM
*DO,I,1,10,1
 I0=(I-1)*2+1
 E,I0,I0+2,I0+1,101
*ENDDO
*DO,I,11,20,1
 I0=(I-1)*2+1
 E,I0,I0+2,I0+1,201
*ENDDO
SECTYPE,1,BEAM,ASEC
SECDATA,18.0,1350.0,0.0,0.54,0.0,2.16
MP,EX,1,71240
MP,NUXY,1,0.31
D,1,ALL
FINISH

/SOLU
NLGEOM,ON
NSUBST,2
F,41,FZ,1.0E-3
/OUT,SCRATCH,,,APPEND
SOLVE
OUTRES,ALL,ALL
ARCLEN,ON
ARCTRM,U,60,41,UZ
F,41,FX,1.485
NSUBST,10
SOLVE
FINISH

/POST26
/AXLAB,X,TIP DISPLACEMENT
/AXLAB,Y,END FORCE
NSOL,2,41,U,Z,DISP
RFORCE,3,1,F,X,FORCE
PROD,4,3, , , , , ,-1.0,1,1,
XVAR,2
!PRVAR,2,4
PLVAR,4
FINISH
```

```
/POST1
SET,2,7,1
NSEL,S,LOC,X,0
FSUM
*GET,CP2,FSUM,,ITEM,FX
*DIM,LABEL2,CHAR,1
*DIM,VALUE2,,1,3
LABEL2(1) = 'FX_CRLD'
*VFILL,VALUE2(1,1),DATA,1.09
*VFILL,VALUE2(1,2),DATA,ABS(CP2)
*VFILL,VALUE2(1,3),DATA,ABS(CP2 / 1.09)
SAVE,TABLE_2
RESUME,TABLE_1
/OUT
/COM,
/OUT,vm216,vrt
/COM,
/COM,------------------- VM216 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM, USING BEAM 188 ELEMENTS
/COM,
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A15,'     ',F8.3,'     ',F15.3,'     ',1F15.3)
/COM,
/NOPR
RESUME,TABLE_2
/COM,
/COM, USING BEAM 189 ELEMENTS
/COM,
/COM,
*VWRITE,LABEL2(1),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A15,'     ',F8.3,'     ',F15.3,'     ',1F15.3)
/COM,
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vm216,vrt
/OUT,SCRATCH,,,APPEND
```

VM217 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM217
/TITLE,VM217, PORTAL FRAME UNDER SYMMETRIC LOADING
! N. J. HOFF, THE ANALYSIS OF STRUCTURES, PG 115
W=-500
A=400
EX=30E6
IO=20300
MROT=((W*A*A*A)/(EX*IO))*(1/27) !CALCULATE MAX ROT TARGET VALUE
BNDM=(W*A*A)*(19/54)  !CALCULATE MAX BEND MOMENT
/GRA,POWER
/GST,ON
/TRIAD,OFF
/ESHAPE,1
/PREP7
ET,1,BEAM188
ET,2,BEAM189
SECTYPE,1,BEAM,I
SECDATA,16.655,16.655,36.74,1.68,1.68,.945
SECPLOT,1
C = 1.49535
SECTYPE,2,BEAM,I
SECDATA,C*16.655,C*16.655,C*36.74,C*1.68,C*1.68,C*.945
SECPLOT,2
MP,EX,1,30E6
```

```
MP,NUXY,1,0.3
MP,EX,2,30E6
MP,NUXY,2,0.3
A = 400
COLUMDIV = 4
SPANDIV = 16
K,1
K,2,,A
K,3,2*A
K,4,2*A,A
L,2,1
L,3,4
L,4,2
LSEL,,,,1
LATT,,,,,3
LSEL,,,,2
LATT,,,,,1
LSEL,,,,3
LATT,,,,,1
ALLSEL
LESIZE,1,,,COLUMDIV
LESIZE,2,,,COLUMDIV
LESIZE,3,,,SPANDIV
TYPE,1
SECNUM,1
REAL,1
LMESH,1,2
TYPE,2
SECNUM,2
REAL,2
LMESH,3
ALLSEL
DK,1,ALL
DK,3,ALL
LSEL,,,,3
ESLL
SFBEAM,ALL,1,PRESS,-500,-500
ALLSEL
/VIEW,1,1,1,1
/ANG,1
EPLOT
FINISH

/SOLUTION
SOLVE
FINISH
/POST1
ETABLE,SMIS2,SMISC,2
ETABLE,SMIS15,SMISC,15
ETABLE,SMIS5,SMISC,5
ETABLE,SMIS18,SMISC,18
PRNSOL,DOF
PRETAB,SMIS2,SMIS15,SMIS5,SMIS18
/VIEW,1,,,1
PLLS,SMIS2,SMIS15
PLDISP,0
ESEL,S,ELEM,,16
ETAB,B_S,SMISC,15
ESEL,ALL
*GET,A,NODE,48,ROT,Z, !GET Mechanical APDL VALUE FOR MAX ROT
*GET,B,ELEM,16,ETAB,B_S !GET Mechanical APDL VALUE FOR MAX BEN MOMENT
/FORMAT,10,E,16

*DIM,LABEL,CHAR,2
*DIM,VALUE,,2,8
LABEL(1) = 'MAX.ROT','BEND.MOM.'
*VFILL,VALUE(1,1),DATA,ABS(MROT),ABS(BNDM)
*VFILL,VALUE(1,2),DATA,ABS(A),ABS(B)
*VFILL,VALUE(1,3),DATA,ABS(A / MROT),ABS(B / BNDM)

/COM
/OUT,vm217,vrt
```

```
/COM,------------------- VM217 RESULTS COMPARISON ---------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'      ',E10.3,'     ',E14.3,'      ',1F15.3)
/COM,
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm217,vrt
```

VM218 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM218
/TITLE,VM218, HYPERELASTICITY TEST: BALLOON/CIRCULAR PLATE PROBLEM
/COM          USING SHELL181 ELEMENTS
/GRAPHICS,POWER
/PREP7
TB,HYPER,1,,,MOONEY
TBDATA,1,80.0,20.0
ET,1,SHELL181
SECT,1,SHELL
THICK = 0.5             !SHELL THICKNESS
SECD,THICK,1
CSYS,1
K,1,0,0,0
K,2,7.5,0,0
K,3,7.5,7.5
L,1,2
L,2,3
L,3,1
A,1,2,3
LESIZE,1, , ,10
LESIZE,2, , ,1
LESIZE,3, , ,10
AMESH,1
D,ALL,UY
D,ALL,ROTX
D,ALL,ROTZ
NSEL,S,LOC,X,0
D,ALL,ALL
DDELE,ALL,UZ
NSEL,S,LOC,X,7.5
D,ALL,UX
D,ALL,UY
D,ALL,UZ
ALLSEL,ALL
LOCAL, 11,1, 0.0,0.0,0.0,0,0.0,0.0
NROTAT,ALL
AUTOTS,ON
NSUBST, 400, 1200,25
NLGEOM,ON
NROPT,FULL, ,OFF
OUTRES, ALL, ALL,
SF,ALL,PRES,50.0
NEQITR,20
FINISH
/SOLUTION
/OUT,SCRATCH
SOLVE
/OUT
FINISH
/POST1
/NOPR     !SUPPRESS GRAPHING DATA
/VIEW,1,,-1
/ANG,1
```

```
/USER
/FOCUS,1,4,,8,0    !SET UP CENTER OF GRAPHICS SCREEN FOR DISPLACEMENT PLOT
/DIST,,12    !SET DISTANCE TO ZOOM OUT
/TRIAD,OFF
SET,FIRST    !SET DISPLACEMENT DATA FOR FIRST SUBSTEP
PLDISP,0    !PLOT DISPLACEMENT DATA
/NOERASE    !SET DISPLAY TO OVERLAY PLOTS
SET,,10
PLDISP,0
SET,,20
PLDISP,0
SET,,25
PLDISP,0
SET,LAST
PLDISP,1    !PLOT FINAL DISPLACEMENT WITH ORIGINAL POSITION
/ERASE
/TRIAD,ON
/GOPR
/ESHAPE,0
FINISH
/POST26
/XRANGE,0,3.0
/YRANGE,0,1
/AXLAB,X,UZ OF CENTER/R-INITIAL
/AXLAB,Y,THICKNESS/ORIGINAL THICKNESS
NSOL,2,1,U,Z,UZ_1
ESOL,3,1, ,SMIS,17,TH_1
ADD,4,2, , ,UZRATIO, , ,0.13333333,0,0,
ADD,5,3, , ,SH.181, , ,2,0,0,
/COLOR,CURVE,MRED
XVAR,4
PLVAR,5
/ERASE
/NOPR
*DIM,X,TABLE,20,1
*DIM,Y,TABLE,20,1
X(  1,1)= 1.25
Y(  1,1)= 1.25
X(  2,1)= 1.8
Y(  2,1)= 2.5
X(  3,1)= 2.25
Y(  3,1)= 4.0
X(  4,1)= 2.6
Y(  4,1)= 5.9
X(  5,1)= 2.9
Y(  5,1)= 7.8
X(  6,1)= 3.2
Y(  6,1)= 9.8
X(  7,1)= 3.5
Y(  7,1)= 11.6
X(  8,1)= 3.62
Y(  8,1)= 12.6
X(  9,1)= 4.1
Y(  9,1)= 15.3
X( 10,1)= 4.9
Y( 10,1)= 18.8
X( 11,1)= 5.7
Y( 11,1)= 22.1
X( 12,1)= 6.2
Y( 12,1)= 24.0
X( 13,1)= 7.2
Y( 13,1)= 27.9
X( 14,1)= 8.3
Y( 14,1)= 31.2
X( 15,1)= 8.9
Y( 15,1)= 32.9
X( 16,1)= 9.9
Y( 16,1)= 35.8
X( 17,1)= 10.9
Y( 17,1)= 38.0
X( 18,1)= 13.1
Y( 18,1)= 42.9
```

```
X( 19,1)= 14.4
Y( 19,1)= 45
X( 20,1)= 15.2
Y( 20,1)= 46
/GOPR
/XRANGE,0,20
/YRANGE,0,60
/AXLAB,X,UZ OF CENTER (IN)
/AXLAB,Y,PRESSURE (LB/SQ IN)
/COLOR,CURVE,YGRE
*VPLOT,X(1,1),Y(1,1)
/NOERASE
NSOL,2,1,U,Z,UZ_1
PROD,7,1, , ,SH.181 , , ,50,0,0,!MULTIPLY SOLUTION BY 50
/COLOR,CURVE,MRED
XVAR,2            !SPECIFY X VARIABLE TO BE DISPLAYED
PLVAR,7           !DISPLAY SOLUTION IN GRPH FILE
/ERASE
PRVAR,7,2          !LIST VARIABLE 7 VERSUS VARIABLE 2
FINISH
/POST1
/NOPR
SET,NEAR,,,,0.08  !SELECT UZ VALUE FOR NODE 1 AT T=0.08
*GET,VR1,NODE,1,U,Z
SET,NEAR,,,,0.48  !UZ VALUE FOR NODE 1 AT T=0.48
*GET,VR2,NODE,1,U,Z
SET,NEAR,,,,0.76  !UZ VALUE FOR NODE 1 AT T=0.76
*GET,VR3,NODE,1,U,Z
PRES1 = (0.08*50)  !SOLVE FOR PRES IN RESULTS TABLE
PRES2 = (0.48*50)
PRES3 = (0.76*50)
*DIM,LABEL,,3          !SETUP RESULTS TABLE DATA
*DIM,VALUE,,3,3
LABEL(1) = PRES1,PRES2,PRES3
*VFILL,VALUE(1,1),DATA,2.25,6.2,10.9
*VFILL,VALUE(1,2),DATA,VR1,VR2,VR3
*VFILL,VALUE(1,3),DATA,(VR1/2.25),(VR2/6.2),(VR3/10.9)
FINISH
SAVE,TABLE_1
/CLEAR,NOSTART
/TITLE,VM218, HYPERELASTICITY TEST: BALLOON/CIRCULAR PLATE PROBLEM
/COM,         USING SHELL208 ELEMENTS

/PREP7
ET1 = 208
ET,1,SHELL208           ! 2 NODE ELEMENT, KEYOPT(3) = 0
THICK = 0.5             !SHELL THICKNESS
SECT,1,SHELL
SECD,THICK
TB,HYPER,1,,,MOONEY
TBDATA,1,80.0,20.0
N  ,     1 ,        0.,         0.
N  ,     2 ,   0.17143,         0.
N  ,     3 ,   0.47143,         0.
N  ,     4 ,   0.90000,         0.
N  ,     5 ,    1.4571,         0.
N  ,     6 ,    2.1429,         0.
N  ,     7 ,    2.9571,         0.
N  ,     8 ,    3.9000,         0.
N  ,     9 ,    4.9714,         0.
N  ,    10 ,    6.1714,         0.
N  ,    11 ,    7.5000,         0.
E,    1,       2
E,    2,       3
E,    3,       4
E,    4,       5
E,    5,       6
E,    6,       7
E,    7,       8
E,    8,       9
E,    9,      10
E,   10,      11
```

```
FINISH
*CREATE,SOLVEIT,MAC
/PREP7
NSEL,S,LOC,X, 0.0  !CONSTRAINTS AT X =0
D, ALL, UX
D, ALL, ROTZ
NSEL,ALL
NSEL,S,LOC,X,7.5
D, ALL,UX
D, ALL,UY
NSEL,ALL
AUTOTS,ON
NSUBST, 400, 1200,25
NLGEOM,ON
NROPT,FULL, ,OFF
OUTRES, ALL, ALL,
SF,ALL,PRES,-50.0
NEQITR,20
/AUTO,1
/VIEW,1,1,1,1
/ANG,1
/ESHAPE,1
EPLOT
FINISH
/SOLUTION
/OUT,SCRATCH
SOLVE
/OUT
FINISH
*END
SOLVEIT
*CREATE,PLOTS,MAC
/POST1
/NOPR     !SUPPRESS GRAPHING DATA
/VIEW,1,,,1
/ANG,1
/USER
/FOCUS,1,4,8,,0    !SET UP CENTER OF GRAPHICS SCREEN FOR DISPLACEMENT PLOT
/DIST,,12    !SET DISTANCE TO ZOOM OUT
/TRIAD,OFF
SET,FIRST    !SET DISPLACEMENT DATA FOR FIRST SUBSTEP
PLDISP,0    !PLOT DISPLACEMENT DATA
/NOERASE    !SET DISPLAY TO OVERLAY PLOTS
SET,,10
PLDISP,0
SET,,20
PLDISP,0
SET,,25
PLDISP,0
SET,LAST
PLDISP,1    !PLOT FINAL DISPLACEMENT WITH ORIGINAL POSITION
/ERASE
/TRIAD,ON
/GOPR
/ESHAPE,0
FINISH
/POST26
/XRANGE,0,3.0
/YRANGE,0,1
/AXLAB,X,UY OF CENTER/R-INITIAL
/AXLAB,Y,THICKNESS/ORIGINAL THICKNESS
NSOL,2,1,U,Y,UY_1
ESOL,3,1, ,SMIS,13,TH_1
ADD,4,2, , ,UZRATIO, , ,0.13333333,0,0,
ADD,5,3, , ,SH.%ET1%, , ,2,0,0,
/COLOR,CURVE,MRED
XVAR,4
PLVAR,5
/ERASE
/NOPR
*DIM,X,TABLE,20,1
*DIM,Y,TABLE,20,1
```

```
X(  1,1)= 1.25
Y(  1,1)= 1.25
X(  2,1)= 1.8
Y(  2,1)= 2.5
X(  3,1)= 2.25
Y(  3,1)= 4.0
X(  4,1)= 2.6
Y(  4,1)= 5.9
X(  5,1)= 2.9
Y(  5,1)= 7.8
X(  6,1)= 3.2
Y(  6,1)= 9.8
X(  7,1)= 3.5
Y(  7,1)= 11.6
X(  8,1)= 3.62
Y(  8,1)= 12.6
X(  9,1)= 4.1
Y(  9,1)= 15.3
X( 10,1)= 4.9
Y( 10,1)= 18.8
X( 11,1)= 5.7
Y( 11,1)= 22.1
X( 12,1)= 6.2
Y( 12,1)= 24.0
X( 13,1)= 7.2
Y( 13,1)= 27.9
X( 14,1)= 8.3
Y( 14,1)= 31.2
X( 15,1)= 8.9
Y( 15,1)= 32.9
X( 16,1)= 9.9
Y( 16,1)= 35.8
X( 17,1)= 10.9
Y( 17,1)= 38.0
X( 18,1)= 13.1
Y( 18,1)= 42.9
X( 19,1)= 14.4
Y( 19,1)= 45
X( 20,1)= 15.2
Y( 20,1)= 46
/GOPR
/XRANGE,0,20
/YRANGE,0,60
/AXLAB,X,UY OF CENTER (IN)
/AXLAB,Y,PRESSURE (LB/SQ IN)
/COLOR,CURVE,YGRE
*VPLOT,X(1,1),Y(1,1)
/NOERASE
NSOL,2,1,U,Y,UY_1
PROD,7,1, , ,SH.%ET1%, , ,50,0,0,!MULTIPLY SOLUTION BY 50
/COLOR,CURVE,MRED
XVAR,2            !SPECIFY X VARIABLE TO BE DISPLAYED
PLVAR,7           !DISPLAY SOLUTION IN GRPH FILE
/ERASE
PRVAR,7,2          !LIST VARIABLE 7 VERSUS VARIABLE 2
FINISH
/POST1
/NOPR
SET,NEAR,,,,0.08   !SELECT UZ VALUE FOR NODE 1 AT T=0.08
*GET,VR1,NODE,1,U,Y
SET,NEAR,,,,0.48   !UZ VALUE FOR NODE 1 AT T=0.48
*GET,VR2,NODE,1,U,Y
SET,NEAR,,,,0.76   !UZ VALUE FOR NODE 1 AT T=0.76
*GET,VR3,NODE,1,U,Y
PRES1 = (0.08*50)   !SOLVE FOR PRES IN RESULTS TABLE
PRES2 = (0.48*50)
PRES3 = (0.76*50)
*DIM,LABEL,,3    !SETUP RESULTS TABLE DATA
*DIM,VALUE,,3,3
LABEL(1) = PRES1,PRES2,PRES3
*VFILL,VALUE(1,1),DATA,2.25,6.2,10.9
*VFILL,VALUE(1,2),DATA,VR1,VR2,VR3
```

```
*VFILL,VALUE(1,3),DATA,(VR1/2.25),(VR2/6.2),(VR3/10.9)
FINISH
*END
PLOTS
SAVE,TABLE_2
/CLEAR,NOSTART
/TITLE,VM218, HYPERELASTICITY TEST: BALLOON/CIRCULAR PLATE PROBLEM
/COM,         USING SHELL208 ELEMENTS
/PREP7
ET1 = 209
ET,1,SHELL209
THICK = 0.5
SECT,1,SHELL
SECD,THICK
TB,HYPER,1,,,MOONEY
TBDATA,1,80.0,20.0
N  ,     1 ,        0.,         0.
N  ,     2 ,   0.17143,         0.
N  ,     3 ,   0.47143,         0.
N  ,     4 ,   0.90000,         0.
N  ,     5 ,    1.4571,         0.
N  ,     6 ,    2.1429,         0.
N  ,     7 ,    2.9571,         0.
N  ,     8 ,    3.9000,         0.
N  ,     9 ,    4.9714,         0.
N  ,    10 ,    6.1714,         0.
N  ,    11 ,    7.5000,         0.
E,    1,       2
E,    2,       3
E,    3,       4
E,    4,       5
E,    5,       6
E,    6,       7
E,    7,       8
E,    8,       9
E,    9,      10
E,   10,      11
EMID,ADD  ! ADD MIDSIDE NODES FOR SHELL209
FINISH
SOLVEIT
PLOTS
SAVE,TABLE_3
/CLEAR,NOSTART
/TITLE,VM218, HYPERELASTICITY TEST: BALLOON/CIRCULAR PLATE PROBLEM
/COM,         USING SHELL281 ELEMENTS
/PREP7
TB,HYPER,1,,,MOONEY
TBDATA,1,80.0,20.0
ET,1,SHELL281
R,1,0.5,
CSYS,1
K,1,0,0,0
K,2,7.5,0,0
K,3,7.5,7.5
L,1,2
L,2,3
L,3,1
A,1,2,3
LESIZE,1, , ,20
LESIZE,2, , ,1
LESIZE,3, , ,20
AMESH,1
D,ALL,UY
D,ALL,ROTX
D,ALL,ROTZ
NSEL,S,LOC,X,0
D,ALL,ALL
DDELE,ALL,UZ
NSEL,S,LOC,X,7.5
D,ALL,UX
D,ALL,UY
D,ALL,UZ
```

```
ALLSEL,ALL
LOCAL, 11,1, 0.0,0.0,0.0,0,0.0,0.0
NROTAT,ALL
AUTOTS,ON
NSUBST, 400, 1200,25
NLGEOM,ON
NROPT,FULL, ,OFF
OUTRES, ALL, ALL,
SF,ALL,PRES,50.0
NEQITR,20
FINISH
/SOLUTION
/OUT,SCRATCH
SOLVE
/OUT
FINISH
/POST1
/NOPR     !SUPPRESS GRAPHING DATA
/VIEW,1,,-1
/ANG,1
/USER
/FOCUS,1,4,,8,0    !SET UP CENTER OF GRAPHICS SCREEN FOR DISPLACEMENT PLOT
/DIST,,12    !SET DISTANCE TO ZOOM OUT
/TRIAD,OFF
SET,FIRST    !SET DISPLACEMENT DATA FOR FIRST SUBSTEP
PLDISP,0    !PLOT DISPLACEMENT DATA
/NOERASE    !SET DISPLAY TO OVERLAY PLOTS
SET,,10
PLDISP,0
SET,,20
PLDISP,0
SET,,25
PLDISP,0
SET,LAST
PLDISP,1    !PLOT FINAL DISPLACEMENT WITH ORIGINAL POSITION
/ERASE
/TRIAD,ON
/GOPR
/ESHAPE,0
FINISH
/POST26
/XRANGE,0,3.0
/YRANGE,0,1
/AXLAB,X,UZ OF CENTER/R-INITIAL
/AXLAB,Y,THICKNESS/ORIGINAL THICKNESS
NSOL,2,1,U,Z,UZ_1
ESOL,3,1, ,SMIS,17,TH_1
ADD,4,2, , ,UZRATIO, , ,0.13333333,0,0,
ADD,5,3, , ,SH.281, , ,2,0,0,
/COLOR,CURVE,MRED
XVAR,4
PLVAR,5
/ERASE
/NOPR
*DIM,X,TABLE,20,1
*DIM,Y,TABLE,20,1
X(  1,1)= 1.25
Y(  1,1)= 1.25
X(  2,1)= 1.8
Y(  2,1)= 2.5
X(  3,1)= 2.25
Y(  3,1)= 4.0
X(  4,1)= 2.6
Y(  4,1)= 5.9
X(  5,1)= 2.9
Y(  5,1)= 7.8
X(  6,1)= 3.2
Y(  6,1)= 9.8
X(  7,1)= 3.5
Y(  7,1)= 11.6
X(  8,1)= 3.62
Y(  8,1)= 12.6
```

```
X(  9,1)= 4.1
Y(  9,1)= 15.3
X( 10,1)= 4.9
Y( 10,1)= 18.8
X( 11,1)= 5.7
Y( 11,1)= 22.1
X( 12,1)= 6.2
Y( 12,1)= 24.0
X( 13,1)= 7.2
Y( 13,1)= 27.9
X( 14,1)= 8.3
Y( 14,1)= 31.2
X( 15,1)= 8.9
Y( 15,1)= 32.9
X( 16,1)= 9.9
Y( 16,1)= 35.8
X( 17,1)= 10.9
Y( 17,1)= 38.0
X( 18,1)= 13.1
Y( 18,1)= 42.9
X( 19,1)= 14.4
Y( 19,1)= 45
X( 20,1)= 15.2
Y( 20,1)= 46
/GOPR
/XRANGE,0,20
/YRANGE,0,60
/AXLAB,X,UZ OF CENTER (IN)
/AXLAB,Y,PRESSURE (LB/SQ IN)
/COLOR,CURVE,YGRE
*VPLOT,X(1,1),Y(1,1)
/NOERASE
NSOL,2,1,U,Z,UZ_1
PROD,7,1, , ,SH.281 , , ,50,0,0,!MULTIPLY SOLUTION BY 50
/COLOR,CURVE,MRED
XVAR,2            !SPECIFY X VARIABLE TO BE DISPLAYED
PLVAR,7           !DISPLAY SOLUTION IN GRPH FILE
/ERASE
PRVAR,7,2          !LIST VARIABLE 7 VERSUS VARIABLE 2
FINISH
/POST1
/NOPR
SET,NEAR,,,,0.08  !SELECT UZ VALUE FOR NODE 1 AT T=0.08
*GET,VR1,NODE,1,U,Z
SET,NEAR,,,,0.48  !UZ VALUE FOR NODE 1 AT T=0.48
*GET,VR2,NODE,1,U,Z
SET,NEAR,,,,0.76  !UZ VALUE FOR NODE 1 AT T=0.76
*GET,VR3,NODE,1,U,Z
PRES1 = (0.08*50)  !SOLVE FOR PRES IN RESULTS TABLE
PRES2 = (0.48*50)
PRES3 = (0.76*50)
*DIM,LABEL,,3   !SETUP RESULTS TABLE DATA
*DIM,VALUE,,3,3
LABEL(1) = PRES1,PRES2,PRES3
*VFILL,VALUE(1,1),DATA,2.25,6.2,10.9
*VFILL,VALUE(1,2),DATA,VR1,VR2,VR3
*VFILL,VALUE(1,3),DATA,(VR1/2.25),(VR2/6.2),(VR3/10.9)
FINISH
SAVE,TABLE_4
/COM
/OUT,vm218,vrt
RESUME,TABLE_1
/COM,============ VM218 RESULTS COMPARISON ============
/COM,
/COM,          |   TARGET   |   Mechanical APDL   |   RATIO
/COM,RESULTS USING SHELL181:
/COM,PRES =
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,F8.1,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
```

```
/COM,RESULTS USING SHELL208:
/COM,PRES =
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,F8.1,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,
/NOPR
RESUME,TABLE_3
/GOPR
/COM,RESULTS USING SHELL209:
/COM,PRES =
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,F8.1,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,
/NOPR
RESUME,TABLE_4
/GOPR
/COM,RESULTS USING SHELL281:
/COM,PRES =
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,F8.1,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,
/COM,***VERIFIED RESULTS TABLE BASED ON GRAPHICAL DATA.
/COM,====================================================
/OUT
FINISH
*LIST,vm218,vrt
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
/DELETE,TABLE_4
/DELETE,SOLVEIT,MAC
/DELETE,PLOTS,MAC
```

VM219 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM219
/PREP7
/TITLE,VM219, FREQUENCY RESPONSE OF A PRE-STRESSED BEAM USING *EIGEN
/COM,
/COM, REFERENCE: " FORMULAS FOR NATURAL FREQUENCY AND MODE SHAPES"
/COM,    PG:144, EQUATION 8-20, R.D. BLEVINS, VAN NOSTRAND
/COM,    REINHOLD CO. 1979
/COM
L=150                       ! BEAM LENGTH (MICROMETERS)
B=4                         ! BEAM WIDTH
H=2                         ! BEAM HEIGTH
I=B*H**3/12                 ! BEAM MOMENT OF INERTIA
E=169E3                     ! MODULUS  ( MICRO NEWTONS/MICROMETER**2)
P=10                        ! MICRO NEWTONS
DENS=2332E-18               ! DENSITY (KG/MICROMETER**3)
M=DENS*B*H                  ! MASS/LENGTH (KG/MICROMETER)
PER0=8.85E-6                ! FREE-SPACE PERMITTIVITY (PF/MICROMETER)
PLATEA=100                  ! CAPACITOR PLATE AREA (MICROMETER**2)

GAPI=1                      ! INITIAL GAP (MICROMETERS)
GAP=GAPI-P*L/E/B/H          ! APPROX DEFLECTED GAP (IGNORE CAP STIFFNESS)  (MICROMETER)
C3=PER0*PLATEA              ! TRANDUCER REAL CONTANT
C3P=C3/(GAP**2)             ! DERIVITIVE OF C3
C3PP=2*C3/(GAP**3)          ! SECOND DERIVITIVE OF C3
VLT=SQRT(2*P/C3P)           ! APPLIED VOLTAGE TO PLATE
KUU=C3PP*VLT**2/2           ! GAP STIFFNESS
KBEAM=E*PLATEA/L            ! BEAM STIFFNESS (NOTE: GAP STIFFNESS ASSUMED << BEAM STIFFNESS)
UX2=P*L/B/H/E               ! DESIRED DEFLECTION

*DIM,FREQ,,5                ! ARRAY PARAMETER FOR BEAM FREQUENCY
*DIM,PFREQ,,5               ! ARRAY PARMETER FOR BEAM PRE-STRESSED FREQUENCY
```

```
PI=4*ATAN(1)
!! CALCULATE ANALYTICAL SOLUTION !!
*DO,J,1,5
LAMDA=J*PI
LAMDAP2=LAMDA**2*SQRT((1 + P*L**2/(E*I*LAMDA**2)))
LAMDAP=SQRT(LAMDAP2)
FREQ(J) = LAMDA**2/(2*PI*L**2)*SQRT(E*I/M)
PFREQ(J) = LAMDAP**2/(2*PI*L**2)*SQRT(E*I/M)
*ENDDO

ET,1,188     ! BEAM188
KEYOPT,1,3,3
SECT,1,BEAM,ASEC   ! BEAM PROPERTIES
SECD,B*H,I,,I,,1
MP,EX,1,E     ! SET EX TO E
MP,DENS,1,DENS    ! SET DENSITY TO DENS
MP,PRXY,,0.3    ! SET PRXY TO 0.3
ET,2,126     ! TRANS126 FOR ELEMENT 2
C3=PER0*PLATEA    ! SET INPUT CAPACITANCE FOR TRANSDUCER
R,2,0,0,1,0,C3
RMORE,C3
N,1,-10      ! SETUP MODEL NODES
N,2,0
N,22,L
FILL
TYPE,2
REAL,2
E,1,2      ! CREATE TRANSDUCER
TYPE,1
SECN,1
E,2,3      ! CREATE BEAM
*REPEAT,20,1,1
NSEL,S,LOC,X,-10
NSEL,A,LOC,X,L
D,ALL,UX,0,,,,UY
NSEL,S,LOC,X,0
D,ALL,UY,0
D,ALL,VOLT,VLT
IC,ALL,VOLT,VLT
NSEL,S,LOC,X,-10
D,ALL,VOLT,0
NSEL,ALL
ESEL,S,TYPE,,1
NSLE
D,ALL,UZ,,,,,ROTX,ROTY
ALLS,ALL
EPLOT      ! PLOT ELEMENTS
FINISH

/out,scratch
/SOLUTION
ANTYP,STATIC
PSTRES,ON     ! PRESTRESSED MODAL ANALYSIS
SOLVE
FINISH

/SOLUTION
ANTYP,MODAL
MODOPT,UNSYM,3      ! EXTRACT 3 MODES
MXPAND,3
PSTRES,ON
WRFULL,1                    ! STOP SOLUTION AFTER WRITING THE .FULL file
SOLVE
FINISH

/SOLU
*SMAT,MATK,D,IMPORT,FULL,vm219.full,STIFF       ! IMPORT THE STIFFNESS MATRIX FROM FULL FILE
*SMAT,MATM,D,IMPORT,FULL,vm219.full,MASS        ! IMPORT THE MASS MATRIX FROM FULL FILE
*EIGEN,MATK,MATM,,EIV,EIM                       ! COMPUTE THE EIGENVALUES AND EIGENVECTORS
*GET,FP1,MODE,1,FREQ
*GET,FP2,MODE,2,FREQ
*GET,FP3,MODE,3,FREQ
```

```
FINI
/out

/POST1
PFREQ1=PFREQ(1)
PFREQ2=PFREQ(2)
PFREQ3=PFREQ(3)

*DIM,LABEL,CHAR,3
*DIM,VALUE,,3,3
LABEL(1) = 'FREQ 1' , 'FREQ 2' , 'FREQ 3'
*VFILL,VALUE(1,1),DATA,PFREQ1,PFREQ2,PFREQ3
*VFILL,VALUE(1,2),DATA,ABS(FP1),ABS(FP2),ABS(FP3)
*VFILL,VALUE(1,3),DATA,ABS(PFREQ1/FP1),ABS(PFREQ2/FP2),ABS(PFREQ3/FP3)
/OUT,vm219,vrt
/COM
/COM,------------------- VM219 RESULTS COMPARISON ---------------------
/COM,
/COM,          |    TARGET   |   Mechanical APDL    |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F11.3,'  ',F15.3,'   ',1F15.3)
/COM,----------------------------------------------------------------
/OUT
/GOPR
FINISH
*LIST,vm219,vrt
```

VM220 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM220
/TITLE,VM220, EDDY CURRENT LOSS IN THICK STEEL PLATE
/NOPR
!
/PREP7
DD=2.5E-3  ! 1/2 HEIGTH OF PLATE
HM=2644.1  ! IMPOSED H FIELD
SIGMA=5.0E6  ! MATERIAL CONDUCTIVITY
FF=50   ! FREQUENCY (Hz.)
DX=DD/6   ! MODELED PLATE WIDTH
DY=DD/6   ! COIL HEIGTH
!
ET,1,PLANE53
MP,MURX,1,1.  ! COIL RELATIVE PERMEABILITY
TB,BH,2,,25  ! PLATE B-H CURVE
TBPT,,100,.46512
TBPT,,200,.72993
TBPT,,300,.90090
TBPT,,400,1.0204
TBPT,,500,1.1086
TBPT,,600,1.1765
TBPT,,700,1.2302
TBPT,,800,1.2739
TBPT,,900,1.3100
TBPT,,1000,1.3405
TBPT,,1400,1.4257
TBPT,,1800,1.4778
TBPT,,2200,1.5131
TBPT,,2600,1.5385
TBPT,,3000,1.5576
TBPT,,3400,1.5726
TBPT,,3800,1.5847
TBPT,,4200,1.5945
TBPT,,4600,1.6028
TBPT,,5000,1.6098
TBPT,,7000,1.6332
TBPT,,9000,1.6465
```

```
TBPT,,11000,1.6551
TBPT,,13000,1.6611
TBPT,,15000,1.6656
/NUM,1
TBPLOT   !PLOT B-H CURVE
MP,RSVX,2,1/SIGMA

RECT,0,DX,0,DD  ! PLATE
RECT,0,DX, DD,DD+DY ! COIL
AGLUE,ALL


ASEL,S,LOC,Y,DD,DD+DY
AATT,1,0,1
ASEL,S,LOC,Y,0,DD
AATT,2,0,1
ASEL,ALL
AMESH,ALL
!
NSEL,S,LOC,Y,
D,ALL,AZ,0.  ! FLUX-PARALLEL
NSEL,S,LOC,Y,DD+DY
CP,1,AZ,ALL  ! COUPLE FOR FLUX-PARALLEL
NSEL,ALL
/PBC,ALL,1
/VIEW,1,,,1
/ANG,1
/PNUM,AREA,1
/NUM,1
APLOT
/PNUM,NODE,1
/PNUM,MAT,1
EPLOT   !PLOT ELEMENTS
FINISH

/SOLU
ANTYPE,HARMIC
ESEL,S,MAT,,1
BFE,ALL,JS,, 0.,0.,HM/DY,0. !APPLY COIL CURRENT DENSITY
ESEL,ALL
HMAGSOLV,FF,,1E-2  ! SOLVE NONLINEAR PROBLEM
FINISH

/POST1
!
! COMPUTE LOSSES
!
SET,LAST,1,,0
ESEL,S,MAT,,2
POWERH   ! EXTRACT LOSSES IN PLATE (W/m)
PAVG=PAVG*2/DX  ! CONVERT TO (W/m**2)
*VWRITE,PAVG
(/'COMPUTED EDDY CURRENT LOSS:', F9.4, 'Watts/m**2')

/VIEW,1,1,1,1
/ANG,1
PLVECT,H,,,,VECT,ELEM,ON,0
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1) = 'CUR LOSS'
*VFILL,VALUE(1,1),DATA,1342.323
*VFILL,VALUE(1,2),DATA,PAVG
*VFILL,VALUE(1,3),DATA,PAVG/1342.323
/OUT,vm220,vrt
/COM
/COM,------------------- VM220 RESULTS COMPARISON ---------------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,
```

```
/COM,***TARGET SOLUTION BASED ON GRAPHICAL RESULTS***
/COM,-----------------------------------------------------------------------
/OUT

FINISH
*LIST,vm220,vrt
```

VM221 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM221
/TITLE,VM221, SIMULATION OF SHAPE MEMORY ALLOY EFFECT
/COM,   REF: ANGELA C.SOUZA, EDGAR N.MAMIYA, NESTOR ZOUAIN,
/COM,   "THREE-DIMENSIONAL MODEL FOR SOLIDS UNDERGOING
/COM,   STRESS-INDUCED PHASE TRANSFORMATIONS"
/COM,   EUR. J. MECH. A/SOLIDS. 17 (1998) 789-806
/COM,
/PREP7
ET,1,SOLID185    !3D 8-NODE STRUCTURAL SOLID ELEMENT

/COM, DEFINING SMA MATERIAL PROPERTIES
MP,EX,1,70E3     !MPA, [AUSTENITE MODULUS]
MP,PRXY,1,0.33

C1=500   !MPA [HARDENING PARAMETER]
C2=253.15 !K   [REF TEMP]
C3=45  !MPA  [ELASTIC LIMIT]
C4=7.5  !MPA
C5=0.03  ![MAX TRANSFORMATION STRAIN]
C6=70E3  !MPA, [MARTENSITE MODULUS]
C7=0            !M = 0, SYMMETRICAL BEHAVIOR

TB,SMA,1,,7,MEFF
TBDATA,1,C1,C2,C3,C4,C5,C6,C7

BLOCK,0.00,5.00,0.00,5.00,0.00,5.00
ESIZE,5
TYPE,1
MAT,1
VMESH,1

NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,ALL
BFUNIF,TEMP,253.15
FINISH
/OUT,SCRATCH
/SOLU
NROPT,UNSYM
OUTRES,ALL,ALL
NSUBST,50,100,30
LD=-70                    !PRESSURE LOADING 70MPA

TIME,1
NSEL,S,LOC,X,5
SF,ALL,PRES,LD*0.75       ! LOADING IN ELASTIC STAGE
ALLSEL
SOLVE

TIME,2
NSEL,S,LOC,X,5
SF,ALL,PRES,LD            ! LOAD TO PHASE TRANSFORMATION
ALLSEL
SOLVE
```

```
TIME,3
NSEL,S,LOC,X,5
SF,ALL,PRES,0.0            ! UNLOAD TO ZERO
ALLSEL
SOLVE

TIME,4
BFUNIF,TEMP,259.15         !   TEMPERATURE LOADING TO RECOVER RESIDUAL STRAIN
ALLSEL
SOLVE
FINISH

/POST1
SET,LAST
*GET,S_Y,NODE,NODE(5,5,0),S,X
*GET,Ee,NODE,NODE(5,5,0),EPEL,X
*GET,Ep,NODE,NODE(5,5,0),EPPL,X

*DIM,LABEL,CHAR,3,1
*DIM,VALUE,,3,2
LABEL(1,1) = 'SY','Ee_X','Ep_X'
*VFILL,VALUE(1,1),DATA,0.0,0.0,0.0
*VFILL,VALUE(1,2),DATA,S_Y,Ee_X,Ep_X
/COM
/OUT,vm221,vrt
/COM,------------------- VM221 RESULTS COMPARISON --------------
/COM,
/COM,               |  TARGET   |   Mechanical APDL
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2)
(1X,A8,'      ',F14.3,'  ',F14.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm221,vrt
```

VM222 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vm222
/TITLE,vm222, Warping Torsion Bar
!
/PREP7
!
!BUILD MODEL USING BEAM188 ELEMENTS
!
K,,
K,,1000
K,,500,100
L,1,2
ET,1,BEAM188
KEYOPT,1,1,1
SECT,1,BEAM,I
SECD,40,40,80,2,2,2
SECPLOT,1
!
MP,EX, 1, 217396.3331684 !SET MATERIAL PROPS
MP,NUXY,1,  0.335579823862
NEL=50
LATT,1,,,,3   !SET DEFAULT ATTRIBUTES
LESIZE,1,,,NEL
LMESH,ALL   !MESH MODEL
DK,1,ALL   !PIN MODEL AT KEYPOINT 1
SAVE,PREPDATA,DB  !SAVE DB FOR FUTURE PARTS OF TEST
DK,2,ALL   !PIN MODEL AT KEYPOINT 2
!
MLOAD1=(1000/NEL)/2
```

```
MLOAD2=MLOAD1*2
/ESHAPE,1 !TURN ESHAPE ON TO SHOW 3-D IMAGE OF MODEL
FINISH
/SOLU
OUTRES,ALL,ALL
F,ALL,MX,MLOAD2
FDEL,1,ALL
FDEL,2,ALL
F,1,MX,MLOAD1
F,2,MX,MLOAD1
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
PRNSOL,DOF
PRRSOL
NSORT,ROT,X
*GET,ROTX1,SORT, ,MAX  !GET VERIFIED RESULT FOR PART 1
PRES,SMISC,27
ETABLE,ROTX,ROT,X
/ESHAPE,1
PLDISP    !PLOT DISPLACED SHAPE
PLETAB,ROTX,NOAV
ETABLE,BIMOMENT,SMISC,27
PLETAB,BIMOMENT,NOAV
PARSAV    !SAVE PARAMETERS FOR NEXT PART OF TEST
FINISH
/CLEAR,NOSTART
PARRES,CHANGE   !RESTORE SAVED PARAMETERS
/PREP7
!
! REBUILD AND REMESH MODEL USING BEAM189 ELEMENTS
!
K,,
K,,1000
K,,500,100
L,1,2
ET,1,BEAM189
KEYOPT,1,1,1
SECT,1,BEAM,I
SECD,40,40,80,2,2,2

MP,EX, 1, 217396.3331684
MP,NUXY,1,  0.335579823862
NEL=50
LATT,1,,,,3
LESIZE,1,,,NEL
LMESH,ALL
!
! APPLY BOUNDRY CONDITIONS AND SET UP NEW PARAMETERS
!
DK,1,ALL
DK,2,ALL
MLOAD=(1000/NEL)/6.0
MLOAD1=MLOAD
MLOAD2=MLOAD*2
MLOAD4=MLOAD*4
FINISH
/SOLU
OUTRES,ALL,ALL
!
! SET UP LOOP TO APPLY LOADS
!
*DO,I,1,NEL,1
 J=NELEM(I,1)
 K=NELEM(I,2)
 L=NELEM(I,3)
 F,J,MX,MLOAD2
 F,K,MX,MLOAD2
 F,L,MX,MLOAD4
*ENDDO
```

```
F,1,MX,MLOAD1
F,2,MX,MLOAD1
FLIST
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
PRNSOL,DOF
NSORT,ROT,X
*GET,ROTX2,SORT, ,MAX  !GET VERIFIED RESULTS FOR PART 2
PRRSOL
PRES,SMISC,4
PRES,SMISC,17
PRES,SMISC,27
T1=ROTX1
T2=ROTX2
!
!SET UP AND FILL VM RATIO TABLE
!
RAT_1 = ABS(T1/0.3292617E-3)
RAT_2 = ABS(T2/0.3292617E-3)
*DIM,LABEL,CHAR,2
*DIM,VALUE,,2,2
*DIM,RESULTS,,2,1
LABEL(1) = 'BEAM188','BEAM189'
*VFILL,VALUE(1,1),DATA,0.3292617E-3,0.3292617E-3
*VFILL,RESULTS(1,1),DATA,T1,T2
*VFILL,VALUE(1,2),DATA,RAT_1,RAT_2
/OUT,vm222,vrt
/COM
/COM,------------------- VM222  RESULTS COMPARISON ---------------------
/COM,    MX TWIST
/COM,    IN X-DIR |    TARGET     |     Mechanical APDL     |     RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),RESULTS(1,1),VALUE(1,2)
(1X,A10,'     ',E10.4,'      ',E14.4,'       ',1F15.3)
/COM,-----------------------------------------------------------------
/out
*LIST,vm222,vrt
FINISH
```

VM223 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM223
/TITLE,VM223, ELECTRO-THERMAL-COMPLIANT MICROACTUATOR
/COM,
/COM, REFERENCE:
/COM, N.D. MANKAME AND G.K. ANANTHASURESH, "COMPREHENSIVE THERMAL MODELLING
/COM, AND CHARACTERIZATION OF AN ELECTRO-THERMAL-COMPLIANT MICROACTUATOR,"
/COM, J. MICROMECH. MICROENG., V.11 (2001), PP. 452-462
/COM,
/NOPR
D1=40E-6                 ! MICROACTUATOR DIMENSIONS, m
D2=255E-6
D3=40E-6
D4=330E-6
D5=1900E-6
D6=90E-6
D7=75E-6
D8=352E-6
D9=352E-6
D11=20E-6
VLT=15                 ! APPLIED VOLTAGE, VOLT
TBLK=300               ! BULK TEMPERATURE, K
/PREP7
ET,1,SOLID227,111      ! STRUCTURAL-THERMOELECTRIC TETRAHEDRON
```

```
MP,EX,1,169E9
MP,PRXY,1,0.3
MP,RSVX,1,4.2E-4
MPTEMP,1,300,400,500,600,700,800
MPTEMP,7,900,1000,1100,1200,1300,1400
MPTEMP,13,1500
MPDATA,ALPX,1,1,2.568E-6,3.212E-6,3.594E-6,3.831E-6,3.987E-6,4.099E-6
MPDATA,ALPX,1,7,4.185E-6,4.258E-6,4.323E-6,4.384E-6,4.442E-6,4.5E-6
MPDATA,ALPX,1,13,4.556E-6
MPDATA,KXX,1,1,146.4,98.3,73.2,57.5,49.2,41.8
MPDATA,KXX,1,7,37.6,34.5,31.4,28.2,27.2,26.1
MPDATA,KXX,1,13,25.1
TREF,TBLK             ! REFERENCE TEMPERATURE
/COM, === SOLID MODEL
K,1,0,0               ! DEFINE KEYPOINTS
K,2,0,D9
K,3,D8,D9
K,4,D8,D1
K,5,D8+D4+D5,D1
K,6,D8+D4+D5,-(D7+D2)
K,7,D8+D4,-(D7+D2)
K,8,D8+D4,-(D7+D3)
K,9,D8,-(D7+D3)
K,10,D8,-(D7+D9)
K,11,0,-(D7+D9)
K,12,0,-D7
K,13,D8+D4+D5-D6,-D7
K,14,D8+D4+D5-D6,0
A,1,2,3,4,5,6,7,8,9,10,11,12,13,14
VEXT,1,,,,,D11

/COM, === FINITE ELEMENT MODEL
LSEL,S,LINE,,31,42   ! ELEMENT SIZE ALONG OUT-OF-PLANE DIMENSION
LESIZE,ALL,D11
LSEL,S,LINE,,1,3     ! ELEMENT SIZE ALONG ANCHOR SIDES
LSEL,A,LINE,,9,11
LSEL,A,LINE,,15,17
LSEL,A,LINE,,23,25
LESIZE,ALL,D9/2
LSEL,S,LINE,,5       ! ELEMENT SIZE ALONG SIDE WALLS
LSEL,A,LINE,,19
LESIZE,ALL,(D1+D2+D7)/6
LSEL,S,LINE,,13      ! ELEMENT SIZE ALONG THE END CONNECTION
LSEL,A,LINE,,27
LESIZE,ALL,D7/3
LSEL,S,LINE,,8       ! ELEMENT SIZE ALONG THE FLEXURE
LSEL,A,LINE,,22
LESIZE,ALL,D4/6
LSEL,S,LINE,,4       ! ELEMENT SIZE ALONG THE THIN ARM
LSEL,A,LINE,,18
LESIZE,ALL,(D4+D5)/30
LSEL,S,LINE,,14
LSEL,A,LINE,,28
LESIZE,ALL,(D8+D4+D5-D6)/40
LSEL,S,LINE,,7       ! ELEMENT SIZE ALONG THE WIDE ARM
LSEL,A,LINE,,21
LESIZE,ALL,D2/5
LSEL,S,LINE,,12
LSEL,A,LINE,,26
LESIZE,ALL,(D8+D4+D5-D6)/35
LSEL,S,LINE,,6
LSEL,A,LINE,,20
LESIZE,ALL,D5/25
LSEL,ALL
VMESH,1              ! MESH THE VOLUME

/COM, === DOF CONSTRAINTS ON THE ANCHORS
NSEL,S,LOC,X,0,D8
NSEL,R,LOC,Z,0       ! BOTTOM SURFACE
D,ALL,UX,0,,,,UY,UZ
D,ALL,TEMP,TBLK
NSEL,ALL
```

```
NSEL,S,LOC,X,0,D8
NSEL,R,LOC,Y,-(D7+D9),-D7
CP,1,VOLT,ALL
N_GR=NDNEXT(0)
D,N_GR,VOLT,0
NSEL,S,LOC,X,0,D8
NSEL,R,LOC,Y,0,D9
CP,2,VOLT,ALL
N_VLT=NDNEXT(0)
D,N_VLT,VOLT,VLT
NSEL,ALL

/COM, === RADIOSITY BOUNDARY CONDITIONS
SF,ALL,RDSF,0.7,1    ! SURFACE-TO-SURFACE RADIATION LOAD
SPCTEMP,1,TBLK       ! AMBIENT TEMPERATURE
STEF,5.6704E-8       ! STEFAN-BOLTZMAN RADIATION CONSTANT, J/(K)4(M)2(S)

/COM, === TEMPERATURE DEPENDENT CONVECTION BOUNDARY CONDITIONS
MPTEMP               ! INITIALIZE TEMPERATURE TABLE
/COM, TEMPERATURE TABLE FOR THERMAL LOADING
MPTEMP,1,300,500,700,900,1100,1300
MPTEMP,7,1500
/COM, === UPPER FACE
ASEL,S,AREA,,2       ! THIN ARM AND FLEXURE
NSLA,S,1
NSEL,R,LOC,X,D8,D8+D4+D5-D6
NSEL,R,LOC,Y,0,D1
SF,ALL,CONV,-1,TBLK
NSLA,S,1
NSEL,R,LOC,X,D8,D8+D4
NSEL,R,LOC,Y,-(D3+D7),-D7
SF,ALL,CONV,-1,TBLK
MPDATA,HF,1,1,17.8,60.0,65.6,68.9,71.1,72.6
MPDATA,HF,1,7,73.2
NSLA,S,1              ! WIDE ARM
NSEL,R,LOC,X,D8+D4,D8+D4+D5-D6
NSEL,R,LOC,Y,-(D2+D7),-D7
SF,ALL,CONV,-2,TBLK
MPDATA,HF,2,1,11.2,37.9,41.4,43.4,44.8,45.7
MPDATA,HF,2,7,46.0
NSLA,S,1              ! END CONNECTION
NSEL,R,LOC,X,D8+D4+D5-D6,D8+D4+D5
SF,ALL,CONV,-3,TBLK
MPDATA,HF,3,1,15.,50.9,55.5,58.2,60.,61.2
MPDATA,HF,3,7,62.7
NSLA,S,1              ! ANCHORS
NSEL,R,LOC,X,0,D8
SF,ALL,CONV,-4,TBLK
MPDATA,HF,4,1,10.3,35.0,38.2,40.,41.3,42.1
MPDATA,HF,4,7,42.5
/COM, === BOTTOM FACE
ASEL,S,AREA,,1
NSLA,S,1             ! THIN ARM AND FLEXURE
NSEL,R,LOC,X,D8,D8+D4+D5-D6
NSEL,R,LOC,Y,0,D1
SF,ALL,CONV,-5,TBLK
NSLA,S,1
NSEL,R,LOC,X,D8,D8+D4
NSEL,R,LOC,Y,-(D3+D7),-D7
SF,ALL,CONV,-5,TBLK
MPDATA,HF,5,1,22.4,69.3,76.1,80.5,83.7,86.0
MPDATA,HF,5,7,87.5
NSLA,S,1             ! WIDE ARM
NSEL,R,LOC,X,D8+D4,D8+D4+D5-D6
NSEL,R,LOC,Y,-(D2+D7),-D7
SF,ALL,CONV,-6,TBLK
MPDATA,HF,6,1,13.,39.6,43.6,46.,47.6,49.
MPDATA,HF,6,7,50.1
NSLA,S,1             ! END CONNECTION
NSEL,R,LOC,X,D8+D4+D5-D6,D8+D4+D5
SF,ALL,CONV,-7,TBLK
```

```
MPDATA,HF,7,1,24.,73.8,81.,85.7,89.2,91.6
MPDATA,HF,7,7,93.2
NSEL,ALL
ASEL,ALL
/COM, === SIDE WALLS (ANCHORS AND AREA BETWEEN THE THIN AND WIDE
/COM, ARMS ARE EXCLUDED)
ASEL,S,AREA,,6,16
ASEL,U,AREA,,11,16
SFA,ALL,,CONV,-8,TBLK
ASEL,ALL
MPDATA,HF,8,1,929,1193,1397,1597,1791,1982
MPDATA,HF,8,7,2176
FINISH

/SOLU
ANTYPE,STATIC
CNVTOL,F,1,1.E-4      ! DEFINE CONVERGENCE TOLERANCES
CNVTOL,HEAT,1,1.E-5
CNVTOL,AMPS,1,1.E-5
NLGEOM,ON             ! LARGE DEFLECTION ANALYSIS
/OUT,SCRATCH
SOLVE
FINISH

/POST1
/DSCALE,1,10
PLNSOL,U,SUM          ! PLOT DISPLACEMENT VECTOR SUM
PLNSOL,TEMP           ! PLOT TEMPERATURE
/OUT,
/COM,
/COM, TARGET RESULTS:
/COM, FIGURE 5 (P. 458) TIP TRANSVERSE DISPLACEMENT VS. VOLTAGE CURVE:
/COM,          VOLTAGE = 15.0 (V), UY = 27E-6 (m)
/COM,
UYANALYT=27.0E-6
NPOST=NODE(0.25820E-02,-0.33000E-03,0.20000E-04)
*GET,UYANSYS,NODE,NPOST,U,SUM
RATIO=ABS(UYANSYS/UYANALYT)
*DIM,LABEL,CHAR,1
LABEL(1) = 'UY (15V)'

/GOPR
/OUT,vm223,vrt
/COM
/COM,------------------- VM223  RESULTS COMPARISON ---------------------
/COM,
/COM,              TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),UYANALYT,UYANSYS,RATIO
(1X,A10,'     ',E10.4,'    ',E14.4,'     ',1F15.3)
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vm223,vrt
```

VM224 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vm224
/TITLE,VM224, Implicit Creep Under Biaxial Load
/COM, NAFEMS Fundamental Tests of Creep Behavior, Becker and Hyde
/NOPR
/COM,
/COM, 2D CREEP TESTS WITH BIAXIAL CONSTANT LOAD,
/COM, REFERENCE: TEST 10(A) FROM NAFEMS R0027.
/COM,
/COM, EXPECTED RESULTS:
/COM,       TIME | EPCRX   | EPCRY
```

```
/COM,   ----------------------------
/COM,        0.0 | 0.0    | -0.0
/COM,        0.1 | 0.0427 | -0.0427
/COM,        1.0 | 0.135  | -0.135
/COM,        5.0 | 0.3019 | -0.3019
/COM,       10.0 | 0.4269 | -0.4269
/COM,       50.0 | 0.9546 | -0.9546
/COM,      100.0 | 1.35   | -1.35
/COM,      500.0 | 3.019  | -3.019
/COM,     1000.0 | 4.2691 | -4.2691
/COM,
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (PRIMARY CREEP)!***
*SET,C1,1.5625E-14   !ASSIGN VALUE
*SET,C2,5.0    !ASSIGN VALUE
*SET,C3,-0.5    !ASSIGN VALUE
*SET,C4,0    !ASSIGN VALUE
C***  TIME PARAMETER
*SET,HOUR,1000    !ASSIGN VALUE
C***   ELASTIC CONSTANT
MP,EX,1,200E3    !DEFINE YOUNG'S MODULUS
MP,NUXY,1,0.3    !DEFINE POISON'S RATIO
TUNIF,HOT    !ASSIGN TEMP TO NODES
TOFF,OFFS    !SPECIFY TEMP RELATIVE TO ABSOLUTE VALUES
TB,CREEP,1,,,6    !ACTIVATE DATA TABLE
TBDATA,1,C1,C2,C3,C4   !DEFINE DATA FOR TABLE
SAVE     !SAVE
/PREP7
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
ET,1,PLANE182
KEYOPT,1,1,1
KEYOPT,1,3,0
E,1,5,9,8
E,5,2,6,9
E,9,6,3,7
E,8,9,7,4
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUT,SCRATCH
OUTRES,ESOL,ALL
SOLVE
/OUT
RATE, ON
DELT,1E-5,1E-5,100
TIME,1000
/OUT,SCRATCH
SOLVE
/OUT
FINISH
/POST26
```

```
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
PLVAR,2,3
*GET,RES1X,VARI,2,RTIME,1000
*GET,RES1Y,VARI,3,RTIME,1000
FINISH
PARSAV,ALL
RESUME
PARRES,CHANGE
/PREP7
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,PLANE183
KEYOPT,1,3,0
E,1,2,3,4,5,6,7,8
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1E-5,1E-5,100
TIME,1000
/OUT,SCRATCH
OUTRES,ESOL,ALL
SOLVE
/OUT
FINISH
/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
PLVAR,2,3
*GET,RES2X,VARI,2,RTIME,1000
*GET,RES2Y,VARI,3,RTIME,1000

*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECRXX ',' ECRYY '
*VFILL,VALUE1(1,1),DATA,4.2691,-4.2691
*VFILL,VALUE1(1,2),DATA,RES1X,RES1Y
*VFILL,VALUE1(1,3),DATA,ABS(RES1X/4.2691),ABS(RES1Y/(-4.2691))

*DIM,LABEL2,CHAR,2
*DIM,VALUE2,,2,3
LABEL2(1) = ' ECRXX ',' ECRYY '
*VFILL,VALUE2(1,1),DATA,4.2691,-4.2691
*VFILL,VALUE2(1,2),DATA,RES2X,RES2Y
*VFILL,VALUE2(1,3),DATA,ABS(RES2X/4.2691),ABS(RES2Y/(-4.2691))

/OUT,vm224,vrt
```

```
/COM
/COM,------------------- VM224 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM, PLANE182
/COM,
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A8,'      ',F7.4,'      ',F14.4,'     ',1F15.3)
/COM,
/COM, PLANE183
/COM,
*VWRITE,LABEL2(1),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,'      ',F7.4,'      ',F14.4,'     ',1F15.3)
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vm224,vrt
```

VM225 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM225
/TITLE, VM225, BEAM WITH PRETENSION LOAD
C***    USING 3-D SOLID45
/COM,
/PREP7     !ENTER PREPROCESSOR
MP,PRXY,,0.3
BLOCK,,12,,1,,.5   !CREATE BLOCK
/VIEW,1,1,2,3    !CHANGE VIEW
ET,1,SOLID45    !SET ELEMENT TYPE
MP,EX,1,30E6,     !DEFINE YOUNG'S MODULUS
MP,PRXY,1,0.3                           !DEFINE POISSON'S RATIO
MP,DENS,1,.283,    !DEFINE DENSITY
DA,2,SYMM    !DEFINE SYMMETRY BC ON AREA
DA,3,SYMM    !DEFINE SYMMETRY BC ON AREA
DA,5,UX     !DEFINE DOF ON AREA
DA,6,UX     !DEFINE DOF ON AREA
VMESH,ALL    !MESH VOLUME
PSMESH, , ,1000,ALL,,0,X,6,,,,EEE,NNN   !APPLY LOAD VIA PRE-TENSION ELEMENT
SLOAD,1,PL01,LOCK,FORC,125,1,2
EPLOT
SAVE                                    !SAVE DATABASE FOR SECOND SOLUTION
FINISH     !EXIT PREP7
/out,scratch
/SOLU     !ENTER SOLVER
SOLVE     !SOLVE
FINISH     !EXIT SOLVER
/out
*CREATE,RES3D,MAC                       !CREATE MACRO TO RETRIEVE RESULTS
/POST1     !ENTER POST PROCESSOR
NSORT,S,INT,1,0,,   !SORT STRESS RESULTS
*GET,MAXNFEA2,SORT,,IMAX  !GET NODE VALUE
*GET,SIGFEA2,NODE,MAXNFEA2,S,INT !GET MAXIMUM VON MISSES STRESS
NSORT,U,X,SUM,1,0,,,   !SORT DEFLECTION RESULTS
*GET,MAXNFEA2,SORT,,IMAX  !GET NODE VALUE
*GET,UXFEA2,NODE,MAXNFEA2,U,X,SUM !GET MAXIMUM UX VALUE
*STAT,UXFEA2    !LIST PARAMETER VALUE
*STAT,SIGFEA2    !LIST PARAMETER VALUE
/COM,**********************************
/COM,*** CLASSICAL ANALYSIS RESULTS ***
/COM,**********************************
SIGCA = 250
UXCA = 0.0001
*DIM,LABEL,CHAR,2
*DIM,VALUE,,2,3
LABEL(1) = 'SIGCA ','UXCA '
```

```
*VFILL,VALUE(1,1),DATA,SIGCA,UXCA
*VFILL,VALUE(1,2),DATA,SIGFEA2,UXFEA2
*VFILL,VALUE(1,3),DATA,ABS(SIGCA / SIGFEA2) ,ABS(UXCA / UXFEA2)
FINISH
*END
RES3D                               !EXECUTE MACRO TO RETRIEVE RESULTS
SAVE,TABLE_1

/CLEAR, NOSTART                     !CLEAR DATABASE FOR SECOND SOLUTION
/TITLE, VM225, BEAM WITH PRETENSION LOAD
C***    USING 3-D SOLID185
/PREP7
RESUME                              !RESUME DATABASE
ET,1,SOLID185                       !ANALYZE AGAIN USING 3-D SOLID185
FINISH                              !EXIT PREP7
/out,scratch
/SOLU     !ENTER SOLVER
SOLVE     !SOLVE
FINISH      !EXIT SOLVER
/out
RES3D                               !EXECUTE MACRO TO RETRIEVE RESULTS
SAVE,TABLE_2

/NOPR
RESUME,TABLE_1
/GOPR
/OUT,vm225,vrt
/COM
/COM,------------------- VM225 RESULTS COMPARISON ---------------------
/COM,
/COM,          |   TARGET   |    Mechanical APDL    |    RATIO
/COM,
/COM, SOLID45
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.5,'   ',F14.5,'     ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM, SOLID185
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.5,'   ',F14.5,'     ',1F15.3)
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vm225,vrt
```

VM226 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vm226
/TITLE,VM226, FOURIER SERIES ANALYSIS OF A DIODE RECTIFIED CIRCUIT
/COM, REF: SEDRA/SMITH "MICROELECTRONIC CIRCUITS 4TH ED." SEC. 3.7
/COM,
/COM   FIRST PART: NO CAPACITANCE
/COM
PI = 4*ATAN(1)
R1=2500                        ! RESISTOR VALUE
OMEGA=2*PI*60
IFINAL=3                       ! NUMBER OF MODES ( 3 -> A0,A1,B1)
IFIN=IFINAL+20   ! WE MUST COMPUTE MORE COEFF THAN WE NEED
U=135

! FOR THE SECOND PART
*DIM,CAPA,ARRAY,2
CAPA(1)=1E-6,10E-6  ! CAPACITOR VALUES
```

```
EPS=1E-09                       ! ERROR CRITERIA FOR TO1

!FOR RESULTS
*DIM,RESUL,ARRAY,IFINAL,(IFINAL+1)*3
*DIM,COEFFOU,CHAR,IFINAL
*DIM,TAUARR,ARRAY,1,IFINAL+1
COEFFOU(1)='A0/2= ','A1= ','B1= '
TAUARR(1,1)=CAPA(1)*R1
TAUARR(1,2)=CAPA(2)*R1

/PREP7
R,1,,U,OMEGA/2/PI,              !SET UP SINUSOIDAL VOLTAGE SOURCE
N,1,-0.85,0.4,0
N,2,-0.85,0.25,0
RMOD,1,15,0,1
ET,1,CIRCU124,4,1
TYPE,1
REAL,1
MAT,1
!
N,3,-0.85,0.325,0
E,1,2,3                        !CREATE IND. SINUSOIDAL VOLT SOURCE
R,2,R1,                        !SET UP 2500 OHM RESISTOR
N,4,-0.75,0.4,0
N,5,-0.75,0.25,0
RMOD,2,15,0,2
ET,2,CIRCU124,0,0
TYPE,2
REAL,2
MAT,1
E,4,5                          !CREATE 2500 OHM RESISTOR
!
! THE FOLLOWING COMMANDS ARE USED TO SET UP THE IDEAL DIODE
!
ET,3,125,
R,3
TYPE,3
REAL,3
E,1,4
!
! APPLY GROUND TO CIRCUIT
!
D,2,VOLT,0
D,5,VOLT,0
SAVE
ALLS
EPLOT
FINISH
!
! SOLVE NON-LINEAR CIRCUIT WITH T = 0 TO 0.025
! USING A TIME STEP OF 0.001 FOR EACH ITERATION
!
/SOLU
ANTYPE,TRANS
OUTRES,ALL,ALL,
TIME,0.025
AUTOTS,-1
DELTIM,0.0001, , ,1
CNVTOL,VOLT,,0.0001,2,1.0E-6    !CONVERGANCE CRITERIA
/OUT,SCRATCH
SOLVE
/OUT
FINISH


/POST26
NSOL,2,4,VOLT,,

/COLOR,CURVE,BLUE,1
/TITLE,VM226, LOAD VOLTAGE WAVEFORM WITH NO CAPACITANCE
/AXLAB,Y,OUTPUT POTENTIAL (VOLT)
PLVAR,2,
```

```
/TITLE,VM226, FOURIER SERIES ANALYSIS OF A DIODE RECTIFIED CIRCUIT
!
! SET UP TABLE ARRAYS TO DISPLAY OUTPUT RESULTS
!
*DIM,VOLTG,TABLE,251
*DIM,TARGET,ARRAY,251
*DO,INC,1,251,1
  T = INC*0.0001
  !TIME(INC) = T
  *GET,V,VARI,2,RTIME,T
  VOLTG(INC,1) = V
  VOLTG(INC,0) = T
  ANAL = U*SIN(OMEGA*T)
  *IF,ANAL,LT,0,THEN            !SET TARGET TO ZERO IF ANALYTICAL SOLUTION
    TARGET(INC) = 0             ! IS NEGATIVE
  *ELSE
    TARGET(INC) = ANAL
  *ENDIF
*ENDDO
FINISH
*DIM,COEFF,,IFIN
*DIM,MODE,TABLE,IFIN
*DIM,ISYM,TABLE,IFIN
*DIM,THETA,TABLE,121
*DIM,CURVEI,TABLE,121                  ! CURVE INPUT TO PROGRAM
*DIM,CURVEO,TABLE,121

*VFILL,THETA(1),RAMP,0,3               ! THETA VALUES INCREMENT 3 DEGREES
*DO,INC,1,121,1
T=(INC-1)*3/360*2*PI/OMEGA
CURVEI(INC)=VOLTG(T,1)
*ENDDO
!     CALCULATE FOURIER COEFFICIENT
MODE(1)=0
ISYM(1)=1
ISTART=2
/COM
/COM *** *DO          *********************************************************
/COM
*DO,I,ISTART,IFIN,2
        MODE(I)=I/2                        ! FILL EVEN INDICIES OF {MODE}
        ISYM(I)=1
*ENDDO
/COM
/COM *** *ENDDO   WAS LAST COMMAND USED   *************************************
/COM
!                                       ! FILL ODD INDICIES OF {MODE}
ISTART=3
*DO,I,ISTART,IFIN,2
        MODE(I)=(I/2)-.5
        ISYM(I)=-1
*ENDDO
*MFOURI,FIT, COEFF(1),MODE(1),ISYM(1),THETA(1),CURVEI(1)
!
! CURVE WHICH WILL BE DEVELOPED FROM GENERATED COEFFICIENTS
!
*MFOURI,EVAL,COEFF(1),MODE(1),ISYM(1),THETA(1),CURVEO(1)


! PLOT CURVE
/TRIAD,OFF
/PLOPTS,LOGO,0
/PLOPTS,INFO,2
/PLOPTS,WP,0
/COLOR,CURVE,CBLU
/XRANGE,0,370
/YRANGE,0,140
/TSPEC,15
/TLAB,1,0.75,CAPACITANCE = 0
/TSPEC,4
/TLAB,1,0.7,BLUE->ANSYS
/TSPEC,1
```

```
/TLAB,1,0.65,RED->FOURIER
*VPLOT,THETA(1),CURVEI(1)            ! PLOT INPUT CURVE VERSUS THETA
/USER
/NOERASE
/COM OVERLAY THE OUTPUT CURVE ON THE INPUT CURVE
/COLOR,CURVE,RED
/COLOR,AXLAB,BLAC
/AXLAB,X,ANGLE IN DEGREE
/AXLAB,Y,VOLT
*VPLOT,THETA(1),CURVEO(1)    ! PLOT OUTPUT CURVE VERSUS THETA
/ERASE
!     ANALYTICAL FOURIER COEFFICIENT
RESUL(1,2)=2*U/PI/2             ! FIRST FOURIER COEFFICIENT = A0/2
ISTART=4
*DO,I,ISTART,IFINAL,4
RESUL(I,2)=-2*U/(PI*((I/2)**2-1))
*ENDDO
*DO,I,2,IFINAL,4
RESUL(I,2)=0
*ENDDO
RESUL(3,2)=U/2
ISTART=5
*DO,I,ISTART,IFINAL,2
RESUL(I,2)=0
*ENDDO
*DO,I,1,IFINAL
RESUL(I,1)=COEFF(I)
RESUL(I,3)=RESUL(I,2)/RESUL(I,1)
*ENDDO
*DO,CAP,1,2   ! START DO LOOP ON CAPACITANCE
PARSAV,ALL
/CLEAR,NOSTART
/COM    SECOND PART: CAPACITANCE VALUE
/COM
/PREP7
RESUME
PARRES,CHANGE
C1=CAPA(CAP)
TAU=TAUARR(1,CAP)
N,6,-0.65,0.4,0

ET,4,CIRCU124,2
R,4,C1
TYPE,4
REAL,4
E,4,6
!
! APPLY GROUND TO CIRCUIT
!
D,6,VOLT,0
ALLS
EPLOT
FINISH
!
! SOLVE NON-LINEAR CIRCUIT WITH T = 0 TO 0.025
! USING A TIME STEP OF 0.0001 FOR EACH ITERATION
!
/SOLU
ANTYPE,TRANS
OUTRES,ALL,ALL,
TIME,0.025
AUTOTS,-1
DELTIM,0.0001, , ,1
CNVTOL,VOLT,,0.0001,2,1.0E-6    !CONVERGANCE CRITERIA
/OUT,SCRATCH
SOLVE
/OUT
FINISH
/POST26
NSOL,2,4,VOLT,,
/COLOR,CURVE,BLUE,1
*IF,CAP,EQ,1,THEN
```

```
/TITLE,VM226, VLOAD WITH CAPACITANCE OF 1E-6F
*ENDIF
*IF,CAP,EQ,2,THEN
/TITLE,VM226, VLOAD WITH CAPACITANCE OF 10E-6F
*ENDIF
*IF,CAP,EQ,3,THEN
/TITLE,VM226, VLOAD WITH CAPACITANCE OF 1E-3F
*ENDIF
/AXLAB,Y,OUTPUT POTENTIAL (VOLT)
PLVAR,2,
/TITLE,VM226, FOURIER SERIES ANALYSIS OF A DIODE RECTIFIED CIRCUIT
!
! DETERMINE T0
!
T0=1/OMEGA*ATAN(1/(OMEGA*TAU))
!
! DETERMINE T0' : MACRO TO DO A BISECTION BETWEEN THE TWO CURVES
!
TINIT=2*PI/OMEGA/4
TFINAL=2*PI/OMEGA
V1=U*COS(OMEGA*TINIT)-U*COS(OMEGA*T0)*EXP(-1*(TINIT-T0)/TAU)
V2=U*COS(OMEGA*TFINAL)-U*COS(OMEGA*T0)*EXP(-1*(TFINAL-T0)/TAU)
V0=U*COS(OMEGA*T0)
*DO,I,1,10000
T3=(TINIT+TFINAL)/2
V3=U*COS(OMEGA*T3)-V0*EXP(-1*(T3-T0)/TAU)
ERROR=ABS(V1-V2)
*IF,ERROR,LT,EPS,THEN
*EXIT
*ENDIF
  *IF,V3,LT,0,THEN
      TINIT=T3
      V1=V3
     *ELSE
      TFINAL=T3
      V2=V3
  *ENDIF
*ENDDO

T01=T3
!
! SET UP TABLE ARRAYS TO DISPLAY OUTPUT RESULTS
!
*DIM,VOLTG,TABLE,250
*DIM,TARGET,ARRAY,250
*DO,INC,1,250,1
  T = INC*0.0001
  !TIME(INC) = T
  *GET,V,VARI,2,RTIME,T
  VOLTG(INC,1) = V
  VOLTG(INC,0) = T
  ANAL = U*SIN(OMEGA*T)
  *IF,T,LE,T0+PI/2/OMEGA,THEN   !SET TARGET TO ZERO IF ANALYTICAL SOLUTION
    TARGET(INC) = ANAL          ! IS NEGATIVE
  *ELSE
    *IF,T,LE,T01+PI/2/OMEGA,THEN
    TARGET(INC) = U*COS(OMEGA*T0)*EXP(-(T-T0-PI/2/OMEGA)/TAU)
    *ELSE
    *IF,T,LE,T0+PI/2/OMEGA+2*PI/OMEGA,THEN
    TARGET(INC) = ANAL
    *ELSE
    TARGET(INC) = U*COS(OMEGA*T0)*EXP(-(T-T0-PI/2/OMEGA-2*PI/OMEGA)/TAU)
    *ENDIF
    *ENDIF
  *ENDIF
*ENDDO
FINISH
*DIM,COEFF,,IFIN
*DIM,MODE,TABLE,IFIN
*DIM,ISYM,TABLE,IFIN
*DIM,THETA,TABLE,121
*DIM,CURVEI,TABLE,121                  ! CURVE INPUT TO PROGRAM
```

```
*VFILL,THETA(1),RAMP,0,3               ! THETA VALUES INCREMENT 3 DEGREES
*DO,INC,1,121,1
T=(INC-1)*3/360*2*PI/OMEGA+PI/2/OMEGA
CURVEI(INC)=VOLTG(T,1)
*ENDDO
!     CALCULATE FOURIER COEFFICIENT
MODE(1)=0
ISYM(1)=1
ISTART=2
/COM
*DO,I,ISTART,IFIN,2
        MODE(I)=I/2                        ! FILL EVEN INDICIES OF {MODE}
        ISYM(I)=1
*ENDDO
/COM
!                                       ! FILL ODD INDICIES OF {MODE}
ISTART=3
*DO,I,ISTART,IFIN,2
        MODE(I)=(I/2)-.5
        ISYM(I)=-1
*ENDDO
*MFOURI,FIT, COEFF(1),MODE(1),ISYM(1),THETA(1),CURVEI(1)

*IF,CAP,EQ,1,THEN
!
! CURVE WHICH WILL BE DEVELOPED FROM GENERATED COEFFICIENTS
!
*MFOURI,EVAL,COEFF(1),MODE(1),ISYM(1),THETA(1),CURVEO(1)


! PLOT CURVE
/TRIAD,OFF
/PLOPTS,LOGO,0
/PLOPTS,INFO,2
/PLOPTS,WP,0
/COLOR,CURVE,CBLU
/XRANGE,0,370
/YRANGE,0,140
/TSPEC,15
/TLAB,-0.25,0.75,CAPACITANCE = 1E-06 FARAD
/TSPEC,4
/TLAB,0,0.7,BLUE->ANSYS
/TSPEC,1
/TLAB,0,0.65,RED->FOURIER
*VPLOT,THETA(1),CURVEI(1)            ! PLOT INPUT CURVE VERSUS THETA
/USER
/NOERASE
/COM OVERLAY THE OUTPUT CURVE ON THE INPUT CURVE
/COLOR,CURVE,RED
/COLOR,AXLAB,BLAC
/AXLAB,X,ANGLE IN DEGREE
/AXLAB,Y,VOLT
*VPLOT,THETA(1),CURVEO(1)    ! PLOT OUTPUT CURVE VERSUS THETA
/ERASE
*ENDIF
!
!     ANALYTICAL FOURIER COEFFICIENT
!
*DIM,ANALY,ARRAY,IFINAL

! FIRST FOURIER COEFFICIENT = A0/2

A01=U/PI*(SIN(OMEGA*T0)-SIN(OMEGA*T01))
A02=2*V0*TAU*OMEGA/2/PI*(1-EXP(-(T01-T0)/TAU))

A0=1/2*(A01+A02)

!SECOND FOURIER COEFFICIENT = A1

A11=U*OMEGA/PI*((T0-T01+2*PI/OMEGA)/2)
A12=U/PI/4*(SIN(2*OMEGA*T0)-SIN(2*OMEGA*T01))
```

```
A13=COS(OMEGA*T0)-OMEGA*TAU*SIN(OMEGA*T0)
A14=(COS(OMEGA*T01)-OMEGA*TAU*SIN(OMEGA*T01))*EXP(-(T01-T0)/TAU)

A1=A11+A12+2*V0*TAU/(1+(OMEGA*TAU)**2)*60*(A13-A14)

! THIRD FOURIER COEFFICIENT = B1

B11=U/PI/2*(SIN(OMEGA*T0)*SIN(OMEGA*T0)-SIN(OMEGA*T01)*SIN(OMEGA*T01))
B12=SIN(OMEGA*T0)+OMEGA*TAU*COS(OMEGA*T0)
B13=(SIN(OMEGA*T01)+OMEGA*TAU*COS(OMEGA*T01))*EXP(-(T01-T0)/TAU)

B1=B11+2*V0*TAU/(1+(OMEGA*TAU)**2)*60*(B12-B13)

RESUL(1,3*CAP+2)=A0,A1,B1

*DO,I,1,IFINAL
RESUL(I,3*CAP+1)=COEFF(I)
RESUL(I,3*CAP+3)=RESUL(I,3*CAP+2)/RESUL(I,3*CAP+1)
*ENDDO
*ENDDO
!
! DISPLAY RESULTS
!
/OUT,vm226,vrt
/COM
/COM,------------------- VM226 RESULTS COMPARISON -------------------------
/COM
*VWRITE,TAUARR(1,1)
('                    TAU=0                       TAU=',F8.4)
/COM
/COM     Mechanical APDL    TARGET     RATIO  |  Mechanical APDL    TARGET    RATIO
/COM     ---------------------------------------------------------------------------
*VWRITE,COEFFOU(1),RESUL(1,1),RESUL(1,2),RESUL(1,3),RESUL(1,4),RESUL(1,5),RESUL(1,6)
(A5,'| ',3F11.4,' |',3F13.4)
/COM
/COM
/COM
*VWRITE,TAUARR(1,2)
('                    TAU=',F8.4)
/COM
/COM     Mechanical APDL    TARGET     RATIO  |
/COM     -----------------------------------------------------------------
*VWRITE,COEFFOU(1),RESUL(1,7),RESUL(1,8),RESUL(1,9)
(A5,'| ',3F11.4,' |',3F13.4)
/COM
/COM,------------------------------------------------------------------------
/OUT
FINISH
*LIST,vm226,vrt
```

VM227 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM227
/TITLE,VM227, Radiation Between Finite Coaxial Cylinders
/COM,* EXPECTED RESULTS:
! RESULTS DERIVED FROM MODEST, RADIATIVE HEAT TRANSFER, P.791
! VIEW FACTOR EVALUATIONS 44, 45
/COM,* FOR INSIDE CYLINDER-INSIDE CYLINDER VFAVG1=0
/COM,* FOR OUTSIDE CYLINDER-INSIDE CYLINDER VFAVG2=0.288
/COM,* FOR OUTSIDE CYLINDER-OUTSIDE CYLINDER VFAVG3=0.503
*SET,NDIV,20          ! ADJUSTED TO DETERMINE SPACING FOR PROBLEM.
*SET,L1,10
*SET,R1,1
*SET,R2,3
/PREP7
BLC4,0,0,R1,L1
BLC4,R2,0,R1,L1
```

```
ET,1,PLANE77                         !CREATE 2D THERMAL ELEMENTS
KEYOPT,1,1,0
KEYOPT,1,3,1
LESIZE,ALL,,,10
MSHAPE,0,2D
MSHKEY,0
AMESH,ALL
SFL,2,RDSF,1, ,1,
SFL,8,RDSF,1, ,1,
FINISH
/AUX12
STEF,0.119E-10                       !SET STEFAN-BOLTZMAN CONSTANT FOR MODEL
hemiopt,,,,,,,,,,,,,,,,,,0
TOFFST,100                           !SET TEMPERATURE OFFSET
RADOPT,0.1,0.1,2,1000,0.1,0.1  !SET RADIOSITY OPTIONS
SPCTEMP,1,0.E+00                     !SET TEMPERATURE FOR RADIATION TO SPACE
                                     !(NO RADIATION WILL APPEAR IN THIS MODEL)
HEMIOPT,1000,0.01  !SET HEMICUBE OPTIONS
V2DOPT,1,NDIV,0.E+00,200             !SET 2D CALCULATIONS TO AXISYMMETRIC
VFOPT,NEW
!VFCALC   !CALCULATE RADIOSITY VIEW FACTORS
ASEL,S, , ,       1
ESLA,S
CM,INSIDE,ELEM
ASEL,S, , ,       2
ESLA,S
CM,OUTSIDE,ELEM
CMPL
allsel
vfopt,read
VFQUERY,INSIDE,INSIDE !EXTRACT VIEW FACTOR FROM INTERIOR CYLINDER ELEMENTS DUE TO INTERIOR CYLINDER
*GET,VFAVG1,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
VFQUERY,OUTSIDE,INSIDE   !EXTRACT VIEW FACTOR FROM EXTERIOR CYLINDER ELEMENTS
                         !DUE TO INTERIOR CYLINDER
*GET,VFAVG2,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
VFQUERY,OUTSIDE,OUTSIDE  !EXTRACT VIEW FACTOR FROM EXTERIOR CYLINDER ELEMENTS
    !DUE TO EXTERIOR CYLINDER
*GET,VFAVG3,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
*status,parm
*DIM,VALUE,,3,3
*VFILL,VALUE(1,1),DATA,0,0.288,0.503
*VFILL,VALUE(1,2),DATA,VFAVG1,VFAVG2,VFAVG3
*VFILL,VALUE(1,3),DATA,0.000,VFAVG2/0.288,VFAVG3/0.503
*DIM,LABEL,CHAR,3,2
LABEL(1,1) = 'VF(1-1)','VF(2-1)','VF(2-2)'
/OUT,vm227,vrt
/COM,
/COM,------------------- VM227 RESULTS COMPARISON --------------
/COM,
/COM,               |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F8.3,'  ',F14.3,'   ',1F17.2)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm227,vrt
```

VM228 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM228
/TITLE,VM228, RADIATION BETWEEN INFINITE COAXIAL CYLINDERS
C*** USING PLANE35

TIN=1000
TOUT=100
/PREP7
```

```
ET,1,PLANE35   !CREATE 2D THERMAL ELEMENTS
MPTEMP,,,,,,,,   !SET MATERIAL PROPERTIES
MPTEMP,1,0
MPDATA,EX,1,,30E6
MPDATA,PRXY,1,,.27
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,DENS,1,,.27
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,KXX,1,,1
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,C,1,,.21
CYL4,0,0,0.5,,1
CYL4,0,0,4, ,5
MSHAPE,1,2D
MSHKEY,0
SMRT,4
AMES,ALL

LSEL,S,,,1,4
LSEL,A,,,13,16
SFL,ALL,RDSF,1, ,1,  !SET ALL FACING SURFACES TO EMISSIVITY 1
LSEL,S,,,9,12
DL,ALL, ,TEMP,TOUT,1  !APPLY UNIFORM TEMPERATURE TO EXTERIOR
LSEL,S,,,5,8
DL,ALL, ,TEMP,TIN,1  !APPLY UNIFORM TEMPERATURE TO INTERIOR
ASEL,S, , ,       1
ESLA,S
CM,INSIDE,ELEM
ASEL,S, , ,       2
ESLA,S
CM,OUTSIDE,ELEM
ALLSEL
FINI

/AUX12
STFCONST=0.119E-10
HEMIOPT,,,,,,,,,,,,,,,,,,,0
STEF,STFCONST    !SET STEFAN-BOLTZMAN CONSTANT FOR MODEL
TOFFST,0.E+00    !SET TEMPERATURE OFFSET
RADOPT,0.1,0.1,0.E+00,1000,0.1,0.1   !SET RADIOSITY OPTIONS
SPCTEMP,1,0.E+00   !SET TEMPERATURE FOR RADIATION TO SPACE

/OUT,SCRATCH
VFOPT,NEW
VFOPT,READ
VFQUERY,INSIDE,INSIDE   !EXTRACT VIEW FACTOR FROM INTERIOR CYLINDER ELEMENTS DUE TO INTERIOR CYLINDER
*GET,VFAVG1,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
VFQUERY,OUTSIDE,INSIDE   !EXTRACT VIEW FACTOR FROM EXTERIOR CYLINDER ELEMENTS DUE TO INTERIOR CYLINDER
*GET,VFAVG2,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
VFQUERY,OUTSIDE,OUTSIDE   !EXTRACT VIEW FACTOR FROM EXTERIOR CYLINDER ELEMENTS DUE TO EXTERIOR CYLINDER
*GET,VFAVG3,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
FINISH


/SOLU
TIME,1
DELTIM,0.5
SOLVE
FINI

/POST1
LSEL,S, , ,1,4
LSEL,A, , ,13,16
NSLL,S,1
*GET,TI,NODE,NODE(0,-1,0),TEMP   !INSIDE CYLINDER SURFACE TEMP
*GET,TO,NODE,NODE(0,-4,0),TEMP   !OUTSIDE CYLINDER SURFACE TEMP
*GET,HFI,NODE,NODE(0,-1,0),TF,SUM   !INSIDE CYLINDER HEAT FLUX
*GET,HFO,NODE,NODE(0,-4,0),TF,SUM   !OUTSIDE CYLINDER HEAT FLUX
```

```
HFIEXP=ABS(TO**4-TI**4)*STFCONST/1
HFOEXP=ABS(TO**4-TI**4)*STFCONST/4

HFIERR=(HFI/HFIEXP)
HFOERR=(HFO/HFOEXP)
/OUT,
*STATUS,PARM
*DIM,VALUE,,5,3
*VFILL,VALUE(1,1),DATA,0,0.25,0.75,HFIEXP,HFOEXP
*VFILL,VALUE(1,2),DATA,VFAVG1,VFAVG2,VFAVG3,HFI,HFO
*VFILL,VALUE(1,3),DATA,0.000,VFAVG2/0.25,VFAVG3/0.75,HFIERR,HFOERR
*DIM,LABEL,CHAR,10,2
LABEL(1,1) = 'VF(1-1)','VF(2-1)','VF(2-2)','HFINSIDE','HFOUTSIDE'
SAVE,TABLE_1
FINI
/CLEAR,NOSTART

!******************************************************************************

/TITLE,VM228, RADIATION BETWEEN INFINITE COAXIAL CYLINDERS
C*** USING PLANE35 AND SURF251


TIN=1000
TOUT=100
/PREP7
ET,1,PLANE35   !CREATE 2D THERMAL ELEMENTS
MPTEMP,,,,,,,,    !SET MATERIAL PROPERTIES
MPTEMP,1,0
MPDATA,EX,1,,30E6
MPDATA,PRXY,1,,.27
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,DENS,1,,.27
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,KXX,1,,1
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,C,1,,.21
CYL4,0,0,0.5,,1
CYL4,0,0,4, ,5
MSHAPE,1,2D
MSHKEY,0
SMRT,4
AMES,ALL
LSEL,S,,,1,4
LSEL,A,,,13,16
SFL,ALL,RDSF,1, ,1,  !SET ALL FACING SURFACES TO EMISSIVITY 1
LSEL,S,,,9,12
DL,ALL, ,TEMP,TOUT,1  !APPLY UNIFORM TEMPERATURE TO EXTERIOR
LSEL,S,,,5,8
DL,ALL, ,TEMP,TIN,1  !APPLY UNIFORM TEMPERATURE TO INTERIOR
ASEL,S, , ,       1
ESLA,S
CM,INSIDE,ELEM
ASEL,S, , ,       2
ESLA,S
CM,OUTSIDE,ELEM
ALLSEL
RDEC,,0.5
RSURF
FINI

/AUX12
STFCONST=0.119E-10
HEMIOPT,,,,,,,,,,,,,,,,,,,0
STEF,STFCONST    !SET STEFAN-BOLTZMAN CONSTANT FOR MODEL
TOFFST,0.E+00    !SET TEMPERATURE OFFSET
RADOPT,0.1,0.1,0.E+00,1000,0.1,0.1   !SET RADIOSITY OPTIONS
SPCTEMP,1,0.E+00   !SET TEMPERATURE FOR RADIATION TO SPACE
```

```
VFCALC     !CALCULATE RADIOSITY VIEW FACTORS
NSEL,S,LOC,X,-1,1
NSEL,R,LOC,Y,-1,1
ESLN,S,1
ESEL,R,TYPE,,2
CM,INRS,ELEM
NSEL,S,LOC,X,-1,1
NSEL,R,LOC,Y,-1,1
NSEL,INVERT
ESLN,S,1
ESEL,R,TYPE,,2
CM,OUTRS,ELEM
ALLSEL

/OUT,SCRATCH
VFQUERY,INRS,INRS   !EXTRACT VIEW FACTOR FROM INTERIOR CYLINDER ELEMENTS DUE TO INTERIOR CYLINDER
*GET,VFAVG1,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
VFQUERY,OUTRS,INRS   !EXTRACT VIEW FACTOR FROM EXTERIOR CYLINDER ELEMENTS DUE TO INTERIOR CYLINDER
*GET,VFAVG2,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
VFQUERY,OUTRS,OUTRS   !EXTRACT VIEW FACTOR FROM EXTERIOR CYLINDER ELEMENTS DUE TO EXTERIOR CYLINDER
*GET,VFAVG3,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
ALLSEL
FINI

/SOLU
TIME,1
DELTIM,0.5
SOLVE
FINI

/POST1
LSEL,S, , ,1,4
LSEL,A, , ,13,16
NSLL,S,1
*GET,TI,NODE,NODE(0,-1,0),TEMP   !INSIDE CYLINDER SURFACE TEMP
*GET,TO,NODE,NODE(0,-4,0),TEMP   !OUTSIDE CYLINDER SURFACE TEMP
*GET,HFI,NODE,NODE(0,-1,0),TF,SUM   !INSIDE CYLINDER HEAT FLUX
*GET,HFO,NODE,NODE(0,-4,0),TF,SUM   !OUTSIDE CYLINDER HEAT FLUX

HFIEXP=ABS(TO**4-TI**4)*STFCONST/1 ! CALCULATE EXPECTED RADIATION FLUX
HFOEXP=ABS(TO**4-TI**4)*STFCONST/4

HFIERR=(HFI/HFIEXP)
HFOERR=(HFO/HFOEXP)
/OUT,
*STATUS,PARM
*DIM,VALUE,,5,3
*VFILL,VALUE(1,1),DATA,0,0.25,0.75,HFIEXP,HFOEXP
*VFILL,VALUE(1,2),DATA,VFAVG1,VFAVG2,VFAVG3,HFI,HFO
*VFILL,VALUE(1,3),DATA,0.000,VFAVG2/0.25,VFAVG3/0.75,HFIERR,HFOERR
*DIM,LABEL,CHAR,10,2
LABEL(1,1) = 'VF(1-1)','VF(2-1)','VF(2-2)','HFINSIDE','HFOUTSIDE'
SAVE,TABLE_2
FINI
/CLEAR,NOSTART

!*****************************************************************************
!*****************************************************************************
!*****************************************************************************

/TITLE,VM228, RADIATION BETWEEN INFINITE COAXIAL CYLINDERS
C*** USING SOLID90

TIN=1000
TOUT=100
/PREP7
ET,1,SOLID90   !CREATE 3D THERMAL ELEMENTS
MPTEMP,,,,,,,,   !SET MATERIAL PROPERTIES
MPTEMP,1,0
MPDATA,EX,1,,30E6
MPDATA,PRXY,1,,.27
MPTEMP,,,,,,,,
```

```
MPTEMP,1,0
MPDATA,DENS,1,,.21
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,KXX,1,,1
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,C,1,,.21
CYL4,0,0,0.5,0,1,90,1
CYL4,0,0,0.5,90,1,180,1
CYL4,0,0,0.5,180,1,270,1
CYL4,0,0,0.5,270,1,360,1
NUMMRG,KP
MSHAPE,0,3D
MSHKEY,1
ESIZE,0.325
VMESH,ALL
ALLSEL,ALL

CYL4,0,0,4,0,5,90,1
CYL4,0,0,4,90,5,180,1
CYL4,0,0,4,180,5,270,1
CYL4,0,0,4,270,5,360,1
NUMMRG,KP
MSHAPE,0,3D
MSHKEY,1
ESIZE,0.325
VMESH,5,8,1
ALLSEL,ALL

CSYS,1
NSEL,S,LOC,X,0.5
D,ALL,TEMP,TIN    !APPLY UNIFORM TEMPERATURE TO INTERIOR
NSEL,S,LOC,X,1
NSEL,A,LOC,X,4
SF,ALL,RDSF,1,1
NSEL,S,LOC,X,5
D,ALL,TEMP,TOUT   !APPLY UNIFORM TEMPERATURE TO EXTERIOR
CSYS,0
ALLSEL,ALL
VSEL,S, , , 1,4,1,
ESLV,S
CM,INSIDE,ELEM
VSEL,S, , , 5,8,1
ESLV,S
CM,OUTSIDE,ELEM
ALLSEL
FINI

/AUX12
STFCONST=0.119E-10
HEMIOPT,,,,,,,,,,,,,,,,,,0
HEMIOPT,100
STEF,STFCONST    !SET STEFAN-BOLTZMAN CONSTANT FOR MODEL
TOFFST,0    !SET TEMPERATURE OFFSET
RADOPT,0.1,0.1,0,1000,0.1,0.1    !SET RADIOSITY OPTIONS
SPCTEMP,1,0    !SET TEMPERATURE FOR RADIATION TO SPACE

/OUT,SCRATCH
VFSM,,1,2
VFOPT,NEW
VFOPT,READ
VFQUERY,INSIDE,INSIDE   !EXTRACT VIEW FACTOR FROM INTERIOR CYLINDER ELEMENTS DUE TO INTERIOR CYLINDER
*GET,VFAVG1,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
VFQUERY,OUTSIDE,INSIDE   !EXTRACT VIEW FACTOR FROM EXTERIOR CYLINDER ELEMENTS DUE TO INTERIOR CYLINDER
*GET,VFAVG2,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
VFQUERY,OUTSIDE,OUTSIDE   !EXTRACT VIEW FACTOR FROM EXTERIOR CYLINDER ELEMENTS DUE TO EXTERIOR CYLINDER
*GET,VFAVG3,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
FINISH

/SOLU
TIME,1
```

```
DELTIM,0.5
SOLVE
FINI

/POST1
ASEL,S, , ,3,21,6
ASEL,A, , ,24,42,6
NSLA,S,1
*GET,TI,NODE,NODE(0,-1,0),TEMP   !INSIDE CYLINDER SURFACE TEMP
*GET,TO,NODE,NODE(0,-4,0),TEMP   !OUTSIDE CYLINDER SURFACE TEMP
*GET,HFI,NODE,NODE(0,-1,0),TF,SUM   !INSIDE CYLINDER HEAT FLUX
*GET,HFO,NODE,NODE(0,-4,0),TF,SUM   !OUTSIDE CYLINDER HEAT FLUX

HFIEXP=ABS(TO**4-TI**4)*STFCONST/1
HFOEXP=ABS(TO**4-TI**4)*STFCONST/4

HFIERR=(HFI/HFIEXP)
HFOERR=(HFO/HFOEXP)
/OUT,
*STATUS,PARM
*DIM,VALUE,,5,3
*VFILL,VALUE(1,1),DATA,0,0.25,0.75,HFIEXP,HFOEXP
*VFILL,VALUE(1,2),DATA,VFAVG1,VFAVG2,VFAVG3,HFI,HFO
*VFILL,VALUE(1,3),DATA,0.000,VFAVG2/0.25,VFAVG3/0.75,HFIERR,HFOERR
*DIM,LABEL,CHAR,10,2
LABEL(1,1) = 'VF(1-1)','VF(2-1)','VF(2-2)','HFINSIDE','HFOUTSIDE'
SAVE,TABLE_3
FINI
/CLEAR,NOSTART

!*******************************************************************************


/TITLE,VM228, RADIATION BETWEEN INFINITE COAXIAL CYLINDERS
C*** USING SOLID90 AND SURF252


TIN=1000
TOUT=100
/PREP7
ET,1,SOLID90   !CREATE 3D THERMAL ELEMENTS
MPTEMP,,,,,,,,   !SET MATERIAL PROPERTIES
MPTEMP,1,0
MPDATA,EX,1,,30E6
MPDATA,PRXY,1,,.27
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,DENS,1,,.21
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,KXX,1,,1
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,C,1,,.21


CYL4,0,0,0.5,0,1,90,1
CYL4,0,0,0.5,90,1,180,1
CYL4,0,0,0.5,180,1,270,1
CYL4,0,0,0.5,270,1,360,1
NUMMRG,KP
MSHAPE,0,3D
MSHKEY,1
ESIZE,0.325
VMESH,ALL
ALLSEL,ALL

CYL4,0,0,4,0,5,90,1
CYL4,0,0,4,90,5,180,1
CYL4,0,0,4,180,5,270,1
CYL4,0,0,4,270,5,360,1
NUMMRG,KP
```

```
MSHAPE,0,3D
MSHKEY,1
ESIZE,0.325
VMESH,5,8,1
ALLSEL,ALL


CSYS,1
NSEL,S,LOC,X,0.5
D,ALL,TEMP,TIN    !APPLY UNIFORM TEMPERATURE TO INTERIOR
NSEL,S,LOC,X,1
NSEL,A,LOC,X,4
SF,ALL,RDSF,1,1
NSEL,S,LOC,X,5
D,ALL,TEMP,TOUT   !APPLY UNIFORM TEMPERATURE TO EXTERIOR
CSYS,0
ALLSEL,ALL
VSEL,S, , , 1,4,1
ESLV,S
CM,INSIDE,ELEM
VSEL,S, , , 5,8,1
ESLV,S
CM,OUTSIDE,ELEM
ALLSEL
RDEC,,0.5,OPTI
RSURF
FINI

/AUX12
STFCONST=0.119E-10
HEMIOPT,,,,,,,,,,,,,,,,,0
STEF,STFCONST    !SET STEFAN-BOLTZMAN CONSTANT FOR MODEL
TOFFST,0.E+00    !SET TEMPERATURE OFFSET
RADOPT,0.1,0.1,0.E+00,1000,0.1,0.1 !SET RADIOSITY OPTIONS
SPCTEMP,1,0.E+00
     !SET TEMPERATURE FOR RADIATION TO SPACE
VFSM,,1,2
VFCALC     !CALCULATE RADIOSITY VIEW FACTORS
NSEL,S,LOC,X,-1.0000,1.0000
NSEL,R,LOC,Y,-1.00000,1.00000
ESLN,S,1
ESEL,R,TYPE,,2
CM,INRS,ELEM
NSEL,S,LOC,X,-1.00000,1.00000
NSEL,R,LOC,Y,-1.00000,1.00000
NSEL,INVERT
ESLN,S,1
ESEL,R,TYPE,,2
CM,OUTRS,ELEM
ALLSEL

/OUT,SCRATCH
VFQUERY,INRS,INRS   !EXTRACT VIEW FACTOR FROM INTERIOR CYLINDER ELEMENTS DUE TO INTERIOR CYLINDER
*GET,VFAVG1,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
VFQUERY,OUTRS,INRS   !EXTRACT VIEW FACTOR FROM EXTERIOR CYLINDER ELEMENTS DUE TO INTERIOR CYLINDER
*GET,VFAVG2,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
VFQUERY,OUTRS,OUTRS   !EXTRACT VIEW FACTOR FROM EXTERIOR CYLINDER ELEMENTS DUE TO EXTERIOR CYLINDER
*GET,VFAVG3,RAD,,VFAVG   !DETERMINE VIEW FACTOR FOR ENTIRE SURFACE
FINISH

/SOLU
TIME,1
DELTIM,0.5
SOLVE
FINI

/POST1
ASEL,S, , ,3,21,6
ASEL,A, , ,24,42,6
NSLA,S,1
*GET,TI,NODE,NODE(0,-1,0),TEMP   !INSIDE CYLINDER SURFACE TEMP
*GET,TO,NODE,NODE(0,-4,0),TEMP   !OUTSIDE CYLINDER SURFACE TEMP
```

```
*GET,HFI,NODE,NODE(0,-1,0),TF,SUM   !INSIDE CYLINDER HEAT FLUX
*GET,HFO,NODE,NODE(0,-4,0),TF,SUM   !OUTSIDE CYLINDER HEAT FLUX
HFIEXP=ABS(TO**4-TI**4)*STFCONST/1 ! CALCULATE EXPECTED RADIATION FLUX
HFOEXP=ABS(TO**4-TI**4)*STFCONST/4

HFIERR=(HFI/HFIEXP)
HFOERR=(HFO/HFOEXP)
/OUT,
*STATUS,PARM
*DIM,VALUE,,5,3
*VFILL,VALUE(1,1),DATA,0,0.25,0.75,HFIEXP,HFOEXP
*VFILL,VALUE(1,2),DATA,VFAVG1,VFAVG2,VFAVG3,HFI,HFO
*VFILL,VALUE(1,3),DATA,0.000,VFAVG2/0.25,VFAVG3/0.75,HFIERR,HFOERR
*DIM,LABEL,CHAR,10,2
LABEL(1,1) = 'VF(1-1)','VF(2-1)','VF(2-2)','HFINSIDE','HFOUTSIDE'
SAVE,TABLE_4

/NOPR
/OUT,vm228,vrt
/COM,
/COM,------------------- VM228 RESULTS COMPARISON --------------
/COM,
/COM,                   |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,
RESUME,TABLE_1
/COM,USING PLANE35
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F8.3,'  ',F14.3,'   ',1F17.2)
/COM,
RESUME,TABLE_2
/COM,USING PLANE35 WITH RSURF (SURF251)
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F8.3,'  ',F14.3,'   ',1F17.2)
/COM,
RESUME,TABLE_3
/COM,USING SOLID90
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F8.3,'  ',F14.3,'   ',1F17.2)
/COM,
RESUME,TABLE_4
/COM,USING SOLID90 WITH RSURF (SURF252)
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F8.3,'  ',F14.3,'   ',1F17.2)
/COM,
/COM,-----------------------------------------------------------
FINISH
/OUT,
*LIST,vm228,vrt
```

VM229 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM229
/TITLE,VM229, FRICTION HEATING OF A SLIDING BLOCK
/COM, REF: WRIGGER AND MIEHE, COMP METH APPL ENGR 113, PP301-319
/PREP7
ET,1,PLANE13,4       ! 2-D COUPLED-FIELD SOLID
RECT,,5,,1.25
RECT,,1.25,1.25,2.5
LESIZE,ALL,0.25, , ,1,1
AMESH,ALL
UIMP,1,EX, , ,70000,
UIMP,1,DENS, , ,2.7E-9,
```

```
UIMP,1,ALPX, , ,23.86E-6,
UIMP,1,NUXY, , ,0.3,
UIMP,1,MU, , ,0.2,
UIMP,1,KXX, , ,150,
UIMP,1,C, , ,9E8,
TOFFSET,460
TUNIF = 0.00
ET,2,TARGE169      ! 2-D TARGET SEGMENT
ET,3,CONTA171      ! 2-D SURFACE-TO-SURFACE CONTACT
KEYOPT,3,1,1
ASEL,S,,,1
NSLA,S,1
NSEL,R,LOC,Y,1.25
R,1
TYPE,2
ESURF
ALLSEL
ASEL,S,,,2
NSLA,S,1
NSEL,R,LOC,Y,1.25
TYPE,3
ESURF
ALLSEL,ALL
*DIM,PRE,TABLE,2,1,1,TIME
SFL,7,PRES, %PRE%
PRE(1,0,1) = 0
PRE(1,1,1) = 10
PRE(2,0,1) = 10
PRE(2,1,1) = 10
ALLSEL
SAVE
FINISH
/SOLU
NSUB,1
ASEL,S,,,2
NSLA,S,1
NSEL,R,LOC,X,1.25
D,ALL,UX,3.75
ALLSEL
ASEL,S,,,1
NSLA,S,1
D,ALL,UX,0
D,ALL,UY,0
ALLSEL
ANTYPE,TRANS
TIMINT,OFF,STRUC
TINTP,,,,1.0
NLGEOM,ON
TIME,3.75E-3
AUTO,ON
NSUB,100,10000,100
OUTRES,ALL,-10
NROP,UNSYM
/OUT,SCRATCH
SOLVE
TIME,1
AUTO,ON
TINTP,,,,1.0
NSUB,100,10000,10
OUTRES,ALL,LAST
SOLVE
/OUT
FINI
/POST1
ALLSEL
PLNSOL,TEMP
/COM  ****************************************************************
/COM   TEST FROM COMP. METH. APPL. MECH. ENG. VOL.113,P301,1994
/COM   SOLUTION TEMPERATURE = 1.235
/COM  ****************************************************************
ESEL,S,ENAME,,CONTA171
NSLE
```

```
PRNSOL,TEMP
*GET,TEMP1,NODE,130,TEMP
/COM  *****************************************************************
/COM   SOLUTION TEMPERATURE = 0.309
/COM  *****************************************************************
ESEL,S,ENAME,,TARGE169
NSLE
PRNSOL,TEMP
*GET,TEMP2,NODE,40,TEMP
*DIM,LABEL,CHAR,2
*DIM,VALUE,,2,3
LABEL(1) = 'TEMP1','TEMP2 '
*VFILL,VALUE(1,1),DATA,1.235,0.309
*VFILL,VALUE(1,2),DATA,TEMP1,TEMP2
*VFILL,VALUE(1,3),DATA,ABS(TEMP1 / 1.235) ,ABS(TEMP2 / 0.309)
SAVE,TABLE_1
FINISH

!* SOLVE USING K(2)=3 OF CONTA171
RESUME
/PREP7
KEYOPT,3,4,2      ! ON NODAL POINT - NORMAL TO TARGET SURFACE
KEYOPT,3,2,4      ! PURE LAGRANGE MULTIPLIER ON CONTACT NORMAL AND TANGENT
FINISH
/SOLU
NSUB,1
ASEL,S,,,2
NSLA,S,1
NSEL,R,LOC,X,1.25
D,ALL,UX,3.75
ALLSEL
ASEL,S,,,1
NSLA,S,1
D,ALL,UX,0
D,ALL,UY,0
ALLSEL
ANTYPE,TRANS
TIMINT,OFF,STRUC
TINTP,,,,1.0
NLGEOM,ON
TIME,3.75E-3
AUTO,ON
NSUB,100,10000,100
OUTRES,ALL,-10
NROP,UNSYM
/OUT,SCRATCH
SOLVE
TIME,1
AUTO,ON
TINTP,,,,1.0
NSUB,100,10000,10
OUTRES,ALL,LAST
SOLVE
/OUT
FINI
/POST1
ALLSEL
PLNSOL,TEMP
/COM  *****************************************************************
/COM   TEST FROM COMP. METH. APPL. MECH. ENG. VOL.113,P301,1994
/COM   SOLUTION TEMPERATURE = 1.235
/COM  *****************************************************************
ESEL,S,ENAME,,CONTA171
NSLE
PRNSOL,TEMP
*GET,TEMP1,NODE,130,TEMP
/COM  *****************************************************************
/COM   SOLUTION TEMPERATURE = 0.309
/COM  *****************************************************************
ESEL,S,ENAME,,TARGE169
NSLE
PRNSOL,TEMP
```

```
*GET,TEMP2,NODE,40,TEMP
*DIM,LABEL,CHAR,2
*DIM,VALUE,,2,3
LABEL(1) = 'TEMP1','TEMP2 '
*VFILL,VALUE(1,1),DATA,1.235,0.309
*VFILL,VALUE(1,2),DATA,TEMP1,TEMP2
*VFILL,VALUE(1,3),DATA,ABS(TEMP1 / 1.235) ,ABS(TEMP2 / 0.309)
SAVE,TABLE_2
FINI
/COM,
/COM, -------------------------
/COM,  USING PLANE 223 ELEMENT
/COM, ------------------------
/CLEAR,NOSTART
/PREP7
ET,1,PLANE223,11       ! 2-D STRUCTURAL-THERMAL SOLID
RECT,,5,,1.25
RECT,,1.25,1.25,2.5
LESIZE,ALL,0.25, , ,1,1
AMESH,ALL
UIMP,1,EX, , ,70000,
UIMP,1,DENS, , ,2.7E-9,
UIMP,1,ALPX, , ,23.86E-6,
UIMP,1,NUXY, , ,0.3,
UIMP,1,MU, , ,0.2,
UIMP,1,KXX, , ,150,
UIMP,1,C, , ,9E8,
TOFFSET,460
TUNIF = 0.00
ET,2,TARGE169        ! 2-D TARGET SEGMENT
ET,3,CONTA172        ! 2-D SURFACE-TO-SURFACE CONTACT
KEYOPT,3,1,1
ASEL,S,,,1
NSLA,S,1
NSEL,R,LOC,Y,1.25
R,1
TYPE,2
ESURF
ALLSEL
ASEL,S,,,2
NSLA,S,1
NSEL,R,LOC,Y,1.25
TYPE,3
ESURF
ALLSEL,ALL
*DIM,PRE,TABLE,2,1,1,TIME
SFL,7,PRES, %PRE%
PRE(1,0,1) = 0
PRE(1,1,1) = 10
PRE(2,0,1) = 10
PRE(2,1,1) = 10
ALLSEL
SAVE
FINISH

/SOLU
NSUB,1
ASEL,S,,,2
NSLA,S,1
NSEL,R,LOC,X,1.25
D,ALL,UX,3.75
ALLSEL
ASEL,S,,,1
NSLA,S,1
D,ALL,UX,0
D,ALL,UY,0
ALLSEL
ANTYPE,TRANS
TIMINT,OFF,STRUC
TINTP,,,,1.0
NLGEOM,ON
TIME,3.75E-3
```

```
AUTO,ON
NSUB,100,10000,100
OUTRES,ALL,-10
NROP,UNSYM
/OUT,SCRATCH
SOLVE
TIME,1
AUTO,ON
TINTP,,,,1.0
NSUB,100,10000,10
OUTRES,ALL,LAST
SOLVE
/OUT
FINI
/POST1
ALLSEL
PLNSOL,TEMP
/COM  ****************************************************************
/COM   TEST FROM COMP. METH. APPL. MECH. ENG. VOL.113,P301,1994
/COM   SOLUTION TEMPERATURE = 1.235
/COM  ****************************************************************
ESEL,S,ENAME,,CONTA172
NSLE
PRNSOL,TEMP
*GET,TEMP1,NODE,NODE(0.5,1.25,0),TEMP
/COM  ****************************************************************
/COM   SOLUTION TEMPERATURE = 0.309
/COM  ****************************************************************
ESEL,S,ENAME,,TARGE169
NSLE
PRNSOL,TEMP
*GET,TEMP2,NODE,NODE(1.75,1.25,0),TEMP
*DIM,LABEL,CHAR,2
*DIM,VALUE,,2,3
LABEL(1) = 'TEMP1','TEMP2 '
*VFILL,VALUE(1,1),DATA,1.235,0.309
*VFILL,VALUE(1,2),DATA,TEMP1,TEMP2
*VFILL,VALUE(1,3),DATA,ABS(TEMP1 / 1.235) ,ABS(TEMP2 / 0.309)
SAVE,TABLE_3
/COM
RESUME,TABLE_1
/OUT,vm229,vrt
/COM
/COM,------------------- VM229 RESULTS COMPARISON ---------------------
/COM,
/COM,        |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM, ------------
/COM,   PLANE13
/COM, ------------
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'  ',F7.4,'      ',F14.4,'     ',1F15.3)
/COM,
/COM,
/OUT,
RESUME,TABLE_2
/OUT,vm229,vrt,,APPEND
/COM,
/COM, ---------------------------------
/COM,  RESULTS USING K(2)=3 OF CONTA171
/COM, ---------------------------------
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'  ',F7.4,'      ',F14.4,'     ',1F15.3)
/COM,
/COM,
/OUT,
RESUME,TABLE_3
/OUT,vm229,vrt,,APPEND
/COM,
/COM, ------------
```

```
/COM,   PLANE223
/COM, ------------
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'  ',F7.4,'      ',F14.4,'     ',1F15.3)
/COM,
/COM,
/COM,----------------------------------------------------------------
FINISH
/OUT,
*LIST,vm229,vrt
FINI
```

VM230 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM230
/TITLE, VM230, Analytical Verification of PDS Results
/COM,Probability Concepts in Engineering Planing and Design, Volume 1
/COM, A Ang, H-S Tang, Wiley, 1975
/COM,
! ---------  make loop file  --------
*CREATE,VM230,INP
X1  = 3.0
X2  = 3.0
X3  = 3.0
X4  = 3.0
X5  = 3.0
Y   = (X1*X2*X3)/(X4*X5)
LOGY= log(Y)
*END
!
! ---------  run loop file  --------
/inp,VM230,INP
!
! ---------  define PDS parameters  --------
LMEAN1 = 1.1
LMEAN2 = 1.2
LMEAN3 = 1.3
LMEAN4 = 1.4
LMEAN5 = 1.5
LDEVI1 = 0.1
LDEVI2 = 0.2
LDEVI3 = 0.3
LDEVI4 = 0.4
LDEVI5 = 0.5
!
! ---------  PDS Definitions  --------
/PDS
PDANL,VM230,INP                  ! Define analysis file
PDVAR,X1,LOG2,LMEAN1,LDEVI1,0.0      ! Define X1 as Log-normal
PDPLOT,X1
PDVAR,X2,LOG2,LMEAN2,LDEVI2,0.0      ! Define X2 as Log-normal
PDVAR,X3,LOG2,LMEAN3,LDEVI3,0.0      ! Define X3 as Log-normal
PDVAR,X4,LOG2,LMEAN4,LDEVI4,0.0      ! Define X4 as Log-normal
PDVAR,X5,LOG2,LMEAN5,LDEVI5,0.0      ! Define X5 as Log-normal
PDVAR,Y,RESP                   ! Define Y as response parameter
PDVAR,LOGY,RESP                      ! Define LOGY as response parameter
!
! ---------  PDS Methods - LHS  --------
/COM, *************************************
/COM, Define and run latin hypercube samples
/COM, *************************************
PDMETH,MCS,LHS                 ! Set LHS as method
PDLHS,2000,1,RAND,,ALL,,,,INIT ! Define LHS options
PDEXEC,LHSRUN,SER              ! Execute LHS runs
!
! ---------  PDS POST-PROCESSING  --------
```

```
/COM,
/COM, **************************************
/COM, Analytical results
/COM, **************************************
LMEANY = LMEAN1 + LMEAN2 + LMEAN3 - LMEAN4 - LMEAN5
LDEVIY = 0.0
LDEVIY = LDEVIY + LDEVI1*LDEVI1
LDEVIY = LDEVIY + LDEVI2*LDEVI2
LDEVIY = LDEVIY + LDEVI3*LDEVI3
LDEVIY = LDEVIY + LDEVI4*LDEVI4
LDEVIY = LDEVIY + LDEVI5*LDEVI5
LDEVIY = SQRT(LDEVIY)
MEANY  = exp(LMEANY + 0.5*LDEVIY*LDEVIY)
HLP1  = exp(2.0*LMEANY + LDEVIY*LDEVIY)
HLP2  = exp(LDEVIY*LDEVIY) - 1.0
STDEVY = sqrt( HLP1*HLP2 )
*MSG,NOTE,LMEANY
The logarithmic mean of Y is      %g
*MSG,NOTE,LDEVIY
The logarithmic deviation of Y is %g
*MSG,NOTE,MEANY
The mean value of Y is            %g
*MSG,NOTE,STDEVY
The standard deviation of Y is    %g
/COM,
/COM, **************************************
/COM, Plot the CDF for LHS
/COM, **************************************
PDCDF,LHSRUN,Y,LOGN
PDCDF,LHSRUN,LOGY
FINISH
```

VM231 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vm231
/TITLE, VM231, PIEZOCERAMIC RECTANGLE UNDER PURE BENDING LOAD
/COM,   REF: PARTON,V.Z., KUDRYAVTSEV, B.A. AND SENIK,N.A. (1989)
/COM,   "MECHANICS OF PIEZOELECTRIC MATERIALS" IN "APPLIED MECHANICS:
/COM,   SOVIET REVIEW.", Vol.2: ELECTROMAGNETOELASTICITY,
/COM,   G.K.MIKHAILOV AND V.Z.PARTON (EDS.), HEMISPHERE PUBL. CORP., P.28
/NOPR
/COM,
/COM,       GEOMETRY DATA
/COM,
L=1.E-3                         ! PLATE LENGTH,m
H=0.5E-3                        ! PLATE THICKNESS,m
/COM,
/COM,       LOAD DATA
/COM,
SIG1=-20E9                      ! PRESSURE SLOPE, N/m**3

/PREP7
/COM,
/COM,       MATERTIAL PROPERTIES FOR THE FINITE ELEMENT SOLUTION:
/COM,       CONSTITUTIVE MATRICES FOR PZT-4 (POLAR AXIS ALONG Y)
/COM,
/COM,   [c11 c13 c12  0  0  0 ]        [ 0 e31  0 ]      [ep11  0    0  ]
/COM,   [c13 c33 c13  0  0  0 ]        [ 0 e33  0 ]      [  0  ep33  0  ]
/COM,   [c12 c13 c11  0  0  0 ]        [ 0 e31  0 ]      [  0   0   ep11]
/COM,   [ 0   0   0  c44 0  0 ]        [e15 0   0 ]
/COM,   [ 0   0   0   0 c44 0 ]        [ 0  0  e15]
/COM,   [ 0   0   0   0  0 c66]        [ 0  0   0 ]
/COM,
MP,PERX,1,728.5                 ! PERMITTIVITY AT CONSTANT STRAIN
MP,PERY,1,634.7
MP,PERZ,1,728.5
TB,ANEL,1                       ! ANISOTROPIC ELASTIC STIFFNESS
```

```
TBDA,1,13.9E10,7.43E10,7.78E10  ! c11,c13,c12
TBDA,7,11.5E10,7.43E10          ! c33,c13
TBDA,12,13.9E10                 ! c11
TBDA,16,2.56E10                 ! c44
TBDA,19,2.56E10                 ! c44
TBDA,21,3.06E10                 ! c66
TB,PIEZ,1                       ! PIEZOELECTRIC STRESS COEFFICIENTS
TBDA,2,-5.2                     ! e31
TBDA,5,15.1                     ! e33
TBDA,8,-5.2                     ! e31
TBDA,10,12.7                    ! e15
TBDA,15,12.7                    ! e15
/COM,
/COM,      FINITE ELEMENT MODEL
/COM,
ANTYPE,STATIC
ET,1,PLANE13,7,0,2,0                 ! PLANE13 (UX,UY,VOLT) PLANE STRESS
N,1,0,0
N,2,L,0
N,3,L,H
N,4,0,H
E,1,2,3,4
NSEL,S,LOC,X,0                  ! DEFINE STRUCTURAL B.C.
DSYM,SYMM,X
NSEL,R,LOC,Y,0
D,ALL,UY,0
D,ALL,VOLT,0
NSEL,S,LOC,Y,0
DSYM,ASYMM,Y
NSEL,ALL
SFGRAD,PRES,0,Y,0,-SIG1         ! SPECIFY PRESSURE LOAD GRADIENT
NSEL,S,LOC,X,L
SF,ALL,PRES,0                   ! APPLY PRESSURE LOAD
NSEL,ALL
FINISH
/SOLVE
OUTPR,,LAST
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
PRNSOL,S,COMP
PRNSOL,EPEL,COMP
PRNSOL,EF,COMP
PRNSOL,D,COMP
!
!       MATERTIAL PROPERTIES FOR THE ANALYTICAL SOLUTION
!
S11=12.3093E-12                 ! ELASTIC COMPLIANCE COEFFICIENTS
S13=-5.34878E-12
D31=-1.23816E-10                ! PIEZOELECTRIC STRAIN COEFFICIENTS
D33= 2.91296E-10
EP33=11.3063E-9                 ! PERMITTIVITY COEFFICIENT AT CONSTANT STRESS
K31=D31*D31/(S11*EP33)          ! ELECTROMECHANICAL COEFFICIENTS
KS=D33*D31/(S13*EP33)
!
!      ANALYTICAL SOLUTION AT NODE 3
!
UX3=S11*(1-K31)*SIG1*NX(3)*NY(3)
UY3=S13*(1-KS)*SIG1*NY(3)**2/2
UY3=UY3-S11*(1-K31)*SIG1*NX(3)**2/2
VOLT3=D31*SIG1*NY(3)**2/(2*EP33)
SX3=SIG1*NY(3)
EFY3=-D31*SIG1*NY(3)/EP33
!
!      RESULT OUTPUT
!
*GET,SX,NODE,3,S,X
*GET,EFY,NODE,3,EF,Y
*DIM,LABEL,CHAR,5,3
*DIM,VALUE,ARRAY,5,3
```

```
LABEL(1,1)='UX, ','UY, ','VOLT, ','SX, ','EFZ, '
LABEL(1,2)='(um)  ','(um)  ','(V) ','(N/mm^2)','(V/mm)'
*VFILL,VALUE(1,1),DATA,UX3*1E6,UY3*1E6,VOLT3,SX3*1E-6,EFY3*1E-3
*VFILL,VALUE(1,2),DATA,UX(3)*1E6,UY(3)*1E6,VOLT(3),SX*1E-6,EFY*1E-3
*VFILL,VALUE(1,3),DATA,ABS(UX(3)/UX3),ABS(UY(3)/UY3),ABS(VOLT(3)/VOLT3)
*VFILL,VALUE(4,3),DATA,ABS(SX/SX3),ABS(EFY/EFY3)
SAVE,table_1
FINISH
/CLEAR,NOSTART

/COM,
/COM,  SOLVING THE PROBLEM USING PLANE223 ELEMENT
/COM,

/NOPR
/COM,
/COM,      GEOMETRY DATA
/COM,
L=1.E-3                         ! PLATE LENGTH,m
H=0.5E-3                        ! PLATE THICKNESS,m
/COM,
/COM,      LOAD DATA
/COM,
SIG1=-20E9                      ! PRESSURE SLOPE, N/m**3

/PREP7
/COM,
/COM,      MATERTIAL PROPERTIES FOR THE FINITE ELEMENT SOLUTION:
/COM,      CONSTITUTIVE MATRICES FOR PZT-4 (POLAR AXIS ALONG Y)
/COM,
/COM,   [c11 c13 c12  0  0  0 ]        [ 0 e31  0 ]      [ep11  0    0  ]
/COM,   [c13 c33 c13  0  0  0 ]        [ 0 e33  0 ]      [  0  ep33  0  ]
/COM,   [c12 c13 c11  0  0  0 ]        [ 0 e31  0 ]      [  0   0   ep11]
/COM,   [ 0   0   0  c44 0  0 ]        [e15 0   0 ]
/COM,   [ 0   0   0   0 c44 0 ]        [ 0  0  e15]
/COM,   [ 0   0   0   0  0 c66]        [ 0  0   0 ]
/COM,
MP,PERX,1,728.5                 ! PERMITTIVITY AT CONSTANT STRAIN
MP,PERY,1,634.7
MP,PERZ,1,728.5
TB,ANEL,1                       ! ANISOTROPIC ELASTIC STIFFNESS
TBDA,1,13.9E10,7.43E10,7.78E10  ! c11,c13,c12
TBDA,7,11.5E10,7.43E10          ! c33,c13
TBDA,12,13.9E10                 ! c11
TBDA,16,2.56E10                 ! c44
TBDA,19,2.56E10                 ! c44
TBDA,21,3.06E10                 ! c66
TB,PIEZ,1                       ! PIEZOELECTRIC STRESS COEFFICIENTS
TBDA,2,-5.2                     ! e31
TBDA,5,15.1                     ! e33
TBDA,8,-5.2                     ! e31
TBDA,10,12.7                    ! e15
TBDA,15,12.7                    ! e15
/COM,
/COM,     FINITE ELEMENT MODEL
/COM,
ANTYPE,STATIC
ET,1,PLANE223,1001,,0                ! PLANE223 (UX,UY,VOLT) PLANE STRESS
N,1,0,0
N,2,L,0
N,3,L,H
N,4,0,H
E,1,2,3,4
EMID    ! MIDSIDE NODES ON
NSEL,S,LOC,X,0                  ! DEFINE STRUCTURAL B.C.
DSYM,SYMM,X
NSEL,R,LOC,Y,0
D,ALL,UY,0
D,ALL,VOLT,0
NSEL,S,LOC,Y,0
DSYM,ASYMM,Y
NSEL,ALL
```

```
SFGRAD,PRES,0,Y,0,-SIG1         ! SPECIFY PRESSURE LOAD GRADIENT
NSEL,S,LOC,X,L
SF,ALL,PRES,0                   ! APPLY PRESSURE LOAD
NSEL,ALL
FINISH
/SOLVE
OUTPR,,LAST
/OUT,SCRATCH
SOLVE
FINISH
/POST1
/OUT,
PRNSOL,S,COMP
PRNSOL,EPEL,COMP
PRNSOL,EF,COMP
PRNSOL,D,COMP
!
!       MATERTIAL PROPERTIES FOR THE ANALYTICAL SOLUTION
!
S11=12.3093E-12                 ! ELASTIC COMPLIANCE COEFFICIENTS
S13=-5.34878E-12
D31=-1.23816E-10                ! PIEZOELECTRIC STRAIN COEFFICIENTS
D33= 2.91296E-10
EP33=11.3063E-9                 ! PERMITTIVITY COEFFICIENT AT CONSTANT STRESS
K31=D31*D31/(S11*EP33)          ! ELECTROMECHANICAL COEFFICIENTS
KS=D33*D31/(S13*EP33)
!
!      ANALYTICAL SOLUTION AT NODE 3
!
UX3=S11*(1-K31)*SIG1*NX(3)*NY(3)
UY3=S13*(1-KS)*SIG1*NY(3)**2/2
UY3=UY3-S11*(1-K31)*SIG1*NX(3)**2/2
VOLT3=D31*SIG1*NY(3)**2/(2*EP33)
SX3=SIG1*NY(3)
EFY3=-D31*SIG1*NY(3)/EP33
!
!      RESULT OUTPUT
!
*GET,SX,NODE,3,S,X
*GET,EFY,NODE,3,EF,Y
*DIM,LABEL,CHAR,5,3
*DIM,VALUE,ARRAY,5,3
LABEL(1,1)='UX, ','UY, ','VOLT, ','SX, ','EFZ, '
LABEL(1,2)='(um)  ','(um)  ','(V) ','(N/mm^2)','(V/mm)'
*VFILL,VALUE(1,1),DATA,UX3*1E6,UY3*1E6,VOLT3,SX3*1E-6,EFY3*1E-3
*VFILL,VALUE(1,2),DATA,UX(3)*1E6,UY(3)*1E6,VOLT(3),SX*1E-6,EFY*1E-3
*VFILL,VALUE(1,3),DATA,ABS(UX(3)/UX3),ABS(UY(3)/UY3),ABS(VOLT(3)/VOLT3)
*VFILL,VALUE(4,3),DATA,ABS(SX/SX3),ABS(EFY/EFY3)
SAVE,table_2
FINISH
RESUME,table_1
/COM
/out,vm231,vrt
/COM
/COM,---------------------- VM231 RESULTS COMPARISON ------------------
/COM,
/COM,     NODE 3       |    TARGET    |    Mechanical APDL    |   RATIO
/COM,
/COM,
/COM,  USING PLANE13 ELEMENTS
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1x,A8,A8,'     ',F9.3,'     ',F14.3,'     ',F17.3)
/COM,
/COM,
/NOPR,
RESUME,table_2
/GOPR
/COM,
/COM, USING PLANE223 ELEMENTS
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
```

```
(1x,A8,A8,'     ',F9.3,'     ',F14.3,'     ',F17.3)
/COM,
/COM,------------------------------------------------------------------
/out,
*list,vm231,vrt
FINISH
/delete,table_1
/delete,table_2
```

VM232 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vm232
/title,VM232, PDS Response Surface Study
/COM, Verification Example using the Weibull and the Exponential
/COM, distribution. We use MCS and RSM to compare with the
/COM, analytical results
!
! ---------  make loop file  --------
*CREATE,PDVERIFY1,INP
XEXPO  = 1.0
XWEIB  = 1.0
COEF1  = 1.0
COEF2  = 0.1
LAMBDA = 0.5
Y = COEF1*XWEIB*XWEIB - COEF2*XEXPO
*END
!
! ---------  run loop file  --------
/INP,PDVERIFY1,INP
!
! ---------  PDS Definitions  --------
/PDS
PDANL,PDVERIFY1,INP            ! Define analysis file
! ----------- Exponential ---------------------------------
PDVAR,XEXPO,EXPO,LAMBDA,0.0    ! Define XEXPO as exponential
PDPLOT,XEXPO
! -----------WEIBULL ---------------------------------
PDVAR,XWEIB,WEIB,2.0,1.0,0.0   ! Define XWEIB as Weibull
PDPLOT,XWEIB
! ----------- OUTPUT ---------------------------------
PDVAR,Y,RESP                   ! Define Y as response parameter
!
! ---------  PDS Methods - LHS  --------
/COM, **************************************
/COM, Define and run latin hypercube samples
/COM, **************************************
PDMETH,MCS,LHS                 ! Set LHS as method
PDLHS,1000,1,RAND,,ALL,,,,INIT ! Define LHS options
PDEXEC,LHSRUN,SER              ! Execute LHS runs
!
! ---------  PDS Methods - CCD  --------
/COM, **************************************
/COM, Define and run central composit design
/COM, **************************************
PDMETH,RSM,CCD                 ! Set CCD as method
PDEXEC,CCDRUN,SER              ! Execute CCD runs
!
! ---------  PDS FIT RESPONSE SURFACE  --------
/COM, *********************************
/COM, Fit response surface for CCD runs
/COM, *********************************
RSFIT,CCDFIT,CCDRUN,Y,QUAX,NONE,,FSR,0.95
!
! ---------  PDS SAMPLES ON RESPONSE SURFACE  --------
/COM, ***************************************
/COM, Perform MCS samples on response surface
/COM, ***************************************
```

```
RSSIMS,CCDFIT,50000,INIT
/DIST,1,1.05
/VIEW,1,-1,-1,1
RSPLOT,CCDFIT,Y,XEXPO,XWEIB,3D,
!
! ---------  PDS POST-PROCESSING  --------
/COM,
/COM, **************************************
/COM, Analytical probability that "Y<0.0"
/COM, **************************************
PROB = 1.0/( (LAMBDA*COEF1/COEF2) + 1.0)
/COM,
/COM, **************************************
/COM, Probability that "Y<0.0" for LHS
/COM, **************************************
PDPROB,LHSRUN,Y,LT,0.0
/COM,
/COM, **************************************
/COM, Probability that "Y<0.0" for CCD
/COM, **************************************
PDPROB,CCDFIT,Y,LT,0.0
Fini
```

VM233 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM233
/TITLE,VM233, STATIC FORCE COMPUTATION OF A 3D SOLENOID ACTUATOR
/COM, REFERENCE: ANALYSIS OF BENCHMARK PROBLEM TEAM20 WITH VARIOUS
/COM,            FORMULATION, PROCEEDINGS OF TEAM WORKSHOP,COMPUMAF RIO
/COM,       PG 18-20,1997.
/COM,       IEEE TRANS. ON MAG, VOL. 34. NO. 5. PG 2481-84,1998
/COM,       IEEE TRANS. ON MAG, VOL. 35. NO. 3. PG 1406-84,1998
/COM,       ANALYSIS SOLUTIONS, VOL.1. ISSUE 2,WINTER 1997-98,PG 10-11.
/COM
/PREP7
/NOPR
/OUT,SCRATCH
ET,1,SOLID98,10
MP,MURX,1,1
MP,MURX,4,1

TB,BH,2,,40
TBPT,,355,.7
,,405,.8
,,470,.9
,,555,1.
,,673,1.1
,,836,1.2
,,1065,1.3
,,1220,1.35
,,1420,1.4
,,1720,1.45
,,2130,1.5
,,2670,1.55
,,3480,1.6
,,4500,1.65
,,5950,1.70
,,7650,1.75
,,10100,1.8
,,13000,1.85
,,15900,1.9
,,21100,1.95
,,26300,2.
,,32900,2.05
,,42700,2.1
,,61700,2.15
,,84300,2.2
```

```
,,110000,2.25
,,135000,2.3
,,200000,2.41
,,400000,2.69
,,800000,3.22

TBCOPY,BH,2,3
XINF=100.
YINF=100.
ZINF=175.
TCUR=5000      ! CURRENT
N,1,0,0,75/1000              ! PATH FOR POST PROCESSING
N,2,63.5/1000,0,75/1000
BLOCK,0,63.5,0,25/2,0,25     ! POLE
BLOCK,38.5,63.5,0,25/2,25,125
BLOCK,13.5,63.5,0,25/2,125,150
VGLUE,ALL
BLOCK,0,12.5,0,5,26.5,125     ! ARMATURE
BLOCK,0,13,0,5.5,26,(125+.5)    ! AIR REGION
VOVLAP,1,2
NUMCMP,VOLU

BLOCK,39/2,75/2,0,14.5,(25+1.7),(125-1.7)
BLOCK,0,14.5,39/2,75/2,(25+1.7),(125-1.7)
LOCAL,11,1,14.5,14.5,25+1.7
WPCSYS,11
CYL4,,,5,0,23,90,(125-1.7)-(25+1.7)
VGLUE,6,8
NUMCMP,VOLU

CSYS,0
WPCSYS,0
CYL4,,,0,0,100,90,175
VOVLAP,ALL
NUMCMP,ALL

VSEL,S,VOLU,,1
VATT,3,1,1
VSEL,S,VOLU,,3,5
VATT,2,1,1
VSEL,S,VOLU,,6
VATT,4,2,1                 ! COIL +Y
VSEL,S,VOLU,,7
VATT,4,4,1                 ! COIL -X
VSEL,S,VOLU,,8
ESYS,11
VATT,4,3,1                 ! COIL +Y THETA

ALLSEL,ALL
SMRT,10
MSHAPE,1,3D
MSHMID,1
MSHKEY,0
VMESH,ALL

ESEL,S,MAT,,3          ! ARMATURE
CM,ARM,ELEM
FMAGBC,'ARM'
ALLSEL,ALL

VLSCALE,ALL,,,.001,.001,.001,,0,1      ! SCALE TO METERS

LOCAL,12,0,0,0,75/1000
WPCSYS,-1
RACE,.0285,.0285,.014,TCUR,.018,.0966     ! CREATE COIL
SAVE
FINISH
/SOLU
NSLE,S
*GET,NMIN,NODE,,NUM,MIN
D,NMIN,MAG,0
NSEL,ALL
```

```
EQSLV,JCG
MAGSOLV,3,,,,,1
FINISH

/POST1
/OUT
*MSG,NOTE,TCUR
%/RESULTS FOR CURRENT = %G (MULTIPLY ORCE BY 4 FOR SYMMETRY)
FMAGSUM,'ARM'
*GET,FVWZ,SSUM, ,ITEM,FVW_Z       ! EXTRACT VIRTUAL FORCE Z DIRECTION
FZ = 4*FVWZ                       ! SCALE FORCE FOR SYMMETRY
ESEL,S,MAT,,2,3
NSLE,S
NSEL,A,NODE,,1,2
LPATH,1,2
PDEF,BZ,B,Z
PRPATH,BZ
*GET,BZPOLE,PATH,0,LAST,BZ        ! EXTRACT BZ AT POLE
*GET,BZARM,PATH,0,MAX,BZ          ! EXTRACT BZ at ARM
*DIM,LABEL,CHAR,3
*DIM,VALUE,,3,3
LABEL(1) = 'FVW(Z) ','POLE(BZ) ','ARM(BZ) '
*VFILL,VALUE(1,1),DATA,80.1,0.46,2.05
*VFILL,VALUE(1,3),DATA,ABS(FZ/80.1),ABS(BZPOLE/0.46),ABS(BZARM/2.05)
*VFILL,VALUE(1,2),DATA,ABS(FZ),ABS(BZPOLE),ABS(BZARM)
/OUT,vm233,vrt,,APPEND
/COM
/COM,------------------- VM233 RESULTS COMPARISON ---------------------
/COM,
/COM,           |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'    ',F7.3,'     ',F14.3,'       ',1F15.3)
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vm233,vrt
```

VM234 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vm234
/TITLE, VM234, CYCLIC LOADING ON RUBBER BLOCK
/COM, REFERENCE: HOLZAPFEL, GERHARD A. " ON LARGE STRAIN VISCOELASTICITY:
/COM,       CONTINUUM, FORMULATION AND FINITE ELEMENT APPLICATIONS TO
/COM,       ELASTOMERIC STRUCTURES", INTERNATIONAL JOURNAL FOR NUMERICAL
/COM,       METHODS, VOL. 39, PG: 3903-3926,1996.
/COM
/OUT,SCRATCH
/PREP7
MP,EX,1,422500.0
TB,HYPER,1, ,3,OGDEN,     ! HYPER ODGEN MATERIAL MODEL
TBDATA,1,6.3E+05*3.0,1.3,1200*3.0,5,-10000*3.0,-2
TB,PRONY,1, ,2,SHEAR
TBDATA,,1.0/3.0,0.40,1.0/3.0,0.20,
N,1, 0.0, 0.0, 0.0
N,2, 0.1, 0.0, 0.0
N,3, 0.1, 0.1, 0.0
N,4, 0.0, 0.1, 0.0
N,5, 0.0, 0.0, 0.1
N,6, 0.1, 0.0, 0.1
N,7, 0.1, 0.1, 0.1
N,8, 0.0, 0.1, 0.1
ET,1,SOLID185,,,,                     ! SOLID 185 ELEMENT
KEYOPT,1,6,1
E,1,2,3,4,5,6,7,8
FINISH
```

```
/SOLUTION
/OUT,SCRATCH
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,ALL
*DIM,AMPL,ARRAY,4                ! AMPLITUDE VECTOR DEFINITION
AMPL(1)=0.01
AMPL(2)=0.02
AMPL(3)=0.03
AMPL(4)=0.04
*DIM,SOLTIME,ARRAY,161           ! TIME VECTOR DEFINITION
SOLTIME(1)=0.0
*DO,I,2,161,1
  SOLTIME(I)=SOLTIME(I-1)+0.1
*ENDDO
*DIM,BC_X,ARRAY,161              ! DISPLACEMENT VECTOR DEFINITION
J=1
*DO,I,1,161,1
  BC_X(I)=AMPL(J)*SIN(SOLTIME(I)/2.0*3.141592654)
  *IF,SOLTIME(I),EQ,(4.0*J),THEN
    J=J+1
  *ENDIF
*ENDDO
NLGEOM,ON                        ! SOLUTION CONTROLS
CNVT,U,1,1.0e-8
CNVT,F,1,1.0e-6
OUTRES,ALL,ALL
TIME,1E-07
DELTIM,1E-07,1E-08,5E-08
/OUT,SCRATCH
SOLVE
*DO,I,2,161,1
  D,2,UX,BC_X(I)
  D,3,UX,BC_X(I)
  D,6,UX,BC_X(I)
  D,7,UX,BC_X(I)
  TIME,SOLTIME(I)
  NSUB,5,10,5
  SOLVE
*ENDDO
TIME,20.0
SOLVE
FINISH
/POST26
/OUT,
ESOL,2,1,7,S,X
ESOL,3,1,7,EPEL,X
NSOL,4,7,U,X
PRVAR,2,3,4
PLVAR,2
PLVAR,3
PLVAR,4
*GET,SIG16,VARI,2,RTIME,16
*GET,SIG20,VARI,2,RTIME,20
*DIM,LABEL,CHAR,2
*DIM,VALUE,,2,3
LABEL(1) = 'SIG16,PA','SIG20,PA'
*VFILL,VALUE(1,1),DATA,601300.0,0.0
*VFILL,VALUE(1,2),DATA,ABS(SIG16),ABS(SIG20)
*VFILL,VALUE(1,3),DATA,ABS(SIG16/601300),0.0
/OUT,vm234,vrt
/COM
/COM,------------------- VM234 RESULTS COMPARISON -------------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.1,'  ',F14.1,'   ',1F15.3)
```

```
/COM,-------------------------------------------------------------------
/OUT
FINISH
*LIST,vm234,vrt
```

VM235 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM235
/PREP7
/TITLE,VM235, FREQUENCY RESPONSE OF A PRE-STRESSED BEAM
/COM,
/COM, REFERENCE: " FORMULAS FOR NATURAL FREQUENCY AND MODE SHAPES"
/COM,    PG:144, EQUATION 8-20, R.D. BLEVINS, VAN NOSTRAND
/COM,    REINHOLD CO. 1979
/COM
L=150                       ! BEAM LENGTH (MICROMETERS)
B=4                         ! BEAM WIDTH
H=2                         ! BEAM HEIGTH
I=B*H**3/12                 ! BEAM MOMENT OF INERTIA
E=169E3                     ! MODULUS  ( MICRO NEWTONS/MICROMETER**2)
P=10                        ! MICRO NEWTONS
DENS=2332E-18               ! DENSITY (KG/MICROMETER**3)
M=DENS*B*H                  ! MASS/LENGTH (KG/MICROMETER)
PER0=8.85E-6                ! FREE-SPACE PERMITTIVITY (PF/MICROMETER)
PLATEA=100                  ! CAPACITOR PLATE AREA (MICROMETER**2)

GAPI=1                      ! INITIAL GAP (MICROMETERS)
GAP=GAPI-P*L/E/B/H          ! APPROX DEFLECTED GAP (IGNORE CAP STIFFNESS)  (MICROMETER)
C3=PER0*PLATEA              ! TRANDUCER REAL CONTANT
C3P=C3/(GAP**2)             ! DERIVITIVE OF C3
C3PP=2*C3/(GAP**3)          ! SECOND DERIVITIVE OF C3
VLT=SQRT(2*P/C3P)           ! APPLIED VOLTAGE TO PLATE
KUU=C3PP*VLT**2/2           ! GAP STIFFNESS
KBEAM=E*PLATEA/L            ! BEAM STIFFNESS (NOTE: GAP STIFFNESS ASSUMED << BEAM STIFFNESS)
UX2=P*L/B/H/E               ! DESIRED DEFLECTION

*DIM,FREQ,,5                ! ARRAY PARAMETER FOR BEAM FREQUENCY
*DIM,PFREQ,,5               ! ARRAY PARMETER FOR BEAM PRE-STRESSED FREQUENCY

PI=4*ATAN(1)
!! CALCULATE ANALYTICAL SOLUTION !!
*DO,J,1,5
LAMDA=J*PI
LAMDAP2=LAMDA**2*SQRT((1 + P*L**2/(E*I*LAMDA**2)))
LAMDAP=SQRT(LAMDAP2)
FREQ(J) = LAMDA**2/(2*PI*L**2)*SQRT(E*I/M)
PFREQ(J) = LAMDAP**2/(2*PI*L**2)*SQRT(E*I/M)
*ENDDO

ET,1,188     ! BEAM188
KEYOPT,1,3,3
SECT,1,BEAM,ASEC   ! BEAM PROPERTIES
SECD,B*H,I,,I,,1
MP,EX,1,E     ! SET EX TO E
MP,DENS,1,DENS    ! SET DENSITY TO DENS
MP,PRXY,,0.3    ! SET PRXY TO 0.3
ET,2,126     ! TRANS126 FOR ELEMENT 2
C3=PER0*PLATEA    ! SET INPUT CAPACITANCE FOR TRANSDUCER
R,2,0,0,1,0,C3
RMORE,C3
N,1,-10      ! SETUP MODEL NODES
N,2,0
N,22,L
FILL
TYPE,2
REAL,2
E,1,2      ! CREATE TRANSDUCER
```

```
TYPE,1
SECN,1
E,2,3      ! CREATE BEAM
*REPEAT,20,1,1
NSEL,S,LOC,X,-10
NSEL,A,LOC,X,L
D,ALL,UX,0,,,,UY
NSEL,S,LOC,X,0
D,ALL,UY,0
D,ALL,VOLT,VLT
IC,ALL,VOLT,VLT
NSEL,S,LOC,X,-10
D,ALL,VOLT,0
NSEL,ALL
ESEL,S,TYPE,,1
NSLE
D,ALL,UZ,,,,,ROTX,ROTY
ALLS,ALL
EPLOT      ! PLOT ELEMENTS
FINISH
/out,scratch
/SOLUTION
ANTYP,STATIC
PSTRES,ON     ! PRESTRESSED MODAL ANALYSIS
SOLVE
FINISH
/out
/POST1
FINISH

/SOLUTION
ANTYP,MODAL
MODOPT,UNSYM,3      ! EXTRACT 3 MODES
MXPAND
PSTRES,ON
SOLVE
FINISH
/POST1
/NOPR      ! SETUP RESULTS TABLE DATA
SET,1,1
PLDISP,1     ! PLOT MODE SHAPE
*GET,FP1,ACTIVE,,SET,FREQ
SET,1,2
PLDISP,1     ! PLOT MODE SHAPE
*GET,FP2,ACTIVE,,SET,FREQ
SET,1,3
PLDISP,1     ! PLOT MODE SHAPE
*GET,FP3,ACTIVE,,SET,FREQ
FINISH

PFREQ1=PFREQ(1)
PFREQ2=PFREQ(2)
PFREQ3=PFREQ(3)

*DIM,LABEL,CHAR,3
*DIM,VALUE,,3,3
LABEL(1) = 'FREQ 1' , 'FREQ 2' , 'FREQ 3'
*VFILL,VALUE(1,1),DATA,PFREQ1,PFREQ2,PFREQ3
*VFILL,VALUE(1,2),DATA,ABS(FP1),ABS(FP2),ABS(FP3)
*VFILL,VALUE(1,3),DATA,ABS(PFREQ1/FP1),ABS(PFREQ2/FP2),ABS(PFREQ3/FP3)
/OUT,vm235,vrt
/COM
/COM,------------------- VM235 RESULTS COMPARISON ---------------------
/COM,
/COM,         |    TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F11.3,'  ',F15.3,'   ',1F15.3)
/COM,-----------------------------------------------------------------
/OUT
/GOPR
FINISH
```

```
*LIST,vm235,vrt
```

VM236 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM236
/TITLE,VM236,HYSTERESIS LOOP VERIFICATION OF A CLAMPED BEAM
/COM, ------------------------------------------------------
/COM,         2D BEAM UNDER ELECTROSTATIC LOAD
/COM,         --------------------------------
/COM,   COMPARE WITH 3D MODEL FROM THE PAPER:
/COM,   J.R.GILBERT, G.K.ANANTHASURESH, S.D.SENTURIA, (MIT)
/COM,   "3D MODELLING OF CONTACT PROBLEMS AND HYSTERESIS IN
/COM,    COUPLED ELECTRO-MECHANICS", MEMS'96, PP. 127-132.
/COM,
/COM,                      3d MODEL:
/COM,   BEAM IS CLAMPED AT EITHER END, SUSPENDED 0.7UM OVER
/COM,   A GROUND PLANE WITH CONTACT STOP AT 0.1UM ABOVE THE
/COM,   GROUND PLANE.   BEAM DIMENSIONS AND MATERIAL PROPERTIES:
/COM,   LENGTH BL=80UM, WIDTH WB=10UM, HEIGHT BH=.5UM, E=169GPA, MU=0.25
/COM,   INITIAL GAP: GAP=0.7UM , FINISHING GAP GFI=0.1UM
/COM,   MAXIMUM DISPLACEMENT IS 0.6UM (GAP-GFI)
/COM,
/COM, VALUE OF THE PULL-IN VOLTAGE: 18v
/COM, BOTH PULL-IN AND RELEASE BEHAVIORS ARE MODELED (HYSTERESIS LOOP).

!-------------- Control parameters ----------------------
*DIM,UU,ARRAY,5   ! RESULTS ARRAY

VLTG1 = 11.0   ! BIAS VOLTAGE 1
VLTG2 = 14.5   ! BIAS VOLTAGE 2
VLTG  = 18.0      ! PULL-IN VOLTAGE

ESIZE=0.5        ! ELEMENT MESH SIZE

!---------------- Geometry parameters ---------------

BL=40    ! BEAM LENGTH
BH=.5    ! BEAM HEIGHT
GAP=.7    ! MAXIMUM GAP
GAP0=.6    ! AIR GAP
EPS0=8.854E-6

!---------------------- Model ---------------

/PREP7

EMUNIT,EPZRO,EPS0

ET,1,182,3,,2
ET,2,223,1001,,,1
ET,3,178,,1

MP,EX,1,169E3
MP,NUXY,1,0.25
MP,PERX,2,1
MP,EX,2,1E-5
MP,NUXY,2,0.0
MP,MU,3,0

R,1,C0,EPS0
R,2,-1690

RECT,,BL,GAP,GAP+BH
RECT,,BL,,GAP+BH
AOVLAP,ALL
NUMMRG,KP
```

```
ASEL,S,LOC,Y,GAP+BH/2
AATT,1,,1
ASEL,INVERT
AATT,2,1,2
CM,AREA1,AREA

ALLS
ESIZE,ESIZE
MSHMID,2

ASEL,S,MAT,,1
MSHAPE,0,2
MSHKEY,2
AMESH,ALL

ASEL,S,MAT,,2
MSHAPE,1,2
MSHKEY,1
AMESH,ALL

TYPE,3    ! GAP ELEMENT MESH
MAT,3
REAL,2
*GET,NOMAX,NODE,0,NUM,MAX
KN=BL/ESIZE
K8=NOMAX+1
XL=0
*DO,I8,1,KN+1
 N52=K8
 N53=N52+1
 N,N52,XL,GAP
 N,N53,XL,GAP-GAP0
 E,N53,N52
 K8=K8+2
 XL=XL+ESIZE
*ENDDO
NUMMRG,NODE
ALLS

!--------------- BOUNDARY CONDITIONS -----------------

ESEL,S,TYPE,,2
NSLE,S
NSEL,R,LOC,Y,GAP
CM,BNODE,NODE

NSLE,S
NSEL,R,LOC,Y,0
D,ALL,VOLT,0   ! GROUND

ALLSEL,ALL
NSEL,S,LOC,X,0       !  FIX LEFT END
NSEL,A,LOC,Y,0       !  FIX BOTTOM
D,ALL,UX,0
D,ALL,UY,0

ALLSEL,ALL
NSEL,S,LOC,X,BL      !  SYMMETRY LINE
D,ALL,UX,0

ESEL,S,TYPE,,3
NSLE,S
NSEL,R,LOC,Y,GAP-GAP0    ! FIX GAP ELEMENTS
D,ALL,ALL

ALLSEL,ALL
D,ALL,UZ   ! CONSTRAIN CONTACT178 ELEMENTS IN Z
FINISH
SAVE

!/PNUM,TYPE,1
/AUTO,1
```

```
EPLOT

!------------------ Loading (below pull-in) ---------------------

/SOLU

EQSLV,SPARSE
CNVTOL,F,1,1.0E-4
AUTOTS,ON
NSUBST,1
OUTRES,ALL,ALL
NEQIT,50
NLGEOM,ON

CMSEL,S,BNODE   ! BIAS 1
D,ALL,VOLT,VLTG1
ALLSEL,ALL

/OUT,SCRATCH
SOLVE

CMSEL,S,BNODE   ! BIAS 2
D,ALL,VOLT,VLTG2
ALLSEL,ALL

SOLVE
FINISH

!---------------------------- POSTPROCESSING ------------------
/POST26
NSEL,S,,,2
NSOL,2,2,U,Y,UY    ! Displacement at the tip
NSOL,3,2,VOLT,,VOLT  ! Voltage at the tip
/OUT,
PRVAR,VOLT,UY
*GET,UU(1),VARI,2,RTIME,1
*GET,UU(2),VARI,2,RTIME,2
ALLSEL,ALL
FINISH

!------------------- Pull-in  -------------------------------------
!--- 2-Step Solution:  - moving beam to close-to-pull-in position
!---   - applying pull-in voltage and releasing BC
!--------------------------------------------------------------------

!-------- Step 1 (displacement) ------------

/SOLU
ANTYPE
ICDELE
IC,ALL,ALL,0.0
CMSEL,S,BNODE
DDELE,ALL,VOLT
ALLSEL,ALL


NSEL,S,LOC,X,BL   ! DISPLACEMENT bc
NSEL,R,LOC,Y,GAP
D,ALL,UY,-0.65
ALLSEL,ALL

NSUBST,1
/OUT,SCRATCH
SOLVE
FINISH
SAVE

/POST1
SET,LIST
/OUT,
ALLSEL,ALL
*GET,NNODE,NODE,,NUM,MAX
```

```
*DIM,ICUX,,NNODE
*DIM,ICUY,,NNODE

SET,LAST
*DO,I,1,NNODE
ICUX(I)=UX(I)
ICUY(I)=UY(I)
*ENDDO
FINISH

!-------- Step 2 (voltage) ------------
/SOLU

ALLSEL,ALL
DDELE,ALL   ! DELETE OLD bc

ESEL,S,TYPE,,2
NSLE,S
NSEL,R,LOC,Y,0
D,ALL,VOLT,0

ALLSEL,ALL
NSEL,S,LOC,X,0       !  FIX ONE END
NSEL,A,LOC,Y,0       !  FIX BOTTOM
D,ALL,UX,0
D,ALL,UY,0

ALLSEL,ALL
NSEL,S,LOC,X,BL      !  SYMMETRY LINE
D,ALL,UX,0
NSEL,ALL

ESEL,S,TYPE,,3
NSLE,S
NSEL,R,LOC,Y,GAP-GAP0    ! FIX GAP ELEMENTS
D,ALL,ALL

ALLSEL,ALL

CMSEL,S,BNODE   ! APPLY PULL-IN VOLTAGE
IC,ALL,VOLT,VLTG
D,ALL,VOLT,VLTG
ALLSEL,ALL

*DO,I,1,NNODE   ! NEW INITIAL CONDIITONS
 ICUQX=ICUX(I)
 ICUQY=ICUY(I)
 IC,I,UX,ICUQX
 IC,I,UY,ICUQY
*ENDDO

OUTRES,ALL,ALL
AUTOTS,ON
NSUBS,1
D,ALL,UZ
/OUT,SCRATCH
SOLVE

!------------------- UNLOADING (from 18V to 11V) -------------

CMSEL,S,BNODE
D,ALL,VOLT,VLTG2  ! APPLY 14.5v
ALLSEL,ALL
SOLVE

CMSEL,S,BNODE
D,ALL,VOLT,VLTG1  ! APPLY 11.0v
ALLSEL,ALL
SOLVE

FINI
```

```
!---------------------------- Postprocessing ------------------
/POST26
ALLS
NSEL,S,,,2
NSOL,2,2,U,Y,uy    ! DISPLACEMENT AT THE TIP
NSOL,3,2,VOLT,,volt  ! VOLTAGE AT THE TIP
/OUT,
PRVAR,2,3
*GET,UU(3),VARI,2,RTIME,1
*GET,UU(4),VARI,2,RTIME,2
*GET,UU(5),VARI,2,RTIME,3

*DIM,LABEL,CHAR,5
*DIM,VALUE,,5,3
LABEL(1) = '@ 11V','@ 14.5V','@ 18V','@ 14.5V','@ 11V'
*VFILL,VALUE(1,1),DATA,-0.0722,-0.1451,-0.6004,-0.6002,-0.0723
*VFILL,VALUE(1,2),DATA,UU(1),UU(2),UU(3),UU(4),UU(5)
V1 = UU(1)/(-0.0722)
V2 = UU(2)/(-0.1451)
V3 = UU(3)/(-0.6004)
V4 = UU(4)/(-0.6002)
V5 = UU(5)/(-0.0723)
*VFILL,VALUE(1,3),DATA,ABS(V1),ABS(V2),ABS(V3),ABS(V4),ABS(V5)
/OUT,vm236,vrt
/COM
/COM,------------------- VM236 RESULTS COMPARISON ---------------------
/COM,
/COM,           |   TARGET   |    Mechanical APDL    |   RATIO
/COM,
/COM, UY ...
/COM
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F12.4,'  ',F16.4,'   ',1F15.3)
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vm236,vrt
```

VM237 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM237
/TITLE,VM237, PIEZOELECTRIC-CIRCUIT ANALYSIS
/COM,  --------------------------------------------------------------
/COM,     FINITE ELEMENT MODEL OF A PIEZOELECTRIC CIRCULAR PLATE
/COM,  --------------------------------------------------------------
A=1E-3                        ! RADIUS, M
T=0.1E-3                      ! THICKNESS, M
/COM,
/COM,  MATERIAL PROPERTIES OF LEAD ZIRCONATE TITANATE (PZT-5A)
/COM,
/COM,  -- MATERIAL MATRICES (POLAR AXIS ALONG Y-AXIS): IEEE INPUT
/COM,
/COM,   [s11 s13 s12  0  0  0 ]        [ 0 d31  0 ]      [ep11  0    0  ]
/COM,   [s13 s33 s13  0  0  0 ]        [ 0 d33  0 ]      [  0  ep33  0  ]
/COM,   [s12 s13 s11  0  0  0 ]        [ 0 d31  0 ]      [  0   0   ep11]
/COM,   [ 0   0   0  s44 0  0 ]        [ 0  0  d15]
/COM,   [ 0   0   0   0 s66 0 ]        [ 0  0   0 ]
/COM,   [ 0   0   0   0  0 s44]        [d15 0   0 ]
/COM,
/COM,   - COMPLIANCE COEFFICIENTS, M2/N
S11=16.4E-12
S12=-5.74E-12
S13=-7.22E-12
S33=18.8E-12
S44=47.5E-12
S66=44.3E-12
/COM,  - PIEZOELECTRIC STRAIN COEFFICIENTS, C/N
```

```
D15=5.84E-10
D31=-1.71E-10
D33=3.74E-10
/COM,  - RELATIVE PERMITTIVITY AT CONSTANT STRESS
EP11=1730
EP33=1700
/COM,  - DENSITY, KG/M3
RHO=7750
/NOPR

/PREP7
/COM,
/COM,  -- MATERIAL MATRICES (POLAR AXIS ALONG Y-AXIS): Mechanical APDL INPUT
/COM,
/COM,   [s11 s13 s12  0  0  0 ]        [ 0 d31  0 ]      [ep11  0    0  ]
/COM,   [s13 s33 s13  0  0  0 ]        [ 0 d33  0 ]      [  0  ep33  0  ]
/COM,   [s12 s13 s11  0  0  0 ]        [ 0 d31  0 ]      [  0   0   ep11]
/COM,   [ 0   0   0  s44 0  0 ]        [d15 0   0 ]
/COM,   [ 0   0   0   0 s44 0 ]        [ 0  0  d15]
/COM,   [ 0   0   0   0  0 s66]        [ 0  0   0 ]

TB,ANEL,1,,,1                 ! ANISOTROPIC ELASTIC COMPLIANCE MATRIX
TBDA,1,S11,S13,S12
TBDA,7,S33,S13
TBDA,12,S11
TBDA,16,S44

TB,PIEZ,1,,,1                 ! PIEZOELECTRIC STRAIN MATRIX
TBDA,2,D31
TBDA,5,D33
TBDA,8,D31
TBDA,10,D15

TB,DPER,1,,,1                 ! DIELECTRIC PERMITTIVITY AT CONSTANT STRESS
TBDA,1,EP11,EP33

TBLIS,ALL                     ! LIST INPUT AND CONVERTED MATRICES

MP,DENS,1,RHO                 ! DENSITY

ET,1,PLANE223,1001,,1         ! PIEZOELECTRIC AXISYMMETRIC ELEMENT TYPE
RECT,,A,,T
ESIZE,T                       ! MESH SOLID MODEL
NUMSTR,NODE,10
AMESH,1
                              ! APPLY STRUCTURAL BC, SIMPLY SUPPORTED PLATE
NSEL,S,LOC,X
D,ALL,UX,0
NSEL,S,LOC,X,A
NSEL,R,LOC,Y,0
D,ALL,UY,0
NSEL,ALL
                              ! APPLY ELECTRIC BC
NSEL,S,LOC,Y,0
CP,1,VOLT,ALL                 ! COUPLE BOTTOM ELECTRODE
*GET,NBOT,NODE,0,NUM,MIN      ! GET MASTER NODE ON BOTTOM ELECTRODE
NSEL,S,LOC,Y,T
CP,2,VOLT,ALL                 ! COUPLE TOP ELECTRODE
*GET,NTOP,NODE,0,NUM,MIN      ! GET MASTER NODE ON TOP ELECTRODE
NSEL,ALL
D,NBOT,VOLT,0                 ! GROUND BOTTOM ELECTRODE
D,NTOP,VOLT,1                 ! APPLY 1V LOAD ON TOP ELECTRODE

FINI
/SOLU
ANTYPE,STATIC                 ! STATIC ANALYSIS
SOLVE
FINI

/POST1
*GET,QT,NODE,NTOP,RF,CHRG     ! GET TOTAL CHARGE ON TOP ELECTRODE
CP=ABS(QT)                    ! CAPACITANCE CP=Q/V, WHERE V=1V
```

```
EPZ0=8.854E-12                 ! FREE SPACE PERMITTIVITY
PI=3.1415                      ! PI CONSTANT
C=EP33*EPZ0*PI*A**2/T          ! ANALYTICAL CAPACITANCE
/COM,    2-D CAPACITANCE (ANALYTICAL) =%C%, F
/COM,    2-D CAPACITANCE (Mechanical APDL) = %CP%, F
FINI

/COM,  ---------------------------------------------------------------
/COM,    FINITE ELEMENT MODEL OF RLC-CIRCUIT
/COM,  ---------------------------------------------------------------
/PREP7
DDELE,NTOP,VOLT                ! DELETE VOLTAGE LOAD ON TOP ELECTRODE
ET,2,CIRCU94,0                 ! DEFINE A RESISTOR
R=3000                         ! RESISTANCE, OHM
R,1,R
N,1
TYPE,2
REAL,1
E,1,NTOP

ET,3,CIRCU94,1                 ! DEFINE AN INDUCTOR
L=15                           ! INDUCTANCE, H
R,2,L
N,2
TYPE,3
REAL,2
E,2,1

ET,4,CIRCU94,4                 ! DEFINE A VOLTAGE SOURCE
V=1                            ! VOLTAGE LOAD, V
R,3,V
N,3
TYPE,4
REAL,3
E,2,NBOT,3
FINI

/SOLU
ANTYPE,TRANS                   ! TRANSIENT ANALYSIS
NSUB,100                       ! NUMBER OF TIME STEPS
TIME,2E-3                      ! ANALYSIS TIME, S
TINTP,,0.25,0.5,0.5            ! INTEGRATION PARAMETERS FOR A PIEZOELECTRIC ANALYSIS
OUTRES,ALL,ALL
SOLVE
FINI

/GOPR
/COM, ANALYTICAL SOLUTION:
/COM,   V_C = 1-EXP(-D*T)*COS(B*T)-D/B*EXP(-D*T)*SIN(B*T)
/COM,   WHERE:
D=R/(2*L)
B=SQRT(1/(L*C)-D**2)
/NOPR

/POST26
NUMVAR,20
NSOL,2,NTOP,VOLT,,V_C_ANSYS

! DERIVE EXACT SOLUTION
*DIM,WORK1,ARRAY,100
*DIM,WORK2,ARRAY,100
FILLDATA,3,,,,1                ! 1
EXP,4,1,,,,,,-D,-1             ! -EXP(-D*T)
PROD,5,1,,,,,,B                ! B*T
VGET,WORK1(1),5
*VFUN,WORK2(1),COS,WORK1(1)
VPUT,WORK2(1),6                ! COS(B*T)
*VFUN,WORK2(1),SIN,WORK1(1)
VPUT,WORK2(1),7                ! SIN(B*T)
ADD,8,6,7,,,,,,D/B             ! COS(B*T) + D/B*SIN(B*T)
PROD,9,4,8                     ! -EXP(-D*T)*[COS(B*T) + D/B*SIN(B*T)]
ADD,10,3,9,,V_C_EXACT          ! 1-EXP(-D*T)*[COS(B*T) + D/B*SIN(B*T)]
```

```
! PRINT AND PLOT Mechanical APDL AND EXACT VOLTAGE ACROSS THE PZT CAPACITOR
PRVAR,2,10
PLVAR,2,10

/NOPR
*DIM,VCE,ARRAY,5  ! EXACT SOLUTION FOR RESULTS TABLE
*DIM,VCA,ARRAY,5  ! Mechanical APDL SOLUTION FOR RESULTS TABLE

*GET,VCE(1),VARI,10,RTIME,0.18E-3
*GET,VCE(2),VARI,10,RTIME,0.40E-3
*GET,VCE(3),VARI,10,RTIME,0.88E-3
*GET,VCE(4),VARI,10,RTIME,0.13E-2
*GET,VCE(5),VARI,10,RTIME,0.186E-2

*GET,VCA(1),VARI,2,RTIME,0.18E-3
*GET,VCA(2),VARI,2,RTIME,0.40E-3
*GET,VCA(3),VARI,2,RTIME,0.88E-3
*GET,VCA(4),VARI,2,RTIME,0.13E-2
*GET,VCA(5),VARI,2,RTIME,0.186E-2

*DIM,LABEL,CHAR,5
*DIM,VALUE,,5,3
LABEL(1) = '1.8E-2s','4.0E-2s','8.8E-2s','1.3E-1s','1.86E-1s'
*VFILL,VALUE(1,1),DATA,VCE(1),VCE(2),VCE(3),VCE(4),VCE(5)
*VFILL,VALUE(1,2),DATA,VCA(1),VCA(2),VCA(3),VCA(4),VCA(5)
V1 = VCA(1)/VCE(1)
V2 = VCA(2)/VCE(2)
V3 = VCA(3)/VCE(3)
V4 = VCA(4)/VCE(4)
V5 = VCA(5)/VCE(5)
*VFILL,VALUE(1,3),DATA,ABS(V1),ABS(V2),ABS(V3),ABS(V4),ABS(V5)
/OUT,vm237,vrt
/COM
/COM,------------------- VM237 RESULTS COMPARISON ---------------------
/COM,
/COM,               |  TARGET  |   Mechanical APDL   |   RATIO
/COM,
/COM, VC for t @ ...
/COM
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F12.4,'  ',F16.4,'   ',1F15.3)
/COM,----------------------------------------------------------------
/OUT
FINI
*LIST,vm237,vrt
```

VM238 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM238
/TITLE,VM238,WHEATSTONE BRIDGE CONNECTION OF PIEZORESISTORS, UMKSV SYSTEM OF UNITS
/COM,
/COM,  GEOMETRIC PARAMETERS:
/COM,
L=180                         ! LENGTH OF THE BEAM, UM
W=120                         ! WIDTH OF THE BEAM, UM
A=100                         ! LENGTH OF PIEZORESISTORS, UM
B=20                          ! WIDTH OF PIEZORESISTORS, UM
D=10                          ! DISTANCE FROM THE EDGE, UM
/COM,
/COM,  MATERIAL PROPERTIES (SI):
/COM,
/COM,  YOUNG MODULUS, MPA
E=165E3
/COM,  POISSON RATIO
NU=0.25
```

```
/COM,
/COM,  RESISTIVITY (P-TYPE SI), TOHM*UM
RHO= 7.8E-8
/COM,
/COM,  PIEZORESISTIVE COEFFICIENTS (P-TYPE SI), (MPA)^1
/COM,   [P11 P12 P12  0 ]
/COM,   [P12 P11 P12  0 ]
/COM,   [P12 P12 P11  0 ]
/COM,   [ 0   0   0  P44]
/COM,
P11=6.5E-5
P12=-1.1E-5
P44=138.1E-5
/COM,
/COM,  PRESSURE LOAD, MPA
P=1
/COM,  SUPPLY VOLTAGE, VOLT
VS=5
/NOPR

/PREP7
ET,1,PLANE223,101             ! PIEZORESISTIVE ELEMENT TYPE
ET,2,PLANE183                  ! STRUCTURAL ELEMENT TYPE
                              ! SPECIFY MATERIAL ORIENTATION:
LOCAL,11
LOCAL,12,,,,,45               ! X-AXIS ALONG <110> DIRECTION
MP,EX,1,E                     ! ELASTIC PROPERTIES
MP,NUXY,1,NU
MP,RSVX,1,RHO                 ! RESISTIVITY
TB,PZRS,1                     ! PIEZORESISTIVE STRESS MATRIX
TBDATA,1,P11,P12,P12
TBDATA,7,P12,P11,P12
TBDATA,13,P12,P12,P11
TBDATA,22,P44
CSYS,11
RECT,-L/2,L/2,-W/2,W/2        ! DEFINE BEAM
RECT,-(L/2-D),-(L/2-D-B),-A/2,A/2   ! RESISTOR 1
RECT,-A/2,A/2,W/2-D-B,W/2-D         ! RESISTOR 2
RECT,-A/2,A/2,-(W/2-D),-(W/2-D-B)   ! RESISTOR 3
RECT,L/2-D-B,L/2-D,-A/2,A/2         ! RESISTOR 4
AOVLAP,ALL                    ! MESH AREAS
ESYS,12
TYPE,1
ESIZE,B/3
AMESH,2,5                     ! MESH RESISTOR AREAS
TYPE,2
MSHAP,1,2-D
ESIZE,B/2
AMESH,6                       ! MESH REST OF THE BEAM
                              ! APPLY ELECTRICAL BC:
LSEL,S,LINE,,5                ! DEFINE SUPPLY VOLTAGE CONTACT
LSEL,A,LINE,,16
NSLL,S,1
CP,1,VOLT,ALL
*GET,NS,NODE,0,NUM,MIN
D,NS,VOLT,VS
LSEL,S,LINE,,10               ! DEFINE GROUND CONTACT
LSEL,A,LINE,,19
NSLL,S,1
CP,2,VOLT,ALL
*GET,NG,NODE,0,NUM,MIN
D,NG,VOLT,0
LSEL,S,LINE,,7                ! DEFINE FIRST OUTPUT CONTACT
LSEL,A,LINE,,12
NSLL,S,1
CP,3,VOLT,ALL
*GET,NO1,NODE,0,NUM,MIN
LSEL,S,LINE,,14               ! DEFINE SECOND OUTPUT CONTACT
LSEL,A,LINE,,17
NSLL,S,1
CP,4,VOLT,ALL
*GET,NO2,NODE,0,NUM,MIN
```

```
NSEL,ALL
LSEL,ALL
                             ! APPLY STRUCTURAL BC
NSEL,S,LOC,X,-L/2
D,ALL,UX,0
NSEL,R,LOC,Y,-W/2
D,ALL,UY,0
NSEL,S,LOC,X,L/2
SF,ALL,PRES,-P               ! PRESSURE LOAD
NSEL,ALL
/PBC,U,,1
/PBC,VOLT,,1
/PBC,CP,,1
/PNUM,TYPE,1
/NUMBER,1
EPLOT
FINI
/SOLU                        ! SOLUTION
ANTYPE,STATIC
CNVTOL,AMPS,1,1.E-3
/OUT,SCRATCH
SOLVE
FINI
/POST1
!!! CALCULATE RESULTS
/OUT,
SX=P
VOC=P44/(2+(P11+P12)*SX)*SX*VS*1.E3   ! CALCULATE ACTUAL RESULT
VOA=ABS(VOLT(NO1)-VOLT(NO2))*1.E3     ! CALCULATE Mechanical APDL RESULT
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1) = 'VO (MV)'
*VFILL,VALUE(1,1),DATA,VOC
*VFILL,VALUE(1,2),DATA,VOA
*VFILL,VALUE(1,3),DATA,ABS(VOA/VOC)
/OUT,vm238,vrt
/COM
/COM,------------------- VM238 RESULTS COMPARISON ---------------------
/COM,
/COM,            |  TARGET  |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'       ',F7.4,'  ',F14.4,'     ',1F15.3)
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vm238,vrt
```

VM239 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM239
/OUT,SCRATCH
/PREP7
/OUT
/COM
/TITLE, VM239, MECHANICS OF THE REVOLUTE AND UNIVERSAL JOINTS
/COM
/COM
/COM    J.E. SHIGLEY AND J.J. UICKER, "THEORY OF MACHINES AND
/COM    MECHANISMS" 2ND EDITION, P. 115, 1995.
/COM
/COM ***ANALYSIS USING ALL FLEXIBLE BODIES
/COM
/COM
!C*** ADD UNIVERSAL JOINT MECHANISM TO THE ABOVE PROBLEM.
!C*** PERFORM ANALYSIS USING ALL FLEXIBLE BODIES
/OUT,SCRATCH
```

```
PI=4*ATAN(1.0)
MULT  = 12
PI15  = PI/MULT
ANG   = PI15*3
R = .5                              ! LENGTH OF ROTATING ARM
L = 1.5                             ! LENGTH OF CRANK
ZDIST = L*SIN(ACOS(R/L))
!C*** DEFINING ELEMENTS AND MATERIAL PROPERTIES
ET,1,BEAM188                        ! BEAM ELEMENTS
ET,2,MPC184,7                       ! UNIVERSAL JOINT
ET,3,MPC184,6                       ! REVOLUTE JOINT
ET,4,MPC184,3                       ! SLIDER
MP,EX,1,30E6
MP,PRXY,1,0.33
MP,DENS,1,10.0
TYPE,1
MAT, 1
SECTYPE, 1, BEAM, CSOLID
SECDATA, .05
!C*** CREATING NODES AND LINK ELEMENTS
N,1, 0,0,0
N,2, 1,0,0
N,3, 1,0,0
N,4, 1+COS(ANG), SIN(ANG), 0.0
N,5, 1+COS(ANG), SIN(ANG), 0.0
N,6, 2+COS(ANG),SIN(ANG),0
N,8, 2+COS(ANG),.5+SIN(ANG),0
N,9, 2+COS(ANG),.5+SIN(ANG),0
N,10, 2+COS(ANG),SIN(ANG),ZDIST
N,11, 2+COS(ANG),SIN(ANG),.75
N,12, 2+COS(ANG),SIN(ANG),2.25
N,13, 2+COS(ANG),SIN(ANG),2.26
N,14, 2+COS(ANG),SIN(ANG),.74
TYPE,1
MAT, 1
SECNUM, 1
EN,1, 1,2
EN,2, 3,4
EN,3, 5,6
EN,4, 6,8
EN,5, 9,10
EN,6, 11,12
EN,11, 12,13
EN,12, 11,14
LOCAL,11,0, 0,0,0,-90.0          ! DEFINING LOCAL CSYS FOR UNIV. JOINTS
LOCAL,12,0, 0,0,0,-45.0
LOCAL,14,0, 0,0,0, 0,            ! DEFINING LOCAL CSYS FOR REVO. JOINTS
LOCAL,15,0, 0,0,0, 0,
CSLIST
!C*** CREATING UNIVERSAL CONNECTIVITY ELEMENTS
SECTYPE,2,JOIN,UNIV,TESTING02      ! DEFINING UNIVERSAL JOINT
SECJOINT,1,11,12
TYPE,2
SECNUM,2
EN,7, 2,3
SECTYPE,3,JOIN,UNIV,TESTING03      ! DEFINING UNIVERSAL JOINT
SECJOINT,1,11,12
TYPE,2
SECNUM,3
EN,8, 5,4
!C*** CREATING REVOLUTE CONNECTIVITY ELEMENTS
SECTYPE,4,JOIN,REVO,TESTING04      ! DEFINING REVOLUTE JOINT
SECJOINT,,14,15
TYPE,3
SECNUM,4
EN,9, 8,9
!C*** CREATING SLIDER CONNECTIVITY ELEMENTS
TYPE,4
EN,10, 10,11,12
CSYS, 12
NROTAT, 4
CSYS,0
```

```
/SOLU                                ! SOLUTION
CSYS,0
ANTYPE, STAT
NLGEOM, ON                           ! LARGE DEFLECTION OPTION
TIME, 1.0
NSUBST, 32, 32, 32
D,1,UX,0,,,,UY,UZ,,ROTY,ROTZ
D,6,UX,0,,,,UY,UZ,,ROTY,ROTZ
NSEL,S,NODE,,13,14,1
D,ALL,ALL
ALLSEL,ALL
D,1,ROTX,2*PI
OUTRES, ALL, ALL
!C*** NOTE: THE FORCES IN THIS PROBLEM ARE REALLY ZERO SINCE
!C*** THIS IS EFFECTIVELY A RIGID BODY ROTATION
CNVTOL,F,1.0
CNVTOL,M,1.0
SOLVE
FINISH
/POST26
NUMVAR,200                            ! TIME-HISTORY POSTPROCESSOR
NSOL,2,1,ROT,X,ROTX_1
NSOL,3,4,ROT,Y,ROTX_4
NSOL,4,6,ROT,X,ROTX_6
STORE,MERGE
PROD, 5, 2, , , , , , 1.0*180/PI
PROD, 6, 3, , , , , , 1.0*180/PI
PROD, 7, 4, , , , , , 1.0*180/PI
/AXLAB, X, Twist Angle of Driving Shaft
/AXLAB, Y, Twist Angle of Driven Shaft
/XRANGE, 0.0, 360
/YRANGE, 0.0, 360
/GROPT, DIVX, 8
/GROPT, DIVY, 8
XVAR,5
PLVAR,6
PLVAR,7
FINISH
/POST1                               ! GENERAL POSTPROCESSOR
SET,,4
NSEL,S,NODE,,10
*GET,X1,NODE,10,U,Z
ALLSEL,ALL
SET,,8
NSEL,S,NODE,,10
*GET,X2,NODE,10,U,Z
ALLSEL,ALL
SET,,12
NSEL,S,NODE,,10
*GET,X3,NODE,10,U,Z
ALLSEL,ALL
SET,,16
NSEL,S,NODE,,10
*GET,X4,NODE,10,U,Z
ALLSEL,ALL
*DIM,LABEL,CHAR,3
*DIM,VALUE,,3,4
LABEL(1) = 'PI/4','PI/2','3*PI/4'
*VFILL,VALUE(1,1),DATA,0.39708,0.58579,0.39708
*VFILL,VALUE(1,2),DATA,ABS(X1),ABS(X2),ABS(X3)
*VFILL,VALUE(1,3),DATA,ABS(X1/0.39708),ABS(X2/0.58579),ABS(X3/0.39708)
SAVE,TABLE_1
FINISH
/CLEAR,NOSTART
/OUT
/TITLE, VM239, MECHANICS OF THE REVOLUTE AND UNIVERSAL JOINTS
/COM
/COM
/COM *** PERFORM ANALYSIS USING ALL RIGID BODIES
/COM
/COM
/OUT,SCRATCH
```

```
/PREP7
PI=4*ATAN(1.0)
MULT  = 12
PI15  = PI/MULT
ANG   = PI15*3
R = .5                                ! LENGTH OF ROTATING ARM
L = 1.5                               ! LENGTH OF CRANK
ZDIST = L*SIN(ACOS(R/L))

C*** DEFINING ELEMENTS, KEY OPTIONS AND MATERIAL PROPERTIES
ET,1,BEAM188                          ! BEAM ELEMENTS
ET,2,MPC184,7                         ! UNIVERSAL JOINT
ET,3,MPC184,6                         ! REVOLUTE JOINT
ET,4,MPC184,3                         ! SLIDER

ET,11,TARGE170                        ! TARGET ELEMENT
KEYOPT,11,2,1                         ! TARGET ELEMENT DEFINED AS RIGID BODY

MP,EX,1,30E6
MP,PRXY,1,0.33
MP,DENS,1,10.0

C*** CREATING NODES AND LINK ELEMENTS
N,1, 0,0,0
N,2, 1,0,0
N,3, 1,0,0
N,4, 1+COS(ANG), SIN(ANG), 0.0
N,5, 1+COS(ANG), SIN(ANG), 0.0
N,6, 2+COS(ANG),SIN(ANG),0
N,8, 2+COS(ANG),.5+SIN(ANG),0
N,9, 2+COS(ANG),.5+SIN(ANG),0
N,10, 2+COS(ANG),SIN(ANG),ZDIST
N,11, 2+COS(ANG),SIN(ANG),.75
N,12, 2+COS(ANG),SIN(ANG),2.25
N,13, 2+COS(ANG),SIN(ANG),2.26

! DEFINE RIGID BODIES
TYPE,11
REAL,11
EN,1, 1,2      ! TARGET ELEMENT FOR 1ST RIGID BODY
REAL, 12
EN,2, 3,4      ! TARGET ELEMENT FOR 2ND RIGID BODY
REAL, 13
EN,3, 6,5
EN,4, 6,8      ! TARGET ELEMENTS FOR 3RD RIGID BODY
REAL, 14
EN,5, 10,9     ! TARGET ELEMENT FOR 4TH RIGID BODY
REAL, 15
EN,6, 11, 12   ! TARGET ELEMENT FOR 5TH RIGID BODY
EN,101, 12,13

! PILOT NODES FOR RIGID BODIES
TYPE,11
REAL,11
TSHAP,PILO
EN,11,1       ! PILOT NODE FOR 1ST RIGID BODY
REAL,12
TSHAP,PILO
EN,12,3       ! PILOT NODE FOR 2ND RIGID BODY
REAL,13
TSHAP,PILO
EN,13,5       ! PILOT NODE FOR 3ND RIGID BODY
REAL,14
TSHAP,PILO
EN,14,10       ! PILOT NODE FOR 4TH RIGID BODY
REAL,15
TSHAP,PILO
EN,15,13      ! PILOT NODE FOR 5TH RIGID BODY

! COORDINATE SYSTEMS FOR JOINTS
LOCAL,11,0, 0,0,0,-90.0         ! DEFINING LOCAL CSYS FOR UNIV. JOINTS
LOCAL,12,0, 0,0,0,-45.0
```

```
LOCAL,14,0, 0,0,0, 0,           ! DEFINING LOCAL CSYS FOR REVO. JOINTS
LOCAL,15,0, 0,0,0, 0,

C*** CREATING UNIVERSAL CONNECTIVITY ELEMENTS
SECTYPE,2,JOIN,UNIV,TESTING02      ! DEFINING UNIVERSAL JOINT
SECJ,1,11,12
TYPE,2
SECNUM,2
EN,7, 2,3
!
SECTYPE,3,JOIN,UNIV,TESTING03      ! DEFINING UNIVERSAL JOINT
SECJ,1,11,12
TYPE,2
SECNUM,3
EN,8, 5,4
!
C*** CREATING REVOLUTE CONNECTIVITY ELEMENTS
SECTYPE,4,JOIN,REVO,TESTING04      ! DEFINING REVOLUTE JOINT
SECJ,,14,15
TYPE,3
SECNUM,4
EN,9, 8,9
!
C*** CREATING SLIDER CONNECTIVITY ELEMENTS
TYPE,4
EN,10, 10,11,12

CSYS, 12
NROTAT, 4
CSYS,0

/SOLU                              ! SOLUTION
CSYS,0
ANTYPE, STAT
NLGEOM, ON                         ! LARGE DEFLECTION OPTION
TIME, 1.0
NSUBST, 32, 6400, 32
D,1,UX,0,,,,UY, UZ
D, 6, UY, 0.0
D, 6, UZ, 0.0
D, 13, UX, 0,,,,UY,UZ,ROTX,ROTY,ROTZ
D,1,ROTX,2*PI
OUTRES, ALL, ALL
LNSRCH,OFF
CNVTOL, F
CNVTOL, M
CNVTOL,U
CNVTOL,ROT
SOLVE
FINISH

/POST26
NUMVAR,200                          ! TIME-HISTORY POSTPROCESSOR
NSOL,2,1,ROT,X,ROTX_1
NSOL,3,4,ROT,Y,ROTX_4
NSOL,4,6,ROT,X,ROTX_6
STORE,MERGE
PROD, 5, 2, , , , , , 1.0*180/PI
PROD, 6, 3, , , , , , 1.0*180/PI
PROD, 7, 4, , , , , , 1.0*180/PI
/AXLAB, X, Twist Angle of Driving Shaft
/AXLAB, Y, Twist Angle of Driven Shaft
/XRANGE, 0.0, 360
/YRANGE, 0.0, 360
/GROPT, DIVX, 8
/GROPT, DIVY, 8
XVAR,5
PLVAR,6
PLVAR,7
FINISH
/POST1                             ! GENERAL POSTPROCESSOR
SET,,4
```

```
NSEL,S,NODE,,10
*GET,X1,NODE,10,U,Z
ALLSEL,ALL
SET,,8
NSEL,S,NODE,,10
*GET,X2,NODE,10,U,Z
ALLSEL,ALL
SET,,12
NSEL,S,NODE,,10
*GET,X3,NODE,10,U,Z
ALLSEL,ALL
SET,,16
NSEL,S,NODE,,10
*GET,X4,NODE,10,U,Z
ALLSEL,ALL
*DIM,LABEL,CHAR,3
*DIM,VALUE,,3,4
LABEL(1) = 'PI/4','PI/2','3*PI/4'
*VFILL,VALUE(1,1),DATA,0.39708,0.58579,0.39708
*VFILL,VALUE(1,2),DATA,ABS(X1),ABS(X2),ABS(X3)
*VFILL,VALUE(1,3),DATA,ABS(X1/0.39708),ABS(X2/0.58579),ABS(X3/0.39708)
SAVE,TABLE_2
FINISH
RESUME,TABLE_1
/OUT,vm239,vrt
/COM
/COM,------------------ VM239 RESULTS COMPARISON --------------------
/COM,
/COM,    APPLIED ROTX    |    TARGET    |   Mechanical APDL    |   RATIO
/COM,
/COM, RESULTS FOR ANALYSIS WITH ALL FLEXIBLE BODIES
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A12,'       ',F10.5,'  ',F14.5,'     ',1F15.1)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM, RESULTS FOR ANALYSIS WITH ALL RIGID BODIES
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A12,'       ',F10.5,'  ',F14.5,'     ',1F15.1)
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vm239,vrt
```

VM240 Input Listing

```
/VERIFY,VM240
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/TITLE,VM240,THERMAL EXPANSION OF RIGID BEAMS IN A COMPOSITE BAR
/COM J.M. GERE, S.P. TIMOSHENKO, MECHANICS OF MATERIALS, 2ND EDITION,
/COM PWS PUBLISHERS, 1984, P. 20-21,71
/COM

/GRAPH,POWER
/AUTO
/VIEW,1,1,1,1
/PNUM,TYPE,1
/PNUM,MAT,1
/NUM,1
/ESHAPE,1

/PREP7
ET,1,185                      ! DEFINING SOLID ELEMENTS
MP,EX,1,10.0e6                ! MATERIAL 1 PROPERTIES
MP,NUXY,1,0.3
```

```
MP,EX,2,5.0e6                ! MATERIAL 2 PROPERTIES
MP,NUXY,2,0.3
ET,2,184                     ! DEFINING RIGID BEAM ELEMENTS
KEYOPT,2,1,1
KEYOPT,2,2,1
TREF,0
MPTEMP,1,0,100
MPDATA,ALPX,3,1,0,0.0003     ! SETTING THERMAL COEFFICIENT FOR RIGID BEAMS
MPDATA,ALPY,3,1,0,0.0003
MPDATA,ALPZ,3,1,0,0.0003

BLOCK,0,40,0,4,0,2           ! CREATING GEOMETRY
BLOCK,0,40,0,4,2,4
VGLUE,1,2

TYPE,1
MAT,1
ESIZE,1
VSEL,S,VOLU,,1
VMESH,ALL                    ! MESHING 1ST MATERIAL
ALLSEL,ALL

MAT,2
VSEL,S,VOLU,,3
VMESH,ALL                    ! MESHING 2ND MATERIAL

TYPE,2
MAT,3
E,661,657                    ! GENERATING RIGID BEAM ELEMENTS
E,701,660
E,702,659
E,703,658
E,616,617
E,863,862
E,905,908
E,904,907
E,903,906
E,821,822
E,251,247
E,291,250
E,292,249
E,293,248
E,206,207
E,453,452
E,495,498
E,494,497
E,493,496
E,411,412
E,1,6
E,3,49
E,4,48
E,5,47
E,2,46

/SOLU
ANTYPE,STATIC
NROPT,FULL
SOLCON,ON
NLGEOM,ON
RESCON,DEFINE,NONE
OUTRES,ALL,ALL
AUTOTS,ON
NSUBST,10,1000,10

NSEL,S,LOC,X,0               ! APPLYING BOUNDARY CONDITIONS
D,ALL,ALL
ALLSEL,ALL

BF,ALL,TEMP,100              ! APPLYING TEMPERATURE LOAD
/OUT,SCRATCH
SOLVE                        ! SOLVING
FINISH
```

```
/POST1                        ! POSTPROCESSING
NSEL,S,LOC,X,20
NSEL,R,LOC,Y,2
NSEL,R,LOC,Z,1
/OUT,
*GET,STRESS1,NODE,557,S,EQV
ALLSEL,ALL
NSEL,S,LOC,X,20
NSEL,R,LOC,Y,2
NSEL,R,LOC,Z,3
*GET,STRESS2,NODE,967,S,EQV
*DIM,LABEL,CHAR,2
*DIM,VALUE,,2,3
LABEL(1) = 'SEQV1','SEQV2'
*VFILL,VALUE(1,1),DATA,300000,150000
*VFILL,VALUE(1,2),DATA,ABS(STRESS1),ABS(STRESS2)
*VFILL,VALUE(1,3),DATA,ABS(STRESS1 / 300000) ,ABS(STRESS2 / 150000)
/OUT,vm240,vrt
/COM
/COM,------------------- VM240 RESULTS COMPARISON -------------------
/COM,
/COM,              |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A10,'     ',E10.4,'    ',E14.4,'     ',1F15.3)
/OUT
FINISH
*LIST,vm240,vrt
```

VM241 Input Listing

```
/VERIFY,VM241
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/TITLE, VM241, TEAM20: 3-D STATIC FORCE PROBLEM
C*** USING SOLID237
/COM
/COM
/COM REFERENCE:
/COM  N.TAKAHASHI,T.NAKATA,H.MORISHIGE,"SUMMARY OF RESULTS FOR
/COM, PROBLEM 20 (3-D STATIC FORCE PROBLEM)", COMPEL, VOL.14,1995,PG:57-75
/NOPR
SMT=10          ! SMART SIZING MESHING PARAMETER
                              ! COIL PARAMETERS
TCUR=5000         ! INPUT CURRENT HERE (AT)
AREA=(18*96.6)*.001**2        ! AREA
CURDEN=TCUR/AREA        ! CURRENT DENSITY

/PREP7
ET,1,MESH200,9
MP,RSVX,4,1E-7

MP,MURX,1,1
MP,MURX,4,1

TB,BH,2,,40
TBPT,,355,.7
,,405,.8
,,470,.9
,,555,1.
,,673,1.1
,,836,1.2
,,1065,1.3
,,1220,1.35
,,1420,1.4
,,1720,1.45
,,2130,1.5
,,2670,1.55
```

```
,,3480,1.6
,,4500,1.65
,,5950,1.70
,,7650,1.75
,,10100,1.8
,,13000,1.85
,,15900,1.9
,,21100,1.95
,,26300,2.
,,32900,2.05
,,42700,2.1
,,61700,2.15
,,84300,2.2
,,110000,2.25
,,135000,2.3
,,200000,2.41
,,400000,2.69
,,800000,3.22

TBCOPY,BH,2,3

N,1,0,0,75/1000      ! PATH NODES FOR POSTPROCESSING
N,2,63.5/1000,0,75/1000

BLOCK,0,63.5,0,25/2,0,25    ! POLE
BLOCK,38.5,63.5,0,25/2,25,125
BLOCK,13.5,63.5,0,25/2,125,150
VGLUE,ALL

BLOCK,0,12.5,0,5,26.5,125    ! ARMATURE
BLOCK,0,13,0,5.5,26,(125+.5)    ! AIR REGION
VOVLAP,1,2
NUMCMP,VOLU

BLOCK,39/2,75/2,0,14.5,(25+1.7),(125-1.7)
BLOCK,0,14.5,39/2,75/2,(25+1.7),(125-1.7)
LOCAL,11,1,14.5,14.5,25+1.7
LOCAL,12,1,.0145,.0145,.001*(25+1.7)
CSYS,11
WPCSYS,11
CYL4,,,5,0,23,90,(125-1.7)-(25+1.7)
VGLUE,6,8
NUMCMP,VOLU

CSYS,0
WPCSYS,0
CYL4,,,0,0,100,90,175
VOVLAP,ALL
NUMCMP,ALL

VSEL,S,VOLU,,1
VATT,3,1,1       ! ARMATURE
VSEL,S,VOLU,,3,5
VATT,2,1,1       ! POLE
VSEL,S,VOLU,,6
VATT,4,2,1       ! COIL +Y
VSEL,S,VOLU,,7
VATT,4,4,1       ! COIL -X
VSEL,S,VOLU,,8
VATT,4,3,1       ! COIL +Y THETA

ALLSEL,ALL
SMRT,SMT       ! SMART SIZING MESHING PARAMETER
MSHKEY,0
VMESH,ALL

ESEL,S,MAT,,3      ! ARMATURE FORCE EXTRACTION
CM,ARM,ELEM
ALLSEL,ALL

VLSCALE,ALL,,,.001,.001,.001,,0,1   ! SCALE TO METERS
CSYS,0
```

```
FINISH

/COM
/COM *** CREATE CURRENT DENSITY LOADING IN THE COIL
/PREP7
ET,1,SOLID232      ! VOLT
ESEL,S,MAT,,4      ! CONDUCTOR
NSLE
NSEL,R,LOC,X,0
D,ALL,VOLT,0
NSLE
NSEL,R,LOC,Y,0
CP,1,VOLT,ALL
F,NDNEXT(0),AMPS,TCUR
NSLE
FINISH

/SOLU
SOLVE
ALLS
FINISH

/POST1
VSEL,S,VOLU,,1,8
ESLV,S
/VIEW,1,,,1
/ANGLE,1,-90
/DIST,,0.042616
/FOCUS,,0.031066,0.004962,0.075038
PLVECT,JT,,,,VECT,,ON
ALLS
FINISH

/COM
/COM *** SOLVE MAGNETIC ANALYSIS
/PREP7
ET,1,SOLID237      ! AZ
KEYOP,1,7,1      ! CORNER NODE FORCE OUTPUT

NSEL,S,EXT
NSLE,R
NSLE,U,CORNER
D,ALL,AZ,0      ! FLUX-PARALLEL MAGNETIC BCS
NSEL,ALL
FINISH

/SOLU
LDREAD,JS,1,1,,,,rth
SOLVE
FINISH

/POST1
VSEL,S,VOLU,,1,8
ESLV,S
/VIEW,1,,1
/ANGLE,1,180
/DIST,,0.09625
/FOCUS,,0.05,0.05,0.0875
PLVECT,B,,,,VECT,,ON
ALLS

*DIM,LABEL,CHAR,3     ! PARAMETERS FOR POSTPROCESSING
*DIM,VALUE,,3,3
LABEL(1) = 'FMAG(Z) '
LABEL(2) = 'POLE(BZ) '
LABEL(3) = 'ARM(BZ) '
VALUE(1,1)=80.1
VALUE(2,1)=0.46
VALUE(3,1)=2.05

*MSG,NOTE,TCUR
%/RESULTS FOR CURRENT = %G (MULTIPLY FORCE BY 4 FOR SYMMETRY)
```

```
/COM, *** SUM UP MAGNETIC FORCES ACTING ON THE ARMATURE
CMSEL,S,'ARM'
NSLE
ESEL,ALL

*GET,NNOD,NODE,,COUNT
_FZSUM=0
ND=0
*DO,I,1,NNOD
 ND=NDNEXT(ND)
 *GET,FZ,NODE,ND,FMAG,Z
 _FZSUM=_FZSUM+FZ
*ENDDO
                                 ! ALTERNATIVELY, ISSUE THE EMFT COMMAND
!EMFT                            ! MACRO TO SUM UP MAGNETIC FORCES

FMAGZ=_FZSUM
FZ=4*FMAGZ                       ! SCALE FORCE FOR SYMMETRY

ESEL,S,MAT,,2,3
NSLE,S
NSEL,A,NODE,,1,2
LPATH,1,2
/COM
/COM, PATH RESULTS FOR ARM AND POLE REGIONS
/COM
PDEF,BZ,B,Z
PRPATH,BZ
*GET,BZPOLE,PATH,0,LAST,BZ      ! EXTRACT BZ AT POLE
*GET,BZARM,PATH,0,MAX,BZ        ! EXTRACT BZ AT ARM
VALUE(1,2)=ABS(FZ)
VALUE(2,2)=ABS(BZPOLE)
VALUE(3,2)=ABS(BZARM)
VALUE(1,3)=ABS(FZ)/VALUE(1,1)
VALUE(2,3)=ABS(BZPOLE)/VALUE(2,1)
VALUE(3,3)=ABS(BZARM)/VALUE(3,1)
*VLEN,3
SAVE,INF1
FINISH
/CLEAR,NOSTART




/TITLE, VM241, TEAM20: 3-D STATIC FORCE PROBLEM
C*** USING SOLID236
SMT=10          ! SMART SIZING MESHING PARAMETER
                               ! COIL PARAMETERS
TCUR=5000         ! INPUT CURRENT HERE (AT)
AREA=(18*96.6)*.001**2        ! AREA
CURDEN=TCUR/AREA        ! CURRENT DENSITY

/PREP7
ET,1,SOLID231
MP,RSVX,4,1E-7

MP,MURX,1,1
MP,MURX,4,1

TB,BH,2,,40
TBPT,,355,.7
,,405,.8
,,470,.9
,,555,1.
,,673,1.1
,,836,1.2
,,1065,1.3
,,1220,1.35
,,1420,1.4
,,1720,1.45
,,2130,1.5
```

```
,,2670,1.55
,,3480,1.6
,,4500,1.65
,,5950,1.70
,,7650,1.75
,,10100,1.8
,,13000,1.85
,,15900,1.9
,,21100,1.95
,,26300,2.
,,32900,2.05
,,42700,2.1
,,61700,2.15
,,84300,2.2
,,110000,2.25
,,135000,2.3
,,200000,2.41
,,400000,2.69
,,800000,3.22

TBCOPY,BH,2,3

N,1,0,0,75/1000       ! PATH NODES FOR POSTPROCESSING
N,2,63.5/1000,0,75/1000

BLOCK,0,63.5,0,25/2,0,25    ! POLE
BLOCK,38.5,63.5,0,25/2,25,125
BLOCK,13.5,63.5,0,25/2,125,150
VGLUE,ALL

BLOCK,0,12.5,0,5,26.5,125    ! ARMATURE
BLOCK,0,13,0,5.5,26,(125+.5)    ! AIR REGION
VOVLAP,1,2
NUMCMP,VOLU

BLOCK,39/2,75/2,0,14.5,(25+1.7),(125-1.7)
BLOCK,0,14.5,39/2,75/2,(25+1.7),(125-1.7)
LOCAL,11,1,14.5,14.5,25+1.7
LOCAL,12,1,.0145,.0145,.001*(25+1.7)
CSYS,11
WPCSYS,11
CYL4,,,5,0,23,90,(125-1.7)-(25+1.7)
VGLUE,6,8
NUMCMP,VOLU

CSYS,0
WPCSYS,0
CYL4,,,0,0,100,90,175
VOVLAP,ALL
NUMCMP,ALL

VSEL,S,VOLU,,1
VATT,3,1,1       ! ARMATURE
VSEL,S,VOLU,,3,5
VATT,2,1,1       ! POLE
VSEL,S,VOLU,,6
VATT,4,2,1       ! COIL +Y
VSEL,S,VOLU,,7
VATT,4,4,1       ! COIL -X
VSEL,S,VOLU,,8
VATT,4,3,1       ! COIL +Y THETA

ALLSEL,ALL
SMRT,SMT       ! SMART SIZING MESHING PARAMETER
MSHKEY,0
MSHAPE,1,3D
VMESH,ALL

ESEL,S,MAT,,3      ! ARMATURE FORCE EXTRACTION
CM,ARM,ELEM
ALLSEL,ALL
```

```
VLSCALE,ALL,,,.001,.001,.001,,0,1   ! SCALE TO METERS
CSYS,0
FINISH

/COM
/COM *** CREATE CURRENT DENSITY LOADING IN THE COIL
/PREP7
ESEL,S,MAT,,4      ! CONDUCTOR
NSLE
NSEL,R,LOC,X,0
D,ALL,VOLT,0
NSLE
NSEL,R,LOC,Y,0
CP,1,VOLT,ALL
F,NDNEXT(0),AMPS,TCUR
NSLE
FINISH

/SOLU
SOLVE
ALLS
FINISH

/POST1
VSEL,S,VOLU,,1,8
ESLV,S
/VIEW,1,,,1
/ANGLE,1,-90
/DIST,,0.042616
/FOCUS,,0.031066,0.004962,0.075038
PLVECT,JT,,,,VECT,,ON
ALLS
FINISH

/COM
/COM *** SOLVE MAGNETIC ANALYSIS
/PREP7
ET,1,SOLID236      ! AZ
KEYOP,1,7,1      ! CORNER NODE FORCE OUTPUT

NSEL,S,EXT
NSLE,R
NSLE,U,CORNER
D,ALL,AZ,0      ! FLUX-PARALLEL MAGNETIC BCS
NSEL,ALL
FINISH

/SOLU
LDREAD,JS,1,1,,,,rth
SOLVE
FINISH

/POST1
VSEL,S,VOLU,,1,8
ESLV,S
/VIEW,1,,1
/ANGLE,1,180
/DIST,,0.09625
/FOCUS,,0.05,0.05,0.0875
PLVECT,B,,,,VECT,,ON
ALLS

*DIM,LABEL,CHAR,3     ! PARAMETERS FOR POSTPROCESSING
*DIM,VALUE,,3,3
LABEL(1) = 'FMAG(Z) '
LABEL(2) = 'POLE(BZ) '
LABEL(3) = 'ARM(BZ) '
VALUE(1,1)=80.1
VALUE(2,1)=0.46
VALUE(3,1)=2.05

*MSG,NOTE,TCUR
```

```
%/RESULTS FOR CURRENT = %G (MULTIPLY FORCE BY 4 FOR SYMMETRY)

/COM, *** SUM UP MAGNETIC FORCES ACTING ON THE ARMATURE
CMSEL,S,'ARM'
NSLE
ESEL,ALL

*GET,NNOD,NODE,,COUNT
_FZSUM=0
ND=0
*DO,I,1,NNOD
 ND=NDNEXT(ND)
 *GET,FZ,NODE,ND,FMAG,Z
 _FZSUM=_FZSUM+FZ
*ENDDO
                                 ! ALTERNATIVELY, ISSUE THE EMFT COMMAND
!EMFT                            ! MACRO TO SUM UP MAGNETIC FORCES

FMAGZ=_FZSUM
FZ=4*FMAGZ                       ! SCALE FORCE FOR SYMMETRY

ESEL,S,MAT,,2,3
NSLE,S
NSEL,A,NODE,,1,2
LPATH,1,2
/COM
/COM, PATH RESULTS FOR ARM AND POLE REGIONS
/COM
PDEF,BZ,B,Z
PRPATH,BZ
*GET,BZPOLE,PATH,0,LAST,BZ      ! EXTRACT BZ AT POLE
*GET,BZARM,PATH,0,MAX,BZ        ! EXTRACT BZ AT ARM
VALUE(1,2)=ABS(FZ)
VALUE(2,2)=ABS(BZPOLE)
VALUE(3,2)=ABS(BZARM)
VALUE(1,3)=ABS(FZ)/VALUE(1,1)
VALUE(2,3)=ABS(BZPOLE)/VALUE(2,1)
VALUE(3,3)=ABS(BZARM)/VALUE(3,1)
*VLEN,3
SAVE,INF2

RESUME,INF1
/OUT,vm241,vrt
/COM
/COM,------------------- VM241 RESULTS COMPARISON ---------------------
/COM,
/COM,          |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,--SOLID237--
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'    ',F7.3,'     ',F14.3,'       ',1F15.3)
/COM,
/NOPR
RESUME,INF2
/COM,--SOLID236--
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'    ',F7.3,'     ',F14.3,'       ',1F15.3)
/COM,----------------------------------------------------------------
/OUT
*LIST,vm241,vrt
FINISH
/DELETE,INF1
/DELETE,INF2
```

VM242 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm242
```

```
/title,vm242,Johnson-Champoux-Allard Equivalent Fluid Model
/com,
/com, Evaluation of the acoustic and non-acoustic properties
/com, of sound absorbing materials using a three-microphone
/com, impedance tube
/com,
/com, Reference:
/com, O.Doutres, Y. Salissou, N. Attalla, R. Panneton, "Evaluation
/com, of the acoustic and non-acoustic properties of sound
/com, absorbing materials using a three-microphone impedance
/com, tube", Applied Acoustics 71 (2010), pg 506-509
/com,


FREQUENCY  = 4000
DIM_WIDTH  = 30e-3
MAT_SPEED  = 343
MAT_DENSITY= 1.2
NUM_EPW    = 8
NUM_STEPS  = 40

MAT_RESIS  = 10800
MAT_PORO   = 0.98
MAT_TORTU  = 1.04
MAT_VISCL  = 129e-6
MAT_THERL  = 198e-6
DIM_PERF   = 51.44e-3

LOADING    = 1e3/MAT_SPEED*2

DIM_WAVELNG= MAT_SPEED/FREQUENCY
DIM_ESIZE  = DIM_WAVELNG/NUM_EPW
DIM_LENGTH = MAT_SPEED/(FREQUENCY/NUM_STEPS)

/prep7
et,1,fluid220   ! FLUID220 elements
keyopt,1,2,1   ! No FSI interface

et,2,fluid220   ! FLUID220 elements
keyopt,2,2,1   ! No FSI Interface

r,1
r,2

mp,sonc,1,MAT_SPEED
mp,dens,1,MAT_DENSITY

mpcopy,,1,2   ! Copy material model data

tb,perf,2
tbdata,1,MAT_RESIS  ! Fluid resistivity
tbdata,2,MAT_PORO  ! Fluid porosity
tbdata,3,MAT_TORTU  ! Fluid tortuosity
tbdata,4,MAT_VISCL  ! Viscous Charactersitic length
tbdata,5,MAT_THERL  ! Thermal Characteristic

block,,DIM_WIDTH,,DIM_LENGTH,,DIM_WIDTH
block,,DIM_WIDTH,,-DIM_PERF,,DIM_WIDTH
nummrg,kp,1e-8,1e-8

vsel,s,loc,y,-DIM_PERF,0
vatt,2,2,2
vsel,all
esize,DIM_ESIZE
vmesh,all

asel,s,loc,y,DIM_LENGTH
nsla,s,1
bf,all,js,LOADING  ! mass source
sf,all,inf   ! Robin radiation boundary flag
allsel,all
finish
```

```
/solu
antype,harmic
harfrq,0,FREQUENCY
nsubst,NUM_STEPS
outres,all,all
kbc,1
solve
finish


/color,curve,blue,1

/post26
numvar,200

asel,s,loc,y,0
nsla,s,1
esln
esel,r,ename,,220,220
MY_NODE=ndnext(0)
nsel,r,node,,MY_NODE
esln
MY_ELEM=elnext(0)

nsol,3,MY_NODE,pres,,P
esol,4,MY_ELEM,MY_NODE,pg,y,V
quot,5,3,4,,Z
filldata,6,,,,MAT_SPEED*MAT_DENSITY,0
quot,7,5,6,,Zratio,,1,-1
filldata,8,,,,1,0
add,9,7,8
add,10,7,8,,,,,1,-1
quot,11,10,9,,R
abs,12,11
prod,13,12,12,,R2
add,14,8,13,,a,,,1,-1

prvar,14
*get,absorp_coeff,vari,14,rtime,1700
/title, Absorption Coefficient vs. Frequency
plvar,14
allsel,all
*dim,label,char,1,2
*dim,value,,1,3

label(1,1)='Absorp'
label(1,2)='Coeff'

*vfill,value(1,1),data,0.988    !absorption coefficient from reference
*vfill,value(1,2),data,absorp_coeff ! absorption coefficient from MAPDL
*vfill,value(1,3),data,abs(0.988/absorp_coeff)

save,table_1
finish
resume,table_1
/com,
/out,vm242,vrt
/com,
/com, ------------------------------VM242 RESULTS COMPARISON----------------------
/com,
/com,                               | TARGET |  Mechanical APDL | RATIO
/com,
/com,
/com,
/com,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'      ','     ',F10.3,'    ',F10.3,'    ',F10.3)
/com,
/com,
/NOPR,
/com,
```

```
/com,
/com, --------------------------------------------------------------------------------
/out,
*list,vm242,vrt
finish
```

VM243 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM243
/TITLE,VM243,CANTILEVER BEAM WITH TRIANGULAR LOADING DEFINED BY FUNCTION
/COM,  REFERENCE: F.P BEER AND E.J. JOHNSTON,JR, MECHANICS OF MATERIALS,
/COM,   MCGRAW-HILL, NEW YORK, NY, 1981, PP. 356,366,397,613
MINLOAD=0     ! MINIMUM LOAD
MAXLOAD=1       ! MAXIMUM LOAD
L=10      ! LENGTH
THICK=1     ! THICKNESS
E1=30e6     ! YOUNGS MODULUS

/PREP7
ET,1,PLANE183
KEYOPT,1,3,3
KEYOPT,1,6,0
KEYOPT,1,10,0
R,1,THICK,
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,1,,E1
MPDATA,PRXY,1,,.27
MPDATA,DENS,1,,1
RECTNG,0,L,0,THICK
RECTNG,0,L,10,10+THICK
AMESH,ALL
*DEL,_FNCNAME
*DEL,_FNCMTID
*SET,_FNCNAME,'PRES1'

*DIM,%_FNCNAME%,TABLE,6,5,1
*SET,%_FNCNAME%(0,0,1), 0.0, -999
*SET,%_FNCNAME%(2,0,1), 0.0
*SET,%_FNCNAME%(3,0,1), 0.0
*SET,%_FNCNAME%(4,0,1), 0.0
*SET,%_FNCNAME%(5,0,1), 0.0
*SET,%_FNCNAME%(6,0,1), 0.0
*SET,%_FNCNAME%(0,1,1), 1.0, -1, 0, (MAXLOAD-MINLOAD)/L, 0, 0, 2
*SET,%_FNCNAME%(0,2,1), 0.0, -2, 0, 1, -1, 3, 2
*SET,%_FNCNAME%(0,3,1),   0, -1, 0, MINLOAD, 0, 0, -2
*SET,%_FNCNAME%(0,4,1), 0.0, -3, 0, 1, -2, 1, -1
*SET,%_FNCNAME%(0,5,1), 0.0, 99, 0, 1, -3, 0, 0

SFL,3,PRES, %PRES1%          ! LOADING BY FUNCTION
SFL,7,PRES,MAXLOAD,MINLOAD   ! LOADING BY TWO END POINT VALUES
DL,4,,ALL,0
DL,8,,ALL,0
FINISH

/SOLU
/STATUS,SOLU
ANTYPE,STATIC
SOLVE
FINISH

/POST1
PLDISP,0
/EFACET,1
AVPRIN,0,
LSEL,S,LINE,,1
NSLL,S,1
```

```
PRNSOL,U,SUM
LSEL,S,LINE,,5
NSLL,S,1
PRNSOL,U,SUM
ALLSEL

I1=(THICK*THICK*THICK*THICK)/12   ! MOMENT OF INERTIA FOR SQUARE BEAM
TARGET_DISP=(11/120)*(L*L*L*MAXLOAD)/(E1*I1)
*GET,TBDISP,NODE,2,U,SUM     ! DISPLACEMENT AT CORNER FOR TABULAR LOADED BEAM
*GET,LDDISP,NODE,127,U,SUM   ! DISPLACEMENT AT CORNER FOR LINEAR LOADED BEAM
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'DISP, TA'
LABEL(1,2) = 'BLE (M)'
LABEL(2,1) = 'DISP, S1'
LABEL(2,2) = 'OPE (M)'

*VFILL,VALUE(1,1),DATA,TARGET_DISP
*VFILL,VALUE(1,2),DATA,TBDISP
*VFILL,VALUE(1,3),DATA,ABS(TBDISP/TARGET_DISP)
*VFILL,VALUE(2,1),DATA,TARGET_DISP
*VFILL,VALUE(2,2),DATA,LDDISP
*VFILL,VALUE(2,3),DATA,ABS(LDDISP/TARGET_DISP)
/COM
/OUT,vm243,vrt
/COM,------------------- VM243 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',E10.3,'  ',E14.3,'   ',1F15.2)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm243,vrt
```

VM244 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM244
/TITLE,VM244, MODAL ANALYSIS OF CYCLIC SYMMETRIC ANNULAR PLATES
C*** ROBERT D BLEVINS,"FORMULAS FOR NATURAL FREQUENCY AND MODE
C*** SHAPE", NEW YORK, NY, VAN NOSTRAND REINHOLD PUBLISHING INC
C*** 1979, PP. 246-247, 286-287
_THETA1 = 0          ! DEGREE, STARTING ANGLE FOR SECTION
_THETA2 = 30   ! DEGREE, ENDING ANGLE FOR SECTION
_FLOWER = 23.381 ! HZ, LOWER FREQUENCY LIMIT PER BLEVINS
_FREQDIF = 2.1   ! PERCENT
_A = 500   ! OUTSIDE RADIUS (MM)
_B = 185   ! INSIDE RADIUS (MM)
_H = 5   ! THICKNESS (MM)
_E = 70000   ! YOUNGS (N/MM^2)
_V = 0.3   ! POISON'S RATIO
_D = 2.7E-9   ! DENSITY AL1100 H14 (NSEC^2/MM^4)
*DIM,VALUE,ARRAY,6,3
*DIM,LABEL,CHAR,6
LABEL(1)='SOLID185'
LABEL(2)='SOLID186'
LABEL(3)='SOLID187'
LABEL(4)='SHELL181'
LABEL(5)='SHELL281'
LABEL(6)='SOLSH190'
*DO,I,1,6,1
*IF,LABEL(I),EQ,'SHELL181',OR,LABEL(I),EQ,'SHELL281',THEN
C*** CYCSYM MODEL, SIMPLE SUPPORT OUTER EDGE, FREE INNER EDGE,
C*** SHELL ELEMENT
/PREP7
MP,EX,1,_E
```

```
MP,NUXY,1,_V
MP,DENS,1,_D
CYL4,0,0,_A,_THETA1,_B,_THETA2
R,1,_H
ET,1,LABEL(I)
AMESH,ALL
NSEL,S,LOC,X,_A
D,ALL,UY
NROTAT,ALL
D,ALL,UZ
NSEL,ALL
CYCLIC
FINISH
*ELSE
C*** CYCSYM MODEL, SIMPLE SUPPORT OUTER EDGE, FREE INNER EDGE
C*** SOLID ELEMENTS
/PREP7
MP,EX,1,_E
MP,NUXY,1,_V
MP,DENS,1,_D
CSYS,6
WPCSYS,6
CYL4,0,0,_A,_THETA1,_B,_THETA2,_H
ET,1,LABEL(I)
*IF,LABEL(I),EQ,'SOLID185',THEN
KEYOPT,1,2,3     ! REDUCE STIFFNESS FORMULATION TO MAKE FREQUENCIES MATCH
*ELSEIF,LABEL(I),EQ,'SOLSH190',THEN
VEORIENT,1,THIN
*ENDIF
VMESH,ALL
CSYS,4
NSEL,S,LOC,X,_A-.00001,_A+.00001
NSEL,R,LOC,Z,0
D,ALL,UY
NROTAT,ALL
D,ALL,UZ
NSEL,ALL
CYCLIC
FINISH
*ENDIF
/SOLU
ANTYPE,2
MODOPT,LANB,3
MXPAND,3, , ,1
MODOPT,LANB,3,1,100000, ,OFF
CYCOPT,HINDEX,0,0
SOLVE
FINISH
/POST1
*GET,F%I%,MODE,1,FREQ
/COM,                 FREQUENCY COMPARE FOR ELEMENT %LABEL(I)%
*IF,(ABS((F%I% - _FLOWER)/_FLOWER))*100,LT,_FREQDIF,THEN
C*** FREQUENCIES COMPARE WITHIN BLEVINS RESULT!!!
*ELSE
C*** FAILURE: FREQUENCIES OUT OF ACCAPTABLE LIMITS!!!
FINISH
*ENDIF
FINISH
PARSAV,ALL
/CLEAR,NOSTART
PARRES,
*ENDDO
*VFILL,VALUE(1,1),DATA,_FLOWER,_FLOWER,_FLOWER,_FLOWER,_FLOWER,_FLOWER
*VFILL,VALUE(1,2),DATA,F1,F2,F3,F4,F5,F6
*VFILL,VALUE(1,3),DATA,ABS(F1/_FLOWER),ABS(F2/_FLOWER),ABS(F3/_FLOWER),ABS(F4/_FLOWER),ABS(F5/_FLOWER),ABS(F6/_F
/OUT,vm244,vrt
/COM,------------------- VM244 RESULTS COMPARISON -------------
/COM,
/COM,                 |    TARGET   |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A10,'     ',E10.4,'    ',E14.4,'     ',1F15.3)
```

```
/COM,---------------------------------------------------------
/OUT
FINISH
*LIST,vm244,vrt
```

VM245 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM245
/TITLE, VM245,SQUEEZE FILM DAMPING-RECTANGULAR PLATE
/COM, REFERENCE:  COUPLED FLUID-STRUCTURAL DOMAIN SOLVER AND ROM
/COM,    EXTRACTION FOR MEMS, J. MEHNER, 1/31/03
/COM,   BENCHMARK #1: RECTANGULAR PLATE
/COM,
/COM, CHARACTERISTICS:
/COM,  UNIFORM VELOCITY (FLUE) LOAD, SINGLE SIDE
/COM,  UMKS UNITS, GLOBAL CARTESIAN C.S.
/COM,    BLOCK LANCHOS, JCG SOLVERS,TRI MESH
/COM,    4-NODE QUAD OPTION, THK AND AMBIENT PRESSURE
/COM,  REFERENCE PRESSURE, MEAN FREE PATH
/COM,  COMPUTE AND EXTRACT SQUEEZE FILM AND DAMPING COEFFICIENT
/COM,
/COM,************************ INPUT PARAMETERS ********************************
/COM,
/COM, PLATE LENGTH = 2000 UM
/COM, PLATE WIDTH = 1000 UM
/COM, FILM THICKNESS = 5 UM
/COM, AMBIENT PRESSURE = 0.1 KG/(UM)(S^2)
/COM, DYNAMIC VISCOSITY = 18.3E-12 KG/(UM)(S)
/COM, ARBITRARY UNIFORM VELOCITY = 2000 UM/S
/COM, OPERATING FREQUENCY = 100000 HZ
/COM,
/COM,************************ EXPECTED RESULTS ********************************
/COM,
/COM, DAMPING COEFFICIENT AT 100 KHZ = 15.29E-3
/COM, SQUEEZE STIFFNESS COEFFICIENT AT 100 KHZ = 28.65E3
/COM,
/COM,*************************************************************************
/COM,

/PREP7

ET,1,FLUID136

A=.001E6    ! PLATE WIDTH (UM)
B=.002E6    ! PLATE LENGTH (UM)
D=5     ! GAP (UM)
PO=0.1     ! NORMNAL PRESSURE (KG/(UM)(S^2))
VISC=18.3E-12    ! VISCOSITY (KG/UM/S)
VELO=0.002E6        ! ARBITRARY UNIFORM VELOCITY (UM/SEC)
AREA=A*B           ! PLATE AREA
FREQ=100000        ! OPERATING FREQUENCY (HZ.)
OMEGA=2*3.14159*FREQ

MP,VISC,1,VISC
R,1,D,,,PO

RECTNG,0,B,0,A
MSHAPE,1
ESIZE,,40
AMESH,ALL

NSEL,EXT
D,ALL,PRESS,0           ! SET PRESSURE TO ZERO
NSEL,ALL

BFE,ALL,FLUE,,VELO
```

```
FINISH

/SOLU
ANTYP,HARM     ! HARMONIC THERMAL ANALYSIS
HARFRQ,FREQ
EQSLV,JCG
SOLVE
FINISH

/POST1
/OUT,SCRATCH
SET,1,1
ETABLE,PRESR,PRESS   ! EXTRACT "REAL" PRESSURE
ETABLE,EAREA,VOLU
SMULT,FORR,PRESR,EAREA   ! COMPUTE "REAL" FORCE
SSUM
*GET,FRE,SSUM,,ITEM,FORR
SET,1,1,,1
ETABLE,PRESI,PRESS   ! EXTRACT "IMAGINARY" PRESSURE
SMULT,FORI,PRESI,EAREA   ! COMPUTE "IMAGINARY" PRESSURE
SSUM
*GET,FIM,SSUM,,ITEM,FORI

K=ABS(FIM*OMEGA/VELO)   ! COMPUTE EQUIVALENT STIFFNESS
C=ABS(FRE/VELO)    ! COMPUTE EQUIVALENT DAMPING

FINISH

/POST1
*GET,EFFECTIVE_VISCOSITY,ELEM,1,NMISC,1
*GET,ACTUAL_GAP_SEPARATION,ELEM,1,NMISC,2
/OUT
/COM,
/COM,************************** OUTPUT RESULTS *******************************
/COM,
*VWRITE, EFFECTIVE_VISCOSITY
(/' EFFECTIVE VISCOSITY = ',E13.6)
*VWRITE, ACTUAL_GAP_SEPARATION
(/' ACTUAL GAP SEPARATION = ',E13.6)
 *VWRITE, K
(/' EQUIVALENT STIFFNESS = ',E13.6)
*VWRITE, C
(/' EQUIVALENT DAMPING = ',E13.6)
/COM,
/COM,***************************************************************************
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'K ','C '
LABEL(1,2) = 'NS/M','N/M'
*VFILL,VALUE(1,1),DATA,28.65E3,15.29E-3
*VFILL,VALUE(1,2),DATA,K,C
*VFILL,VALUE(1,3),DATA,ABS(K/28.65E3),ABS(C/15.29E-3)
/COM
/OUT,vm245,vrt
/COM,------------------- VM245 RESULTS COMPARISON -------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm245,vrt

FINISH
```

VM246 Input Listing

```
/VERIFY,VM246
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/TITLE,VM246, CYCLIC ANALYSIS OF AN END-LOADED HOLLOW CYLINDRICAL CANTILEVER BEAM
/COM,************************************************************
/COM,* PREMISE OF TEST:   TEST UTILIZES THE FUNDAMENTAL FEATURES *
/COM,*                    OF ANSYS TO VERIFY FEA RESULTS          *
/COM,*                    TO CALCULATED APPROXIMATION RESULTS     *
/COM,************************************************************
/COM,************************************************************
/COM,*                   TEST OBJECTIVES:                         *
/COM,*                                                            *
/COM,* TEST THAT DEFLECTION VALUES MATCH THEORETICAL DEFLECTION   *
/COM,* TEST CYCLIC EXPANSION FEATURE                              *
/COM,*                                                            *
/COM,************************************************************
/COM,************************************************************
/COM,*                   VARIABLE DEFINITION:                     *
/COM,*                                                            *
/COM,*  _THETA1    = STARTING ANGLE FOR SECTION                   *
/COM,*  _THETA2    = ENDING ANGLE FOR SECTION                     *
/COM,*  _FLOWER    = MAX DISPLACEMENT                             *
/COM,*                                                            *
/COM,************************************************************
/COM,************************************************************
/COM,*                       REFFERENCES:                         *
/COM,*                                                            *
/COM,*  F. P. BEER, E. R. JOHNSTON, JR.,"MECHANICS OF MATERIALS" *
/COM,*  NEW YORK, NY, MCGRAW-HILL,INC 1981, P 598.                *
/COM,*                                                            *
/COM,************************************************************
/OUT,SCRATCH
/COM,**********************************************************
/COM,*                                                        *
/COM,*              ANALYSIS PARAMETER DEFINITIONS            *
/COM,*                                                        *
/COM,**********************************************************
/SHOW,PLOTS,GRPH
/GRAPHICS,POWER

_A = .5   !OUTSIDE RADIUS (IN)
_B = .25  !INSIDE RADIUS (IN)
_L = 10   !LENGTH (IN)
_E = 70000  !YOUNGS (PSI)
_V = 0.3  !POISON'S RATIO
_THETA1 = 0  !DEGREE
_THETA2 = 30  !DEGREE
_FLOWER =0.5187         !DISPLACEMENT
_FREQDIF = 2.1  !PERCENT

*DIM,VALUE,ARRAY,3,3
*DIM,LABEL,CHAR,3
LABEL(1)='SOLID185'
LABEL(2)='SOLID186'
LABEL(3)='SOLID187'

*DO,I,1,3,1

/COM,***********************************************************
/COM,*                                                         *
/COM,* FOLLOWING BLOCK OF INPUT WAS USED TO GENERATE MODEL     *
/COM,*                                                         *
/COM,***********************************************************
/COM,***********************************************************
/COM,*                                                         *
/COM,*  CYCSYM MODEL, FIXED AT ORGIN, 5LB LOAD AT FREE END     *
/COM,*  SOLID ELEMENTS                                         *
/COM,*                                                         *
```

```
/COM,************************************************************

/PREP7
        MP,EX,1,_E
 MP,NUXY,1,_V
 CSYS,1
 CYL4,0,0,_A,_THETA1,_B,_THETA2,_L
        ET,1,LABEL(I)
        TYPE,1

*IF,LABEL(I),EQ,'SOLID185',THEN
 KEYOPT,1,2,2                      !ENHANCED STRAIN FORMULATION


*ELSEIF,LABEL(I),EQ,'SOLID186',THEN
 KEYOPT,1,2,1                         !FULL INTERGRATION


*ELSE,LABEL(I),EQ,'SOLID187',THEN
 KEYOPT,1,6,0                      !USE PURE DISPLACEMENT FORMULATION
*ENDIF

        VMESH,ALL

        CYCLIC
        /CYCEXP,,ON

ASEL,S,AREA,,1
DA,ALL,ALL
ALLSEL

        /COM,SECTOR 12 FN
        CYCOPT,LDSECT,12
        NSEL,S,LOC,Z,10
 NSEL,R,LOC,X,_A
 NSEL,R,LOC,Y,0
        F,ALL,FX,-5
        ALLSEL

FINISH                                !EXIT PREPROCESSING
/SOLU           !ENTER SOLUTION
SOLVE

FINISH      !EXIT SOLUTION
/POST1      !ENTER POST PROCESSING
/CYCEXPAND,,ON
SET,FIRST
PLNSOL,U,SUM
*GET,F%I%,PLNSOL,0,MAX

/OUT
/COM,
/COM,*********************************************************************
/COM,
/COM,                        COMPARE RESULTS:
/COM,             DISPLACEMENT COMPARE FOR ELEMENT %LABEL(I)%
/COM,*********************************************************************
/COM,
/OUT,SCRATCH
*IF,(ABS((F%I% - _FLOWER)/_FLOWER))*100,LT,_FREQDIF,THEN
        /OUT
           /COM,*********************************************************
           /COM,*                                                       *
           /COM,*  DISPLACEMENT MATCHES THEORETICAL RESULT!!!           *
           /COM,*                                                       *
           /COM,*********************************************************
           /COM,
 /OUT,SCRATCH
        *ELSE
        /OUT
           /COM,*********************************************************
           /COM,*                                                       *
```

```
            /COM,*  FAILURE: DISPLACEMENT OUT OF ACCAPTABLE LIMITS!!!     *
            /COM,*                                                        *
            /COM,**********************************************************
         FINISH                          !EXIT PREP7
         *ENDIF                          !CLOSE IF LOOP

 FINISH
 PARSAV,ALL
 /CLEAR,NOSTART
 PARRES,
 *ENDDO

 *VFILL,VALUE(1,1),DATA,_FLOWER,_FLOWER,_FLOWER
 *VFILL,VALUE(1,2),DATA,F1,F2,F3
 *VFILL,VALUE(1,3),DATA,ABS(F1/_FLOWER),ABS(F2/_FLOWER),ABS(F3/_FLOWER)

 *STAT,VALUE
 /OUT,vm246,vrt
 /OUT,
 /COM,------------------- VM246 RESULTS COMPARISON -------------
 /COM,
 /COM,                 |     TARGET    |     Mechanical APDL    |     RATIO
 /COM,
 *VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
 (8X,A9,4X,F8.2,4X,E15.5,4X,E15.5,4X,F14.5)
 /COM,----------------------------------------------------------
 /COM,
 /COM,
 /COM,*************************************************
 /COM,*************************************************
 /COM,********* ALL TEST WERE SUCCESSFUL !!! **********
 /COM,*************************************************
 /COM,*************************************************
 FINISH                                    !FINISH
 *LIST,vm246,vrt
 QAEND,23
```

VM247 Input Listing

```
 /COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
 /VERIFY,VM247
 /TITLE, VM247 CAMPBELL DIAGRAMS AND CRITICAL SPEEDS USING SYMMETRIC BEARINGS
 /COM,   REF: "THE DYNAMICS OF ROTOR-BEARING SYSTEMS USING FINITE ELEMENTS"
 /COM,   JOURNAL OF ENG. FOR INDUSTRY - MAY 1976
 /COM
 /PREP7
 *DIM,SPIN,,4                                    ! SPIN VELOCITY (RPM)
 SPIN(1) = 0.
 SPIN(2) = 35000.
 SPIN(3) = 70000.
 SPIN(4) = 105000.
 RO = 7806                                          ! MATERIAL #1 : STEEL
 PEX = 2.078E+11
 PGXY = 1.E+12                                     ! NO SHEAR
 MP,EX,1,PEX
 MP,DENS,1,RO
 MP,GXY,1,PGXY
 ET,1,BEAM188,,,2                                           ! ELEMENT TYPE #1 : SHAFT
 NBDIAM = 18                                                ! SHAFT SECTION PROPERTIES
 *DIM,DIAM,ARRAY,NBDIAM
 DIAM(1) = 1.02E-2
 DIAM(2) = 2.04E-2
 DIAM(3) = 1.52E-2
 DIAM(4) = 4.06E-2
 DIAM(5) = DIAM(4)
 DIAM(6) = 6.6E-2
 DIAM(7) = DIAM(6)
 DIAM(8) = 5.08E-2
```

```
DIAM(9) = DIAM(8)
DIAM(10) = 2.54E-2
DIAM(11) = DIAM(10)
DIAM(12) = 3.04E-2
DIAM(13) = DIAM(12)
DIAM(14) = 2.54E-2
DIAM(15) = DIAM(14)
DIAM(16) = 7.62E-2
DIAM(17) = 4.06E-2
DIAM(18) = DIAM(17)
*DO,I,1,NBDIAM
   SECTYPE,I,BEAM,CSOLID
   SECDATA,DIAM(I)/2
*ENDDO
SECTYPE,7,BEAM,CTUBE
SECDATA,(DIAM(7)/2 - (DIAM(7) - 3.04E-2)/2),DIAM(7)/2
SECTYPE,8,BEAM,CTUBE
SECDATA,(DIAM(8)/2 - (DIAM(8) - 3.56E-2)/2),DIAM(8)/2
SECTYPE,18,BEAM,CTUBE
SECDATA,(DIAM(18)/2 - (DIAM(18) - 3.04E-2)/2),DIAM(18)/2
ET,2,MASS21                                                  ! ELEMENT TYPE #2 : DISK
R,20,1.401,1.401,1.401,0.002,0.00136,0.00136                 ! REAL FOR DISK
ET,3,COMBIN14                                                ! ELEMENT TYPE #3 : BEARINGS
KEYOPT,3,2,2                                            ! Y DIRECTION
ET,4,COMBIN14
KEYOPT,4,2,3                                            ! Z DIRECTION
R,30,4.378E+7                                                ! BEARINGS
N,1 ,0.
N,2 ,1.27E-2
N,3 ,5.08E-2
N,4 ,7.62E-2
N,5 ,8.89E-2
N,6 ,10.16E-2
N,7 ,10.67E-2
N,8 ,11.43E-2
N,9 ,12.7E-2
N,10,13.46E-2
N,11,16.51E-2
N,12,19.05E-2
N,13,22.86E-2
N,14,26.67E-2
N,15,28.7E-2
N,16,30.48E-2
N,17,31.5E-2
N,18,34.54E-2
N,19,35.5E-2
BRG = 0                                            ! BEARING "LENGTH" FOR VISUALISATION
N,20,16.51E-2,BRG
N,21,16.51E-2,,BRG
N,22,28.7E-2,BRG
N,23,28.7E-2,,BRG
TYPE,1                                                      ! CREATE SHAFT ELEMENTS
MAT,1
*DO,I,1,NBDIAM
   SECNUM,I
   E,I,I+1
*ENDDO
TYPE,2                                                      ! CREATE DISK ELEMENTS
REAL,20
E,5
TYPE,3                                                      ! CREATE BEARING ELEMENTS
REAL,30
E,11,20
E,15,22
TYPE,4
REAL,30
E,11,21
E,15,23
FINI
/SOLU
D,ALL,UX                                                    ! NO TRACTION & NO TORSION
D,ALL,ROTX
```

```
D,20,ALL
D,21,ALL
D,22,ALL
D,23,ALL
RATIO = 4*ATAN(1)/30
ANTYPE,MODAL
CORIOLIS,ON,,,ON                                        ! CORIOLIS ON IN A STATIONARY REFERENCE FRAME
NBF = 20
MODOPT,QRDAMP,NBF,,,ON
QRDOPT,ON          ! REUSE FLAG ON
/OUT,SCRATCH
*DO,I,1,4
   OMEGA,SPIN(I)*RATIO
   MXPAND,NBF
   SOLVE
*ENDDO
FINI
/POST1
PRCAMP,,1.,RPM                                         ! PRINT CAMPBELL VALUES FOR SLOPE=1, UNIT= RPM
PLCAMP,,1.,RPM
*GET,CRIC1,CAMP,1,VCRI,,,
*GET,CRIC2,CAMP,2,VCRI,,,
*GET,CRIC3,CAMP,3,VCRI,,,
*GET,CRIC4,CAMP,4,VCRI,,,
*GET,CRIC5,CAMP,5,VCRI,,,
*GET,CRIC6,CAMP,6,VCRI,,,

PRCAMP,,4.,RPM                                         ! PRINT CAMPBELL VALUES FOR SLOPE=4, UNIT= RPM
PLCAMP,,4.,RPM
*GET,CRIC7,CAMP,1,VCRI,,,
*GET,CRIC8,CAMP,2,VCRI,,,
*GET,CRIC9,CAMP,3,VCRI,,,
*GET,CRIC10,CAMP,4,VCRI,,,
*GET,CRIC11,CAMP,5,VCRI,,,
*GET,CRIC12,CAMP,6,VCRI,,,

*DIM,LABEL,CHAR,1,12
*DIM,VALUE,,12,3
LABEL(1,1) = 'CRIC1'
LABEL(1,2) = 'CRIC2'
LABEL(1,3) = 'CRIC3'
LABEL(1,4) = 'CRIC4'
LABEL(1,5) = 'CRIC5'
LABEL(1,6) = 'CRIC6'
LABEL(1,7) = 'CRIC7'
LABEL(1,8) = 'CRIC8'
LABEL(1,9) = 'CRIC9'
LABEL(1,10) = 'CRIC10'
LABEL(1,11) = 'CRIC11'
LABEL(1,12) = 'CRIC12'
/COM,
/COM, WHIRL SPEEDS OBTAINED FOR SLOPE = 1
/COM,
*VFILL,VALUE(1,1),DATA,15470                           ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE
*VFILL,VALUE(1,2),DATA,CRIC1
*VFILL,VALUE(1,3),DATA,ABS(CRIC1/15470)
*VFILL,VALUE(2,1),DATA,17159                           ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE
*VFILL,VALUE(2,2),DATA,CRIC2
*VFILL,VALUE(2,3),DATA,ABS(CRIC2/17159)
*VFILL,VALUE(3,1),DATA,46612                           ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE
*VFILL,VALUE(3,2),DATA,CRIC3
*VFILL,VALUE(3,3),DATA,ABS(CRIC3/46612)
*VFILL,VALUE(4,1),DATA,49983                           ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE
*VFILL,VALUE(4,2),DATA,CRIC4
*VFILL,VALUE(4,3),DATA,ABS(CRIC4/49983)
*VFILL,VALUE(5,1),DATA,64752                           ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE
*VFILL,VALUE(5,2),DATA,CRIC5
*VFILL,VALUE(5,3),DATA,ABS(CRIC5/64752)
*VFILL,VALUE(6,1),DATA,96457                           ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE
*VFILL,VALUE(6,2),DATA,CRIC6
*VFILL,VALUE(6,3),DATA,ABS(CRIC6/96457)
/COM,
```

```
/COM, WHIRL SPEEDS OBTAINED FOR SLOPE = 4
/COM,
*VFILL,VALUE(7,1),DATA,4015                            ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(7,2),DATA,CRIC7
*VFILL,VALUE(7,3),DATA,ABS(CRIC7/4015)
*VFILL,VALUE(8,1),DATA,4120.25                         ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(8,2),DATA,CRIC8
*VFILL,VALUE(8,3),DATA,ABS(CRIC8/4120)
*VFILL,VALUE(9,1),DATA,11989.25                        ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(9,2),DATA,CRIC9
*VFILL,VALUE(9,3),DATA,ABS(CRIC9/11989)
*VFILL,VALUE(10,1),DATA,12200                          ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(10,2),DATA,CRIC10
*VFILL,VALUE(10,3),DATA,ABS(CRIC10/12200)
*VFILL,VALUE(11,1),DATA,18184.25                       ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(11,2),DATA,CRIC11
*VFILL,VALUE(11,3),DATA,ABS(CRIC11/18184)
*VFILL,VALUE(12,1),DATA,20162.25                       ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(12,2),DATA,CRIC12
*VFILL,VALUE(12,3),DATA,ABS(CRIC12/20162)
/COM
/OUT,vm247,vrt
/COM,------------ VM247 RESULTS COMPARISON --------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL    |   RATIO
/COM,
/COM, ---------------------------------------
/COM, WHIRL SPEEDS WITH SLOPE = 1.0
/COM, --------------------------------------
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,3),VALUE(3,1),VALUE(3,2),VALUE(3,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,4),VALUE(4,1),VALUE(4,2),VALUE(4,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,5),VALUE(5,1),VALUE(5,2),VALUE(5,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,6),VALUE(6,1),VALUE(6,2),VALUE(6,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM, ------------------------------------
/COM, WHIRL SPEEDS WITH SLOPE = 4.0
/COM, ------------------------------------
*VWRITE,LABEL(1,7),VALUE(7,1),VALUE(7,2),VALUE(7,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,8),VALUE(8,1),VALUE(8,2),VALUE(8,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,9),VALUE(9,1),VALUE(9,2),VALUE(9,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,10),VALUE(10,1),VALUE(10,2),VALUE(10,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,11),VALUE(11,1),VALUE(11,2),VALUE(11,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,12),VALUE(12,1),VALUE(12,2),VALUE(12,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM
/OUT
FINISH
*LIST,vm247,vrt
```

VM248 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM248
/TITLE, VM248, DELAMINATION OF DOUBLE CANTILEVER BEAM - 2D PLANE STRAIN
C*** USING INTER202
```

```
/COM,   REF: ALFANO, G. AND CRISFIELD, M. A.,
/COM,   "FINITE ELEMENT INTERFACE MODELS FOR THE DELAMINATION ANALYSIS
/COM,   OF LAMINATED COMPOSITES: MECHANICAL AND COMPUTATIONAL ISSUES"
/COM,   INT. J. NUMER. METH. ENGNG 2001, 50:1701-1736.
/PREP7
ET,1,182                    !* 2D 4-NODE STRUCTURAL SOLID ELEMENT
KEYOPT,1,1,2                !* ENHANCE STRAIN FORMULATION
KEYOPT,1,3,2                !* PLANE STRAIN
ET,2,182
KEYOPT,2,1,2
KEYOPT,2,3,2
ET,3,202                    !* 2D 4-NODE COHESIVE ZONE ELEMENT
KEYOPT,3,3,2                !* PLANE STRAIN
MP,EX,4,1.353E5             !* E11 = 135.3 GPA
MP,EY,4,9.0E3               !* E22 =   9.0 GPA
MP,EZ,4,9.0E3               !* E33 =   9.0 GPA
MP,GXY,4,5.2E3              !* G12 =   5.2 GPA
MP,PRXY,4,0.24
MP,PRXZ,4,0.24
MP,PRYZ,4,0.46
GMAX = 0.004
TNMAX = 25                  !* TENSILE STRENGTH
TB,CZM,5,,,EXPO             !* COHESIVE ZONE MATERIAL
TBDATA,1,TNMAX,GMAX,1000.0
RECTNG,0,100,0,1.5          !* DEFINE AREAS
RECTNG,0,100,0,-1.5
LSEL,S,LINE,,2,8,2          !* DEFINE LINE DIVISION
LESIZE,ALL,0.75
LSEL,INVE
LESIZE,ALL, , ,200
ALLSEL,ALL
TYPE,1                      !* MESH AREA 2
MAT,4
LOCAL,11,0,0,0,0
ESYS,11
AMESH,2
CSYS,0
TYPE,2                      !* MESH AREA 1
ESYS,11
AMESH,1
CSYS,0
NSEL,S,LOC,X,30,100
NUMMRG,NODES
ESLN
TYPE,3
MAT,5
CZMESH,,,1,Y,0,             !* GENERATE INTERFACE ELEMENTS
ALLSEL,ALL
NSEL,S,LOC,X,100            !* APPLY CONSTRAINTS
D,ALL,ALL
NSEL,ALL
FINISH
/SOLU
ESEL,S,TYPE,,2
NSLE,S
NSEL,R,LOC,X
NSEL,R,LOC,Y,1.5            !* APPLY DISPLACEMENT LOADING ON TOP
D,ALL,UY,10
NSEL,ALL
ESEL,ALL
ESEL,S,TYPE,,1
NSLE,S
NSEL,R,LOC,X
NSEL,R,LOC,Y,-1.5           !* APPLY DISPLACEMENT LOADING ON BOTTOM
D,ALL,UY,-10
NSEL,ALL
ESEL,ALL
NLGEOM,ON
AUTOTS,ON
TIME,1
NSUBST,40,40,40
OUTRES,ALL,ALL
```

```
/OUT,SCRATCH
SOLVE                      !* PERFORM SOLUTION
FINISH
/POST26
NSEL,S,LOC,Y,1.5
NSEL,R,LOC,X,0
*GET,NTOP,NODE,0,NUM,MAX
NSEL,ALL
NSOL,2,NTOP,U,Y,UY
RFORCE,3,NTOP,F,Y,FY
PROD,4,3, , ,RF, , ,20
/TITLE,VM248, DCB: REACTION AT TOP NODE VERSES PRESCRIBED DISPLACEMENT
/AXLAB,X,DISP U (mm)
/AXLAB,Y,REACTION FORCE R (N)
/YRANGE,0,60
XVAR,2
PLVAR,4
PRVAR,UY,RF
*GET,TMAX,VARI,4,EXTREM,TMAX   !* TIME CORRESPONDING TO MAX RFORCE
FINISH
/POST1
SET, , , , ,TMAX               !* RETRIEVE RESULTS AT TMAX
NSEL,S,NODE, ,NTOP             !* SELECT NODE NTOP
/OUT,
*GET,RF_NTOP,NODE,NTOP,RF,FY   !* FY RFORCE AT NODE NTOP
*GET,UY_NTOP,NODE,NTOP,U,Y     !* DISP AT NODE NTOP CORRESPONDING TO RFORCE
RF_MAX = RF_NTOP*20            !* PLANE STRAIN OPTION AND WIDTH = 20 mm
SET,LAST                       !* RETRIEVE RESULTS AT LAST SUBSTEP
*GET,RF_END,NODE,NTOP,RF,FY    !* FY RFORCE AT NODE NTOP AT LAST SUBSTEP
*GET,UY_END,NODE,NTOP,U,Y      !* DISP AT NODE NTOP CORRESPONDING TO RFORCE
RF_END = RF_END*20             !* PLANE STRAIN OPTION AND WIDTH = 20 mm
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
*DIM,VALUE2,,2,3
LABEL(1,1) = 'RFORCE','DISP '
LABEL(1,2) = 'FY (N)','UY (mm)'
*VFILL,VALUE(1,1),DATA,60.0,1.0
*VFILL,VALUE(1,2),DATA,RF_MAX,UY_NTOP
*VFILL,VALUE(1,3),DATA,ABS(RF_MAX/60.0),ABS(UY_NTOP/1.0)
*VFILL,VALUE2(1,1),DATA,24,10.0
*VFILL,VALUE2(1,2),DATA,RF_END,UY_END
*VFILL,VALUE2(1,3),DATA,ABS(RF_END/24.0),ABS(UY_END/10.0)
SAVE,INF1
FINI
/CLEAR,NOSTART
/OUT,SCRATCH



/TITLE, VM248, DELAMINATION OF DOUBLE CANTILEVER BEAM - 2D PLANE STRAIN
C*** USING INTER203
/PREP7
ET,1,183                   !* 2D 8-NODE STRUCTURAL SOLID ELEMENT
KEYOPT,1,3,2               !* PLANE STRAIN
ET,2,183
KEYOPT,2,3,2
ET,3,203                   !* 2D 6-NODE COHESIVE ZONE ELEMENT
KEYOPT,3,3,2               !* PLANE STRAIN
MP,EX,4,1.353E5            !* E11 = 135.3 GPA
MP,EY,4,9.0E3              !* E22 =   9.0 GPA
MP,EZ,4,9.0E3              !* E33 =   9.0 GPA
MP,GXY,4,5.2E3             !* G12 =   5.2 GPA
MP,PRXY,4,0.24
MP,PRXZ,4,0.24
MP,PRYZ,4,0.46
GMAX = 0.004
TNMAX = 25                 !* TENSILE STRENGTH
TB,CZM,5,,,EXPO            !* COHESIVE ZONE MATERIAL
TBDATA,1,TNMAX,GMAX,1000.0
RECTNG,0,100,0,1.5         !* DEFINE AREAS
RECTNG,0,100,0,-1.5
LSEL,S,LINE,,2,8,2         !* DEFINE LINE DIVISION
```

```
LESIZE,ALL,1.5
LSEL,INVE
LESIZE,ALL, , ,200
ALLSEL,ALL
TYPE,1                      !* MESH AREA 2
MAT,4
LOCAL,11,0,0,0,0
ESYS,11
AMESH,2
CSYS,0
TYPE,2                      !* MESH AREA 1
ESYS,11
AMESH,1
CSYS,0
NSEL,S,LOC,X,30,100
NUMMRG,NODES
ESLN
TYPE,3
MAT,5
CZMESH,,,1,Y,0,             !* GENERATE INTERFACE ELEMENTS
ALLSEL,ALL
NSEL,S,LOC,X,100            !* APPLY CONSTRAINTS
D,ALL,ALL
NSEL,ALL
FINISH
/SOLU
ESEL,S,TYPE,,2
NSLE,S
NSEL,R,LOC,X
NSEL,R,LOC,Y,1.5            !* APPLY DISPLACEMENT LOADING ON TOP
D,ALL,UY,10
NSEL,ALL
ESEL,ALL
ESEL,S,TYPE,,1
NSLE,S
NSEL,R,LOC,X
NSEL,R,LOC,Y,-1.5           !* APPLY DISPLACEMENT LOADING ON BOTTOM
D,ALL,UY,-10
NSEL,ALL
ESEL,ALL
NLGEOM,ON
AUTOTS,ON
TIME,1
NSUBST,40,40,40
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE                       !* PERFORM SOLUTION
FINISH
/POST26
NSEL,S,LOC,Y,1.5
NSEL,R,LOC,X,0
*GET,NTOP,NODE,0,NUM,MAX
NSEL,ALL
NSOL,2,NTOP,U,Y,UY
RFORCE,3,NTOP,F,Y,FY
PROD,4,3, , ,RF, , ,20
/TITLE,VM248, DCB: REACTION AT TOP NODE VERSES PRESCRIBED DISPLACEMENT
/AXLAB,X,DISP U (mm)
/AXLAB,Y,REACTION FORCE R (N)
/YRANGE,0,60
XVAR,2
PLVAR,4
PRVAR,UY,RF
*GET,TMAX,VARI,4,EXTREM,TMAX   !* TIME CORRESPONDING TO MAX RFORCE
FINISH
/POST1
SET, , , , ,TMAX               !* RETRIEVE RESULTS AT TMAX
NSEL,S,NODE, ,NTOP             !* SELECT NODE NTOP
/OUT,
*GET,RF_NTOP,NODE,NTOP,RF,FY   !* FY RFORCE AT NODE NTOP
*GET,UY_NTOP,NODE,NTOP,U,Y     !* DISP AT NODE NTOP CORRESPONDING TO RFORCE
RF_MAX = RF_NTOP*20            !* PLANE STRAIN OPTION AND WIDTH = 20 mm
```

```
SET,LAST                       !* RETRIEVE RESULTS AT LAST SUBSTEP
*GET,RF_END,NODE,NTOP,RF,FY    !* FY RFORCE AT NODE NTOP AT LAST SUBSTEP
*GET,UY_END,NODE,NTOP,U,Y      !* DISP AT NODE NTOP CORRESPONDING TO RFORCE
RF_END = RF_END*20             !* PLANE STRAIN OPTION AND WIDTH = 20 mm
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
*DIM,VALUE2,,2,3
LABEL(1,1) = 'RFORCE','DISP '
LABEL(1,2) = 'FY (N)','UY (mm)'
*VFILL,VALUE(1,1),DATA,60.0,1.0
*VFILL,VALUE(1,2),DATA,RF_MAX,UY_NTOP
*VFILL,VALUE(1,3),DATA,ABS(RF_MAX/60.0),ABS(UY_NTOP/1.0)
*VFILL,VALUE2(1,1),DATA,24,10.0
*VFILL,VALUE2(1,2),DATA,RF_END,UY_END
*VFILL,VALUE2(1,3),DATA,ABS(RF_END/24.0),ABS(UY_END/10.0)
SAVE,INF2
FINI
/CLEAR,NOSTART
/OUT,SCRATCH



/TITLE, VM248, DELAMINATION OF DOUBLE CANTILEVER BEAM - 2D PLANE STRAIN
C*** USING INTER205
/PREP7
ET,1,185     !* 3D 8-NODE STRUCTURAL SOLID ELEMENT
KEYOPT,1,2,2              !* PLANE STRAIN
ET,2,185
KEYOPT,2,2,2
ET,3,205                  !* 3D 8-NODE COHESIVE ZONE ELEMENT
MP,EX,4,1.353E5           !* E11 = 135.3 GPA
MP,EY,4,9.0E3             !* E22 =   9.0 GPA
MP,EZ,4,9.0E3             !* E33 =   9.0 GPA
MP,GXY,4,5.2E3            !* G12 =   5.2 GPA
MP,GYZ,4,5.2E3
MP,GXZ,4,3.08E3
MP,PRXY,4,0.24
MP,PRXZ,4,0.24
MP,PRYZ,4,0.46
GMAX = 0.004
TNMAX = 25                !* TENSILE STRENGTH
TB,CZM,5,,,EXPO           !* COHESIVE ZONE MATERIAL
TBDATA,1,TNMAX,GMAX,1000.0
BLC4,0,0,100,1.5,1        !* DEFINE VOLUMES
BLC4,0,0,100,-1.5,1
LSEL,S,LINE,,10,11,1      !* DEFINE LINE DIVISION
LSEL,A,LINE,,22,23,1
LESIZE,ALL,,,1
LSEL,S,LINE,,7,17,10
LESIZE,ALL,,,200
LSEL,S,LINE,,6,18,12
LESIZE,ALL,1.5
ALLSEL,ALL
TYPE,1                    !* MESH VOLUME 2
MAT,4
LOCAL,11,0,0,0,0
ESYS,11
VMESH,2
CSYS,0
TYPE,2                    !* MESH VOLUME 1
ESYS,11
VMESH,1
CSYS,0
NSEL,S,LOC,X,30,100
NUMMRG,NODES
ESLN
TYPE,3
MAT,5
CZMESH,,,1,Y,0,           !* GENERATE INTERFACE ELEMENTS
ALLSEL,ALL
NSEL,S,LOC,X,100          !* APPLY CONSTRAINTS
D,ALL,ALL
```

```
NSEL,ALL
D,ALL,UZ,0

FINISH
/SOLU
ESEL,S,TYPE,,2
NSLE,S
NSEL,R,LOC,X
NSEL,R,LOC,Y,1.5           !* APPLY DISPLACEMENT LOADING ON TOP
D,ALL,UY,10
NSEL,ALL
ESEL,ALL
ESEL,S,TYPE,,1
NSLE,S
NSEL,R,LOC,X
NSEL,R,LOC,Y,-1.5          !* APPLY DISPLACEMENT LOADING ON BOTTOM
D,ALL,UY,-10
NSEL,ALL
ESEL,ALL
NLGEOM,ON
AUTOTS,ON
TIME,1
NSUBST,40,40,40
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE                      !* PERFORM SOLUTION
FINISH
/POST26
NSEL,S,LOC,Y,1.5
NSEL,R,LOC,X,0
NSEL,R,LOC,Z,0
*GET,NTOP,NODE,0,NUM,MAX
NSEL,ALL
NSOL,2,NTOP,U,Y,UY
RFORCE,3,NTOP,F,Y,FY
PROD,4,3, , ,RF, , ,20
/TITLE,VM248, DCB: REACTION AT TOP NODE VERSES PRESCRIBED DISPLACEMENT
/AXLAB,X,DISP U (mm)
/AXLAB,Y,REACTION FORCE R (N)
/YRANGE,0,60
XVAR,2
PLVAR,4
PRVAR,UY,RF
*GET,TMAX,VARI,4,EXTREM,TMAX   !* TIME CORRESPONDING TO MAX RFORCE
FINISH
/POST1
SET, , , , ,TMAX               !* RETRIEVE RESULTS AT TMAX
NSEL,S,NODE, ,NTOP             !* SELECT NODE NTOP
/OUT,
*GET,RF_NTOP,NODE,NTOP,RF,FY   !* FY RFORCE AT NODE NTOP
*GET,UY_NTOP,NODE,NTOP,U,Y     !* DISP AT NODE NTOP CORRESPONDING TO RFORCE
RF_MAX = RF_NTOP*40         !* PLANE STRAIN OPTION AND WIDTH = 20 mm
SET,LAST                       !* RETRIEVE RESULTS AT LAST SUBSTEP
*GET,RF_END,NODE,NTOP,RF,FY    !* FY RFORCE AT NODE NTOP AT LAST SUBSTEP
*GET,UY_END,NODE,NTOP,U,Y      !* DISP AT NODE NTOP CORRESPONDING TO RFORCE
RF_END = RF_END*40         !* PLANE STRAIN OPTION AND WIDTH = 20 mm
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
*DIM,VALUE2,,2,3
LABEL(1,1) = 'RFORCE','DISP '
LABEL(1,2) = 'FY (N)','UY (mm)'
*VFILL,VALUE(1,1),DATA,60.0,1.0
*VFILL,VALUE(1,2),DATA,RF_MAX,UY_NTOP
*VFILL,VALUE(1,3),DATA,ABS(RF_MAX/60.0),ABS(UY_NTOP/1.0)
*VFILL,VALUE2(1,1),DATA,24,10.0
*VFILL,VALUE2(1,2),DATA,RF_END,UY_END
*VFILL,VALUE2(1,3),DATA,ABS(RF_END/24.0),ABS(UY_END/10.0)
SAVE,INF3
/OUT,SCRATCH

RESUME,INF1
/COM
```

```
/OUT,vm248,vrt
/COM,------------------- VM248 RESULTS COMPARISON --------------
/COM,
/COM,                   |   TARGET   |   Mechanical APDL    |   RATIO
/COM,
/COM,MAX RFORCE AND CORRESPONDING DISP USING INTER202:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
/COM,
/COM,RFORCE CORRESPONDING TO DISP U = 10.0 USING INTER202:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
/COM,
/NOPR
RESUME,INF2
/COM,MAX RFORCE AND CORRESPONDING DISP USING INTER203:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
/COM,
/COM,RFORCE CORRESPONDING TO DISP U = 10.0 USING INTER203:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
/COM,
RESUME,INF3
/COM,MAX RFORCE AND CORRESPONDING DISP USING INTER205:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
/COM,
/COM,RFORCE CORRESPONDING TO DISP U = 10.0 USING INTER205:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINI
*LIST,vm248,vrt
/DELETE,INF1
/DELETE,INF2
/DELETE,INF3
```

VM249 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM249
/TITLE,VM249, GASKET MATERIAL UNDER UNIAXIAL COMPRESSION LOAD
/COM,   REF: ANY NONLINEAR MATERIAL VERIFICATION TEXT
/COM,   USING 2D 4-NODE INTER192 GASKET ELEMENTS
/PREP7
MP, EX, 1,15.2E6*6890
MP,NUXY, 1, 0.21
MP,DENS,1,7203
TB,GASKET,2,,13,COMP             !* COMPRESSION CURVE
TBPT,,0.508000E-04, 0.161226E+07
TBPT,,0.101600E-03, 0.520884E+07
TBPT,,0.152400E-03, 0.113134E+08
TBPT,,0.203200E-03, 0.200499E+08
TBPT,,0.254000E-03, 0.259960E+08
TBPT,,0.304800E-03, 0.290345E+08
TBPT,,0.355600E-03, 0.357453E+08
TBPT,,0.406400E-03, 0.440064E+08
TBPT,,0.457200E-03, 0.563189E+08
TBPT,,0.508000E-03, 0.748254E+08
TBPT,,0.558800E-03, 0.967287E+08
```

```
TBPT,,0.609600E-03, 0.129001E+09
TBPT,,0.683260E-03, 0.157147E+09
TB,GASKET,2,,5,LUNL              !* COMPRESSION CURVE
TBPT,,0.152400E-03, 2.430000E+11
TBPT,,0.304800E-03, 3.565000E+11
TBPT,,0.406400E-03, 5.923000E+11
TBPT,,0.558800E-03, 1.088000E+12
TBPT,,0.683260E-03, 1.490000E+12
*DIM,XA,TABLE,13,1
*DIM,YA,TABLE,13,1
XA(1,1) = 0.508000E-04
XA(2,1) = 0.101600E-03
XA(3,1) = 0.152400E-03
XA(4,1) = 0.203200E-03
XA(5,1) = 0.254000E-03
XA(6,1) = 0.304800E-03
XA(7,1) = 0.355600E-03
XA(8,1) = 0.406400E-03
XA(9,1) = 0.457200E-03
XA(10,1)= 0.508000E-03
XA(11,1)= 0.558800E-03
XA(12,1)= 0.609600E-03
XA(13,1)= 0.683260E-03
YA(1,1) = 0.161226E+07
YA(2,1) = 0.520884E+07
YA(3,1) = 0.113134E+08
YA(4,1) = 0.200499E+08
YA(5,1) = 0.259960E+08
YA(6,1) = 0.290345E+08
YA(7,1) = 0.357453E+08
YA(8,1) = 0.440064E+08
YA(9,1) = 0.563189E+08
YA(10,1)= 0.748254E+08
YA(11,1)= 0.967287E+08
YA(12,1)= 0.129001E+09
YA(13,1)= 0.157147E+09
*DIM,XB,TABLE,2,1
*DIM,YB,TABLE,2,1
XB(1,1) = 1.06E-04
YB(1,1) = 0.0
XB(2,1) = 0.152400E-03
YB(2,1) = 11313400
*DIM,XC,TABLE,2,1
*DIM,YC,TABLE,2,1
XC(1,1) = 2.23E-04
YC(1,1) = 0
XC(2,1) = 0.304800E-03
YC(2,1) = 29034500
*DIM,XD,TABLE,2,1
*DIM,YD,TABLE,2,1
XD(1,1) = 3.32E-04
YD(1,1) = 0.0
XD(2,1) = 0.406400E-03
YD(2,1) = 44006400
*DIM,XE,TABLE,2,1
*DIM,YE,TABLE,2,1
XE(1,1) = 4.70E-04
YE(1,1) = 0.0
XE(2,1) = 0.558800E-03
YE(2,1) = 96728700
*DIM,XF,TABLE,2,1
*DIM,YF,TABLE,2,1
XF(1,1) = 5.78E-04
YF(1,1) = 0.0
XF(2,1) = 0.683260E-03
YF(2,1) = 157147000
SAVE
/PREP7
ET,1,182                         !* 2D 4-NODE STRUCTURAL SOLID ELEMENT
ET,2,192                         !* 2D 4-NODE GASKET ELEMENT
RECTNG,0,1,0,1
RECTNG,0,1,1.02,2.02
```

```
A,4,3,6,5
ESIZE,,10
TYPE,1
MAT, 1
AMESH,1
TYPE,2
MAT, 2
IMESH,LINE,3,5, ,0,0.02, ,0.001  !* GENERATE GASKET ELEMENTS
TYPE,1
MAT, 1
AMESH,2
NSEL,S,LOC,X,0
NSEL,A,LOC,X,1
D,ALL,UX
NSEL,S,LOC,Y,0
D,ALL,UY
NSEL,ALL
FINISH
/SOLU
ERESX,NO
NLGEOM,ON
NSUBST,50,50,50
OUTRES,ALL,ALL
NSEL,S,LOC,Y,2.02
SF,ALL,PRES,44006400         !* 1ST LOAD STEP -- LOAD THE MODEL
NSEL,ALL
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,2.02
SF,ALL,PRES,0                !* 2ND LOAD STEP -- UNLOAD THE MODEL
NSEL,ALL
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,2.02            !* 3RD LOAD STEP -- RELOAD THE MODEL
SF,ALL,PRES,157147000
NSEL,ALL
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,2.02
SF,ALL,PRES,0                !* 4TH LOAD STEP -- UNLOAD THE MODEL
NSEL,ALL
/OUT,SCRATCH
SOLVE
/OUT
FINISH
/POST26
/COLOR,CURVE,YGRE
/YRANGE,0,20E7
/XRANGE,0,8E-4
/AXLAB,X,CLOSURE
/AXLAB,Y,PRES
*VPLOT,XA(1,1),YA(1,1)
/NOERASE
*VPLOT,XB(1,1),YB(1,1)
*VPLOT,XC(1,1),YC(1,1)
*VPLOT,XD(1,1),YD(1,1)
*VPLOT,XE(1,1),YE(1,1)
*VPLOT,XF(1,1),YF(1,1)
ESOL,2,105,27,GKS,X
ESOL,3,105,27,GKD,X
PROD,4,2, , ,PRES, , ,-1
PROD,5,3, , ,CLOSURE, , ,-1
/COLOR,CURVE,MRED
/GMARKER,1,4,10
XVAR,5
PLVAR,4
/OUT,SCRATCH
PRVAR,5,4
FINISH
```

```
/POST1
/OUT,
SET,1,LAST
*GET,GK_PRES1,NODE,27,GKS,X
*GET,GK_CLOS1,NODE,27,GKD,X
SET,3,LAST
*GET,GK_PRES2,NODE,12,GKS,X
*GET,GK_CLOS2,NODE,12,GKD,X
GK_PRES1 = ABS(GK_PRES1)
GK_CLOS1 = ABS(GK_CLOS1)
GK_PRES2 = ABS(GK_PRES2)
GK_CLOS2 = ABS(GK_CLOS2)
R1 = GK_PRES1/44006400
R2 = GK_CLOS1/0.406400E-03
R3 = GK_PRES2/157147000
R4 = GK_CLOS2/0.683260E-03
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
*DIM,VALUE2,,2,3
LABEL(1,1) = 'GK','GK'
LABEL(1,2) = '-PRES','-CLOS'
*VFILL,VALUE(1,1),DATA,44006400,0.406400E-03
*VFILL,VALUE(1,2),DATA,GK_PRES1,GK_CLOS1
*VFILL,VALUE(1,3),DATA,R1,R2
*VFILL,VALUE2(1,1),DATA,157147000,0.683260E-03
*VFILL,VALUE2(1,2),DATA,GK_PRES2,GK_CLOS2
*VFILL,VALUE2(1,3),DATA,R3,R4
FINISH
SAVE,TABLE_1
/CLEAR, NOSTART                  !* CLEAR DATABASE FOR SECOND SOLUTION
/TITLE,VM249, GASKET MATERIAL UNDER UNIAXIAL COMPRESSION LOAD
/COM,   USING 2D 4-NODE INTER193 GASKET ELEMENTS
RESUME
/PREP7
ET,1,183                          !* 2D 8-NODE STRUCTURAL SOLID ELEMENT
ET,2,193,,,,0                     !* 2D 6-NODE GASKET ELEMENT
RECTNG,0,1,0,1
RECTNG,0,1,1.02,2.02
A,4,3,6,5
ESIZE,,10
TYPE,1
MAT, 1
AMESH,1
TYPE,2
MAT, 2
IMESH,LINE,3,5, ,0,0.02, ,0.001  !* GENERATE GASKET ELEMENTS
TYPE,1
MAT, 1
AMESH,2
NSEL,S,LOC,X,0
NSEL,A,LOC,X,1
D,ALL,UX
NSEL,S,LOC,Y,0
D,ALL,UY
NSEL,ALL
FINISH
/SOLU
ERESX,NO
NLGEOM,ON
!NSUBST,100,1000,100
NSUBST,100,100,100
OUTRES,ALL,ALL
NSEL,S,LOC,Y,2.02
SF,ALL,PRES,44006400         !* 1ST LOAD STEP -- LOAD THE MODEL
NSEL,ALL
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,2.02
SF,ALL,PRES,0                !* 2ND LOAD STEP -- UNLOAD THE MODEL
NSEL,ALL
SOLVE
```

```
NSEL,S,LOC,Y,2.02             !* 3RD LOAD STEP -- RELOAD THE MODEL
SF,ALL,PRES,157147000
NSEL,ALL
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,2.02
SF,ALL,PRES,0                 !* 4TH LOAD STEP -- UNLOAD THE MODEL
NSEL,ALL
/OUT,SCRATCH
SOLVE
/OUT
FINISH
/POST26
/COLOR,CURVE,YGRE
/YRANGE,0,20E7
/XRANGE,0,8E-4
/AXLAB,X,CLOSURE
/AXLAB,Y,PRES
*VPLOT,XA(1,1),YA(1,1)
/NOERASE
*VPLOT,XB(1,1),YB(1,1)
*VPLOT,XC(1,1),YC(1,1)
*VPLOT,XD(1,1),YD(1,1)
*VPLOT,XE(1,1),YE(1,1)
*VPLOT,XF(1,1),YF(1,1)
ESOL,2,105,52,GKS,X
ESOL,3,105,52,GKD,X
PROD,4,2, , ,PRES, , ,-1
PROD,5,3, , ,CLOSURE, , ,-1
/COLOR,CURVE,MRED
/GMARKER,1,4,10
XVAR,5
PLVAR,4
/OUT,SCRATCH
PRVAR,5,4
FINISH
/POST1
/OUT,
SET,1,LAST
*GET,GK_PRES1,NODE,52,GKS,X
*GET,GK_CLOS1,NODE,52,GKD,X
SET,3,LAST
*GET,GK_PRES2,NODE,52,GKS,X
*GET,GK_CLOS2,NODE,52,GKD,X
GK_PRES1 = ABS(GK_PRES1)
GK_CLOS1 = ABS(GK_CLOS1)
GK_PRES2 = ABS(GK_PRES2)
GK_CLOS2 = ABS(GK_CLOS2)
R1 = GK_PRES1/44006400
R2 = GK_CLOS1/0.406400E-03
R3 = GK_PRES2/157147000
R4 = GK_CLOS2/0.683260E-03
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
*DIM,VALUE2,,2,3
LABEL(1,1) = 'GK','GK'
LABEL(1,2) = '-PRES','-CLOS'
*VFILL,VALUE(1,1),DATA,44006400,0.406400E-03
*VFILL,VALUE(1,2),DATA,GK_PRES1,GK_CLOS1
*VFILL,VALUE(1,3),DATA,R1,R2
*VFILL,VALUE2(1,1),DATA,157147000,0.683260E-03
*VFILL,VALUE2(1,2),DATA,GK_PRES2,GK_CLOS2
*VFILL,VALUE2(1,3),DATA,R3,R4
SAVE,TABLE_2
RESUME,TABLE_1
/COM,
/OUT,vm249,vrt
/COM,------------------- VM249 RESULTS COMPARISON --------------
/COM,
/COM,               |  TARGET   |   Mechanical APDL  |  RATIO
/COM,
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```
/COM,RESULTS USING INTER192 ELEMENTS:
/COM,
/COM,GASKET PRESSURE AND CLOSURE AT END OF 1ST LOADING:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A2,A8,'   ',E12.6,'  ',1E15.6,'   ',1F15.3)
/COM,
/COM,GASKET PRESSURE AND CLOSURE AT THE END OF 2ND LOADING:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A2,A8,'   ',E12.6,'  ',1E15.6,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING INTER193 ELEMENTS:
/COM,
/COM,GASKET PRESSURE AND CLOSURE AT END OF 1ST LOADING:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A2,A8,'   ',E12.6,'  ',1E15.6,'   ',1F15.3)
/COM,
/COM,GASKET PRESSURE AND CLOSURE AT THE END OF 2ND LOADING:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A2,A8,'   ',E12.6,'  ',1E15.6,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm249,vrt
```

VM250 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM250
/TITLE,VM250, GASKET MATERIAL UNDER UNIAXIAL COMPRESSION LOAD
/COM,   REF: ANY NONLINEAR MATERIAL VERIFICATION TEXT
/COM,   USING 3D 8-NODE INTER195 GASKET ELEMENTS
/PREP7
MP, EX, 1,15.2E6*6890
MP,NUXY, 1, 0.21
MP,DENS,1,7203
TB,GASKET,2,,13,COMP             !* COMPRESSION CURVE
TBPT,,0.508000E-04, 0.161226E+07
TBPT,,0.101600E-03, 0.520884E+07
TBPT,,0.152400E-03, 0.113134E+08
TBPT,,0.203200E-03, 0.200499E+08
TBPT,,0.254000E-03, 0.259960E+08
TBPT,,0.304800E-03, 0.290345E+08
TBPT,,0.355600E-03, 0.357453E+08
TBPT,,0.406400E-03, 0.440064E+08
TBPT,,0.457200E-03, 0.563189E+08
TBPT,,0.508000E-03, 0.748254E+08
TBPT,,0.558800E-03, 0.967287E+08
TBPT,,0.609600E-03, 0.129001E+09
TBPT,,0.683260E-03, 0.157147E+09
TB,GASKET,2,,5,LUNL              !* COMPRESSION CURVE
TBPT,,0.152400E-03, 2.430000E+11
TBPT,,0.304800E-03, 3.565000E+11
TBPT,,0.406400E-03, 5.923000E+11
TBPT,,0.558800E-03, 1.088000E+12
TBPT,,0.683260E-03, 1.490000E+12
*DIM,XA,TABLE,13,1
*DIM,YA,TABLE,13,1
XA(1,1) = 0.508000E-04
XA(2,1) = 0.101600E-03
XA(3,1) = 0.152400E-03
XA(4,1) = 0.203200E-03
XA(5,1) = 0.254000E-03
XA(6,1) = 0.304800E-03
XA(7,1) = 0.355600E-03
XA(8,1) = 0.406400E-03
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XA(9,1) = 0.457200E-03
XA(10,1)= 0.508000E-03
XA(11,1)= 0.558800E-03
XA(12,1)= 0.609600E-03
XA(13,1)= 0.683260E-03
YA(1,1) = 0.161226E+07
YA(2,1) = 0.520884E+07
YA(3,1) = 0.113134E+08
YA(4,1) = 0.200499E+08
YA(5,1) = 0.259960E+08
YA(6,1) = 0.290345E+08
YA(7,1) = 0.357453E+08
YA(8,1) = 0.440064E+08
YA(9,1) = 0.563189E+08
YA(10,1)= 0.748254E+08
YA(11,1)= 0.967287E+08
YA(12,1)= 0.129001E+09
YA(13,1)= 0.157147E+09
*DIM,XB,TABLE,2,1
*DIM,YB,TABLE,2,1
XB(1,1) = 1.06E-04
YB(1,1) = 0.0
XB(2,1) = 0.152400E-03
YB(2,1) = 11313400
*DIM,XC,TABLE,2,1
*DIM,YC,TABLE,2,1
XC(1,1) = 2.23E-04
YC(1,1) = 0
XC(2,1) = 0.304800E-03
YC(2,1) = 29034500
*DIM,XD,TABLE,2,1
*DIM,YD,TABLE,2,1
XD(1,1) = 3.32E-04
YD(1,1) = 0.0
XD(2,1) = 0.406400E-03
YD(2,1) = 44006400
*DIM,XE,TABLE,2,1
*DIM,YE,TABLE,2,1
XE(1,1) = 4.70E-04
YE(1,1) = 0.0
XE(2,1) = 0.558800E-03
YE(2,1) = 96728700
*DIM,XF,TABLE,2,1
*DIM,YF,TABLE,2,1
XF(1,1) = 5.78E-04
YF(1,1) = 0.0
XF(2,1) = 0.683260E-03
YF(2,1) = 157147000
SAVE
/PREP7
ET,1,185                        !* 3D 8-NODE STRUCTURAL SOLID ELEMENT
ET,2,195,,0                     !* 3D 8-NODE GASKET ELEMENT
BLOCK,0,1,0,1,0,1
BLOCK,0,1,0,1,1.02,2.02
V,5,6,7,8,10,12,11,9
ESIZE,,4
TYPE,1
MAT, 1
VMESH,1
TYPE,2
MAT,2
IMESH,AREA,2,7, ,0,0,0.02,0.001  !* GENERATE GASKET ELEMENTS
TYPE,1
MAT, 1
VMESH,2
NSEL,S,LOC,X,0
D,ALL,UX
NSEL,S,LOC,Y,0
D,ALL,UY
NSEL,S,LOC,Z,0
D,ALL,UZ
NSEL,ALL
```

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FINISH
/out,scratch
/SOLU
NLGEOM,ON
NSUBST,50,50,50
OUTRES,ALL,-10
NSEL,S,LOC,Z,2.02
SF,ALL,PRES,44006400         !* 1ST LOAD STEP -- LOAD THE MODEL
NSEL,ALL
SOLVE
NSEL,S,LOC,Z,2.02
SF,ALL,PRES,0                !* 2ND LOAD STEP -- UNLOAD THE MODEL
NSEL,ALL
SOLVE
NSEL,S,LOC,Z,2.02            !* 3RD LOAD STEP -- RELOAD THE MODEL
SF,ALL,PRES,157147000
NSEL,ALL
SOLVE
NSEL,S,LOC,Z,2.02
SF,ALL,PRES,0                !* 4TH LOAD STEP -- UNLOAD THE MODEL
NSEL,ALL
SOLVE
FINISH
/out
/POST26
/COLOR,CURVE,YGRE
/YRANGE,0,20E7
/XRANGE,0,8E-4
/AXLAB,X,CLOSURE
/AXLAB,Y,PRES
*VPLOT,XA(1,1),YA(1,1)
/NOERASE
*VPLOT,XB(1,1),YB(1,1)
*VPLOT,XC(1,1),YC(1,1)
*VPLOT,XD(1,1),YD(1,1)
*VPLOT,XE(1,1),YE(1,1)
*VPLOT,XF(1,1),YF(1,1)
ESOL,2,70,145,GKS,X
ESOL,3,70,145,GKD,X
PROD,4,2, , ,PRES, , ,-1
PROD,5,3, , ,CLOSURE, , ,-1
/COLOR,CURVE,MRED
/GMARKER,1,4,10
XVAR,5
PLVAR,4
PRVAR,5,4
FINISH
/POST1
SET,1,LAST
*GET,GK_PRES1,NODE,145,GKS,X
*GET,GK_CLOS1,NODE,145,GKD,X
SET,3,LAST
*GET,GK_PRES2,NODE,145,GKS,X
*GET,GK_CLOS2,NODE,145,GKD,X
GK_PRES1 = ABS(GK_PRES1)
GK_CLOS1 = ABS(GK_CLOS1)
GK_PRES2 = ABS(GK_PRES2)
GK_CLOS2 = ABS(GK_CLOS2)
R1 = GK_PRES1/44006400
R2 = GK_CLOS1/0.406400E-03
R3 = GK_PRES2/157147000
R4 = GK_CLOS2/0.683260E-03
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
*DIM,VALUE2,,2,3
LABEL(1,1) = 'GK','GK'
LABEL(1,2) = '-PRES','-CLOS'
*VFILL,VALUE(1,1),DATA,44006400,0.406400E-03
*VFILL,VALUE(1,2),DATA,GK_PRES1,GK_CLOS1
*VFILL,VALUE(1,3),DATA,R1,R2
*VFILL,VALUE2(1,1),DATA,157147000,0.683260E-03
*VFILL,VALUE2(1,2),DATA,GK_PRES2,GK_CLOS2
```

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*VFILL,VALUE2(1,3),DATA,R3,R4
FINISH
SAVE,TABLE_1
/CLEAR, NOSTART                 !* CLEAR DATABASE FOR SECOND SOLUTION
/TITLE,VM250, GASKET MATERIAL UNDER UNIAXIAL COMPRESSION LOAD
/COM   USING 3D 16-NODE INTER194 GASKET ELEMENT
RESUME
/PREP7
ET,1,186                         !* 3D 20-NODE STRUCTURAL SOLID ELEMENT
ET,2,194,,0,,0                   !* 3D 16-NODE GASKET ELEMENT
BLOCK,0,1,0,1,0,1
BLOCK,0,1,0,1,1.02,2.02
V,5,6,7,8,10,12,11,9
ESIZE,,4
TYPE,1
MAT, 1
VMESH,1
TYPE,2
MAT,2
IMESH,AREA,2,7, ,0,0,0.02,0.001  !* GENERATE GASKET ELEMENTS
TYPE,1
MAT, 1
VMESH,2
NSEL,S,LOC,X,0
D,ALL,UX
NSEL,S,LOC,Y,0
D,ALL,UY
NSEL,S,LOC,Z,0
D,ALL,UZ
NSEL,ALL
FINISH
/out,scratch
/SOLU
NLGEOM,ON
NSUBST,50,50,50
OUTRES,ALL,-10
NSEL,S,LOC,Z,2.02
SF,ALL,PRES,44006400         !* 1ST LOAD STEP -- LOAD THE MODEL
NSEL,ALL
SOLVE
NSEL,S,LOC,Z,2.02
SF,ALL,PRES,0                !* 2ND LOAD STEP -- UNLOAD THE MODEL
NSEL,ALL
SOLVE
NSEL,S,LOC,Z,2.02            !* 3RD LOAD STEP -- RELOAD THE MODEL
SF,ALL,PRES,157147000
NSEL,ALL
SOLVE
NSEL,S,LOC,Z,2.02
SF,ALL,PRES,0                !* 4TH LOAD STEP -- UNLOAD THE MODEL
NSEL,ALL
SOLVE
FINISH
/out
/POST26
/COLOR,CURVE,YGRE
/YRANGE,0,20E7
/XRANGE,0,8E-4
/AXLAB,X,CLOSURE
/AXLAB,Y,PRES
*VPLOT,XA(1,1),YA(1,1)
/NOERASE
*VPLOT,XB(1,1),YB(1,1)
*VPLOT,XC(1,1),YC(1,1)
*VPLOT,XD(1,1),YD(1,1)
*VPLOT,XE(1,1),YE(1,1)
*VPLOT,XF(1,1),YF(1,1)
ESOL,2,70,472,GKS,X
ESOL,3,70,472,GKD,X
PROD,4,2, , ,PRES, , ,-1
PROD,5,3, , ,CLOSURE, , ,-1
/COLOR,CURVE,MRED
```

```
/GMARKER,1,4,10
XVAR,5
PLVAR,4
PRVAR,5,4
FINISH
/POST1
SET,1,LAST
*GET,GK_PRES1,NODE,472,GKS,X
*GET,GK_CLOS1,NODE,472,GKD,X
SET,3,LAST
*GET,GK_PRES2,NODE,472,GKS,X
*GET,GK_CLOS2,NODE,472,GKD,X
GK_PRES1 = ABS(GK_PRES1)
GK_CLOS1 = ABS(GK_CLOS1)
GK_PRES2 = ABS(GK_PRES2)
GK_CLOS2 = ABS(GK_CLOS2)
R1 = GK_PRES1/44006400
R2 = GK_CLOS1/0.406400E-03
R3 = GK_PRES2/157147000
R4 = GK_CLOS2/0.683260E-03
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
*DIM,VALUE2,,2,3
LABEL(1,1) = 'GK','GK'
LABEL(1,2) = '-PRES','-CLOS'
*VFILL,VALUE(1,1),DATA,44006400,0.406400E-03
*VFILL,VALUE(1,2),DATA,GK_PRES1,GK_CLOS1
*VFILL,VALUE(1,3),DATA,R1,R2
*VFILL,VALUE2(1,1),DATA,157147000,0.683260E-03
*VFILL,VALUE2(1,2),DATA,GK_PRES2,GK_CLOS2
*VFILL,VALUE2(1,3),DATA,R3,R4
SAVE,TABLE_2
RESUME,TABLE_1
/COM,
/OUT,vm250,vrt
/COM,------------------- VM250 RESULTS COMPARISON --------------
/COM,
/COM,                   |  TARGET   |   Mechanical APDL  |  RATIO
/COM,
/COM,RESULTS USING INTER195 ELEMENTS:
/COM,
/COM,GASKET PRESSURE AND CLOSURE AT END OF 1ST LOADING:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A2,A8,'   ',E12.6,'  ',1E15.6,'   ',1F15.3)
/COM,
/COM,GASKET PRESSURE AND CLOSURE AT THE END OF 2ND LOADING:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A2,A8,'   ',E12.6,'  ',1E15.6,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING INTER194 ELEMENTS:
/COM,
/COM,GASKET PRESSURE AND CLOSURE AT END OF 1ST LOADING:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A2,A8,'   ',E12.6,'  ',1E15.6,'   ',1F15.3)
/COM,
/COM,GASKET PRESSURE AND CLOSURE AT THE END OF 2ND LOADING:
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A2,A8,'   ',E12.6,'  ',1E15.6,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm250,vrt
```

VM251 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM251
/TITLE,VM251, SHAPE MEMORY ALLOY UNDER UNIAXIAL TENSION LOAD
/COM,   REF: FERDINANDO AURICHIO, ROBERT L. TAYLOR, JACOB LUBLINER
/COM,   "SHAPE-MEMORY ALLOYS: MACROMODELLING AND NUMERICAL SIMULATIONS
/COM,   OF SUPERELASTIC BEHAVIOR"
/COM,   COMPUT. METHODS APPL. MECH. ENGNG. 146 (1997) 281-312
/COM,   USING 2D 4-NODE PLANE182 STRUCTURAL SOLID ELEMENTS
/PREP7
ET,1,182                        !* 2D 4-NODE STRUCTURAL SOLID ELEMENT
KEYOPT,1,3,1                    !* AXISYMMETRIC OPTION
MP, EX, 1, 60.0E3               !* MPA
MP,NUXY, 1, 0.3
TB,SMA,1
TBDATA,1,520,600,300,200,0.07,0 !* SHAPE MEMORY ALLOY
N,101, 0.00, 0.00
N,102,10.00, 0.00
N,103,10.00,10.00
N,104, 0.00,10.00
TYPE,1
MAT,1
E,101,102,103,104
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
FINISH
/SOLU
NLGEOM,ON
NSUBST,100,100,100
OUTRES,ALL,1
NSEL,S,LOC,Y,10
SF,ALL,PRES,-600        !* 1ST LOAD STEP -- LOAD THE MODEL
NSEL,ALL
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,Y,10
SF,ALL,PRES,0          !* 2ND LOAD STEP -- UNLOAD THE MODEL
NSEL,ALL
SOLVE
FINISH
/POST26
ESOL,2,1,103,S,EQV           !* EQUIVALENT STRESS AT NODE 103
ESOL,3,1,103,EPEL,EQV        !* ELASTIC STRAIN AT NODE 103
ESOL,4,1,103,EPPL,EQV        !* PLASTIC STRAIN AT NODE 103
ADD,5,3,4                    !* TOTAL STRAIN AT NODE 103
PROD,6,5, , ,STRAIN, , ,100  !* PERCENT TOTAL STRAIN
XVAR,6
/AXLAB,X,Strain[%]
/AXLAB,Y,Stress [MPa]
/YRANGE,0,700                !* SET Y-RANGE
/XRANGE,0,8                  !* SET X-RANGE
/GROPT,DIVY,7
PLVAR,2                      !* PLOT TOTAL STRAIN VS EQV STRESS
/OUT,
PRVAR,2,5
FINISH
/POST1
SET, , , , ,0.87
*GET,SIG_SAS,NODE,103,S,EQV
*GET,EPTO_SAS,NODE,103,EPTO,EQV
SET, , , , ,1
*GET,SIG_FAS,NODE,103,S,EQV
*GET,EPTO_FAS,NODE,103,EPTO,EQV
SET, , , , ,1.5
*GET,SIG_SSA,NODE,103,S,EQV
*GET,EPTO_SSA,NODE,103,EPTO,EQV
SET, , , , ,1.67
*GET,SIG_FSA,NODE,103,S,EQV
*GET,EPTO_FSA,NODE,103,EPTO,EQV
R1 = SIG_SAS/520
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R2 = EPTO_SAS/0.01
R3 = SIG_FAS/600
R4 = EPTO_FAS/0.08
R5 = SIG_SSA/300
R6 = EPTO_SSA/0.074
R7 = SIG_FSA/200
R8 = EPTO_FSA/0.32E-02
*DIM,LABEL,CHAR,8,2
*DIM,VALUE,,8,3
LABEL(1,1) = 'SIG','EPTO','SIG','EPTO','SIG','EPTO','SIG','EPTO'
LABEL(1,2) = '-SAS','-SAS','-FAS','-FAS','-SSA','-SSA','-FSA','-FSA'
*VFILL,VALUE(1,1),DATA,520,0.01,600,0.08,300,0.074,200,0.32E-02
*VFILL,VALUE(1,2),DATA,SIG_SAS,EPTO_SAS,SIG_FAS,EPTO_FAS,SIG_SSA,EPTO_SSA,SIG_FSA,EPTO_FSA
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8
SAVE,TABLE_1
FINISH
/CLEAR, NOSTART                  !* CLEAR DATABASE FOR SECOND SOLUTION
/TITLE,VM251, SHAPE MEMORY ALLOY UNDER UNIAXIAL TENSION LOAD - 2D AXISYMMETRIC
/COM    USING 2D 8-NODE PLANE183 STRUCTURAL SOLID ELEMENTS
/PREP7
ET,1,183                         !* 3D 8-NODE STRUCTURAL SOLID ELEMENT
KEYOPT,1,3,1                     !* AXISYMMETRIC OPTION
MP, EX, 1, 60.0E3                !* MPA
MP,NUXY, 1, 0.3
TB,SMA,1
TBDATA,1,520,600,300,200,0.07,0 !* SHAPE MEMORY ALLOY
N,101, 0.00, 0.00
N,102, 1.00, 0.00
N,103, 1.00, 1.00
N,104, 0.00, 1.00
N,105, 0.50, 0.00
N,106, 1.00, 0.50
N,107, 0.50, 1.00
N,108, 0.00, 0.50
TYPE,1
MAT,1
E,101,102,103,104,105,106,107,108
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
FINISH
/SOLU
NLGEOM,ON
NSUBST,200,200,200
OUTRES,ALL,1
NSEL,S,LOC,Y,1.0
SF,ALL,PRES,-600        !* 1ST LOAD STEP -- LOAD THE MODEL
NSEL,ALL
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,Y,1.0
SF,ALL,PRES,0          !* 2ND LOAD STEP -- UNLOAD THE MODEL
NSEL,ALL
SOLVE
FINISH
/POST26
ESOL,2,1,103,S,EQV           !* EQUIVALENT STRESS AT NODE 103
ESOL,3,1,103,EPEL,EQV        !* ELASTIC STRAIN AT NODE 103
ESOL,4,1,103,EPPL,EQV        !* PLASTIC STRAIN AT NODE 103
ADD,5,3,4                    !* TOTAL STRAIN AT NODE 103
PROD,6,5, , ,STRAIN, , ,100  !* PERCENT TOTAL STRAIN
XVAR,6
/TITLE,UNIAXIAL TENSION STRESS-STRAIN RESPONSE FRO A Ni-Ti ALLOY
/AXLAB,X,Strain[%]
/AXLAB,Y,Stress [MPA]
/GROPT,DIVY,7
/YRANGE,0,700                !* SET Y-RANGE
/XRANGE,0,8                  !* SET X-RANGE
PLVAR,2                      !* PLOT TOTAL STRAIN VS EQV STRESS
/OUT,
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```
PRVAR,2,5
FINISH
/POST1
SET, , , , ,0.87
*GET,SIG_SAS,NODE,103,S,EQV
*GET,EPTO_SAS,NODE,103,EPTO,EQV
SET, , , , ,1
*GET,SIG_FAS,NODE,103,S,EQV
*GET,EPTO_FAS,NODE,103,EPTO,EQV
SET, , , , ,1.5
*GET,SIG_SSA,NODE,103,S,EQV
*GET,EPTO_SSA,NODE,103,EPTO,EQV
SET, , , , ,1.67
*GET,SIG_FSA,NODE,103,S,EQV
*GET,EPTO_FSA,NODE,103,EPTO,EQV
R1 = SIG_SAS/520
R2 = EPTO_SAS/0.01
R3 = SIG_FAS/600
R4 = EPTO_FAS/0.08
R5 = SIG_SSA/300
R6 = EPTO_SSA/0.074
R7 = SIG_FSA/200
R8 = EPTO_FSA/0.32E-02
*DIM,LABEL,CHAR,8,2
*DIM,VALUE,,8,3
LABEL(1,1) = 'SIG','EPTO','SIG','EPTO','SIG','EPTO','SIG','EPTO'
LABEL(1,2) = '-SAS','-SAS','-FAS','-FAS','-SSA','-SSA','-FSA','-FSA'
*VFILL,VALUE(1,1),DATA,520,0.01,600,0.08,300,0.074,200,0.32E-02
*VFILL,VALUE(1,2),DATA,SIG_SAS,EPTO_SAS,SIG_FAS,EPTO_FAS,SIG_SSA,EPTO_SSA,SIG_FSA,EPTO_FSA
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8
SAVE,TABLE_2
FINISH
/CLEAR, NOSTART                 !* CLEAR DATABASE FOR SECOND SOLUTION
/TITLE,VM251, SHAPE MEMORY ALLOY UNDER UNIAXIAL TENSION LOAD
/COM    USING 3D 8-NODE SOLID185 STRUCTURAL SOLID ELEMENTS
/PREP7
ET,1,185                        !* 3D 8-NODE STRUCTURAL SOLID ELEMENT
MP, EX, 1, 60.0E3               !* MPA
MP,NUXY, 1, 0.3
TB,SMA,1
TBDATA,1,520,600,300,200,0.07,0 !* SHAPE MEMORY ALLOY
N,101, 0.00, 0.00
N,102, 10.00, 0.00
N,103, 10.00, 10.00
N,104, 0.00, 10.00
N,105, 0.00, 0.00,10.00
N,106, 10.00, 0.00,10.00
N,107, 10.00, 10.00,10.00
N,108, 0.00, 10.00,10.00
TYPE,1
MAT,1
E,101,102,103,104,105,106,107,108
TYPE,1
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,ALL
FINISH
/SOLU
NLGEOM,ON
NSUBST,100,100,100
OUTRES,ALL,1
NSEL,S,LOC,Y,10.0
SF,ALL,PRES,-600        !* 1ST LOAD STEP -- LOAD THE MODEL
NSEL,ALL
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,Y,10.0
SF,ALL,PRES,0          !* 2ND LOAD STEP -- UNLOAD THE MODEL
```

```
NSEL,ALL
SOLVE
FINISH
/POST26
ESOL,2,1,103,S,EQV           !* EQUIVALENT STRESS AT NODE 103
ESOL,3,1,103,EPEL,EQV        !* ELASTIC STRAIN AT NODE 103
ESOL,4,1,103,EPPL,EQV        !* PLASTIC STRAIN AT NODE 103
ADD,5,3,4                    !* TOTAL STRAIN AT NODE 103
PROD,6,5, , ,STRAIN, , ,100  !* PERCENT TOTAL STRAIN
XVAR,6
/axlab,x,Strain[%]
/axlab,y,Stress [MPa]
/YRANGE,0,700                !* SET Y-RANGE
/XRANGE,0,8                  !* SET X-RANGE
/GROPT,DIVY,7
PLVAR,2                      !* PLOT TOTAL STRAIN VS EQV STRESS
/OUT,
PRVAR,2,5
FINISH
/POST1
SET, , , , ,0.87
*get,SIG_SAS,node,103,s,eqv
*get,EPTO_SAS,node,103,epto,eqv
SET, , , , ,1
*get,SIG_FAS,node,103,s,eqv
*get,EPTO_FAS,node,103,epto,eqv
SET, , , , ,1.5
*get,SIG_SSA,node,103,s,eqv
*get,EPTO_SSA,node,103,epto,eqv
SET, , , , ,1.67
*get,SIG_FSA,node,103,s,eqv
*get,EPTO_FSA,node,103,epto,eqv
R1 = SIG_SAS/520
R2 = EPTO_SAS/0.01
R3 = SIG_FAS/600
R4 = EPTO_FAS/0.08
R5 = SIG_SSA/300
R6 = EPTO_SSA/0.074
R7 = SIG_FSA/200
R8 = EPTO_FSA/0.32E-02
*DIM,LABEL,CHAR,8,2
*DIM,VALUE,,8,3
LABEL(1,1) = 'Sig','EPTO','Sig','EPTO','Sig','EPTO','Sig','EPTO'
LABEL(1,2) = '-SAS','-SAS','-FAS','-FAS','-SSA','-SSA','-FSA','-FSA'
*VFILL,VALUE(1,1),DATA,520,0.01,600,0.08,300,0.074,200,0.32E-02
*VFILL,VALUE(1,2),DATA,SIG_SAS,EPTO_SAS,SIG_FAS,EPTO_FAS,SIG_SSA,EPTO_SSA,SIG_FSA,EPTO_FSA
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8
SAVE,TABLE_3
RESUME,TABLE_1
/COM
/OUT,vm251,vrt
/COM,------------------- VM251 RESULTS COMPARISON --------------
/COM,
/COM,                |  TARGET   |   Mechanical APDL  |  RATIO
/COM,
/COM,RESULTS USING PLANE182 ELEMENT
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A4,A8,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING PLANE183 ELEMENT
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A4,A8,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM,RESULTS USING SOLID185 ELEMENT
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A4,A8,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
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/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm251,vrt
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VM252 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM252
/TITLE,VM252,GURSON BAR-NECKING BENCHMARK WITH APPLIED DISPLACEMENT
/COM, REFERENCE:
/COM, N. ARAVAS, "ON THE NUMERICAL INTEGRATION OF A CLASS OF PRESSURE
/COM, DEPENDENT PLASTICITY MODELS." INT. J. FOR NUMERICAL METHODS IN
/COM, ENGINEERING.  VOLUME. 24, PP. 1395-1416 (1987)
/COM, SECTION 5.3, FIGURE 10.
! DEFINED CONSTANTS
PI=3.141592654
MYSUBST=100                 ! NUMBER OF SUBSTEPS FOR SOLUTION
UAPP=0.7602                 ! APPLIED DISPLACEMENT
R0=1                        ! WIDTH OF ROD
DR0=0.005*R0                ! NODE OFFSET TO CREATE NOTCH
L0=4.0*R0                   ! LENGTH OF MODEL
YOUNG=1000000               ! YOUNG'S MODULUS
NU=0.3                      ! POISSON RATIO
! GURSON COEFFICIENTS
Q1=1.5                      ! FIRST TVERGAARD CONSTANT
Q2=1                        ! SECOND TVERGAARD CONSTANT
Q3=Q1*Q1                    ! THIRD TVERGAARD CONSTANT
SIGMA_Y=YOUNG/300.0         ! YIELD STRESS
YIELD=1.0D0/SIGMA_Y/PI/R0/R0 ! YIELD STRENGTH
F_0=1E-8                    ! INITIAL POROSITY
F_N=0.04                    ! VOLUME FRACTION/ VOID NUCLEATION
S_N=0.1                     ! STANDARD DEV. OF MEAN STRAIN FOR NUCLEATION.
STRAIN_N=0.3                ! MEAN STRAIN FOR NUCLEATIONS
POWER_N=0.1                 ! FOR ELASTIC MATERIAL DEFINITION
/PREP7
MP,EX,1,YOUNG               ! MATERIAL PROPERTIES
MP,NUXY,1,NU
TB,NLISO,1,1,2,5            ! ELASTIC MODEL
TBDATA,1,SIGMA_Y,POWER_N

TB,GURS,1,,5,BASE   ! BASE DEFINED
TBDATA,1,SIGMA_Y,F_0,Q1,Q2,Q3

TB,GURS,1,,3,SNNU   ! SNNU DEFINED
TBDATA,1,F_N,STRAIN_N,S_N

ET,1,PLANE182,,,1                ! AXISYMMETRIC 2D
RECT,0,R0,0,L0/8            ! DEFINE GEOMETRY AND MESH
RECT,0,R0,L0/8,L0
AGLUE,ALL
LSEL,S,LOC,X,R0/2
LESIZE,ALL,,,10
LSEL,S,LOC,Y,L0/16
LESIZE,ALL,,,5
LSEL,S,LOC,Y,L0/8,L0
LESIZE,ALL,,,20,4
SAVE,MODEL
AMESH,ALL
MODMSH,DETACH
NMODIF,NODE(R0,0,0),R0-DR0,0,0     ! TO CREATE NOTCH AT BOTTOM OF ROD
NSEL,S,LOC,X,0                     ! BOUNDARY CONDITIONS
D,ALL,UX,0
NSEL,S,LOC,Y,0
D,ALL,UY,0
ALLS
NSEL,S,LOC,Y,L0
D,ALL,UY,UAPP
```

```
ALLS
FINISH
*CREATE,MACRO,MAC    ! MACRO FOR SOLUTION AND POST PROCESSING
/SOLU                             ! NON-LINEAR SOLUTION
OUTRES,ALL,ALL
NLGEOM,ON
NROPT,UNSYM
SOLCONTROL,ON
CNVTOL,F,1.0,0.1
NSUBST,MYSUBST,MYSUBST,MYSUBST
ALLS
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH
/POST1                            ! REACTION FORCES AT TOP OF BAR
*DIM,X,ARRAY,MYSUBST
*DIM,Y,ARRAY,MYSUBST
*DO,J,1,MYSUBST
SET,1,J
*GET,DISPY,NODE,NODE(R0,L0,0),U,Y
X(J)=LOG(1+DISPY/L0)              ! AS DEFINED BY REFERENCE
TOTFORCE=0.0D0
NSEL,ALL
ESLN
NSLE
*GET,NNODE,NODE,,COUNT
*DO,K,1,NNODE
*IF,NY(K),EQ,4.0,THEN
*GET,NFOR,NODE,K,RF,FY
TOTFORCE=TOTFORCE+NFOR            ! TOTAL FORCE
*ENDIF
*ENDDO
Y(J)=TOTFORCE*YIELD               ! Y DATA TO BE PLOTTED
*ENDDO
MAXIMUM=0.01                      ! LOOP TO DETERMINE MAXIMUM IN VECTOR Y
*DO,KK,1,MYSUBST,1
*IF,Y(KK),LT,MAXIMUM,THEN
MAXIMUM=Y(KK-1)
*EXIT
*ELSE
MAXIMUM=Y(KK)
KK=KK+1
*ENDIF
*ENDDO
/AXLAB,Y,NORMALIZED LOAD
*VPLOT,X(1),Y(1)
*DIM,VALUE,ARRAY,1,3
*DIM,LABEL,CHAR,1,1
LABEL(1) = 'LOADING'
*VFILL,VALUE(1,1),DATA,1.25
*VFILL,VALUE(1,2),DATA,MAXIMUM
*VFILL,VALUE(1,3),DATA,1.25/MAXIMUM
*END
MACRO
SAVE,TABLE_1
RESUME,MODEL
/PREP7
ET,1,PLANE183,,,1
AMESH,ALL
MODMSH,DETACH
NMODIF,NODE(R0,0,0),R0-DR0,0,0    ! TO CREATE NOTCH AT BOTTOM OF ROD
NSEL,S,LOC,X,0                    ! BOUNDARY CONDITIONS
D,ALL,UX,0
NSEL,S,LOC,Y,0
D,ALL,UY,0
ALLS
NSEL,S,LOC,Y,L0
D,ALL,UY,UAPP
ALLS
FINISH
MACRO
```

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SAVE,TABLE_2
RESUME,TABLE_1
/COM,
/OUT,vm252,vrt
/COM,--------------- VM252 RESULTS COMPARISON -------------------
/COM,
/COM,            |  TARGET  |  Mechanical APDL |  RATIO  |
/COM,
/COM,PLANE182 RESULTS COMPARISON
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F8.4,'   ',F14.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,PLANE183 RESULTS COMPARISON
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F8.4,'   ',F14.4,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm252,vrt
/DELETE,TABLE_1
/DELETE,TABLE_2
```

VM253 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vm253
/TITLE,VM253,GURSON HYDROSTATIC TENSION BENCHMARK
/COM, REFERENCE:
/COM, N. ARAVAS, "ON THE NUMERICAL INTEGRATION OF A CLASS OF PRESSURE
/COM, DEPENDENT PLASTICITY MODELS." INT. J. FOR NUMERICAL METHODS IN
/COM, ENGINEERING.  VOLUME. 24, PP. 1395-1416 (1987)
/COM, SECTION 5.2, FIGURE 7.
! DEFINED CONSTANTS
PI=3.141592654
UAPP=0.15                    ! APPLIED DISPLACEMENT
YOUNG=1000000                ! YOUNG'S MODULUS
NU=0.3                       ! POISSON RATIO
! GURSON COEFFICIENTS
Q1=1.5                       ! FIRST TVERGAARD CONSTANT
Q2=1                         ! SECOND TVERGAARD CONSTANT
Q3=Q1*Q1                     ! THIRD TVERGAARD CONSTANT
SIGMA_Y=YOUNG/300.0          ! YIELD STRESS
YIELD=1.0D0/SIGMA_Y/PI       ! YIELD STRENGTH
F_0=0.04                     ! INITIAL POROSITY
F_N=0.04                     ! VOLUME FRACTION OF VOID NUCLEATING PARTICLES
S_N=0.1                      ! STANDARD DEVIATION OF MEAN STRAIN FOR NUCLEA.
STRAIN_N=0.3                 ! MEAN STRAIN FOR NUCLEATIONS
POWER_N=0.1                  ! POWER FOR ELASTIC MODEL
/PREP7
MP,EX,1,YOUNG
MP,NUXY,1,NU
TB,NLISO,1,1,2,5             ! ELASTIC MODEL DEFINITION
TBDATA,1,SIGMA_Y,POWER_N

TB,GURS,1,,5,BASE   ! BASE DEFINED
TBDATA,1,SIGMA_Y,F_0,Q1,Q2,Q3

TB,GURS,1,,3,SNNU   ! SNNU DEFINED
TBDATA,1,F_N,STRAIN_N,S_N

BLOCK,,1,,1,,1               ! GEOMETRY AND MESHING
SAVE,MODEL
ET,1,SOLID185
VMESH,ALL
NSEL,S,LOC,X,0               ! BOUNDARY CONDITIONS
```

```
D,ALL,UX,0
NSEL,S,LOC,Y,0
D,ALL,UY,0
NSEL,S,LOC,Z,0
D,ALL,UZ,0
ALLS
FINISH
/SOLU
NSEL,S,LOC,X,1
D,ALL,UX,UAPP
NSEL,S,LOC,Y,1
D,ALL,UY,UAPP
NSEL,S,LOC,Z,1
D,ALL,UZ,UAPP
ALLS
NLGEOM,ON                     ! NON-LINEAR SOLUTION
NROPT,UNSYM
AUTOTS,OFF
SOLCONTROL,ON
CNVTOL,F,1.0,1E-5
NSUBST,100,100,100
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH
*CREATE,MACRO,MAC             ! MACRO FOR PLOTTING AND DATA COLLECTION
/POST26                       ! VOLUMETRIC PRESSURE VS. VOLUMETRIC STRAIN
NSOL,2,NODE(1,0,0),U,X
EXP,3,2,,,ONE,,,1E-10,1.0
ADD,4,2,3
NLOG,5,4,,,EPSV,,,1.0,3.0     ! X-AXIS ADJUSTMENT
ESOL,6,1,,NL,HPRES
PROD,7,6,,,P_SIGMAY,,,1/SIGMA_Y
XVAR,5
/AXLAB,X,VOLUMETRIC STRAIN
/AXLAB,Y,PRESSURE
PLVAR,7
*GET,EPSV10,VARI,7,RTIME,0.23
*GET,EPSV24,VARI,7,RTIME,0.55
*GET,EPSV40,VARI,7,RTIME,0.93
*DIM,TARGET,ARRAY,3,1
*DIM,ANSYS,ARRAY,3,1
*DIM,RATIO,ARRAY,3,1
*DIM,LABEL,CHAR,10
LABEL(1) = '0.10','0.24','0.40'
*VFILL,TARGET(1,1),DATA,1.62,1.00,0.62
*VFILL,ANSYS(1,1),DATA,EPSV10,EPSV24,EPSV40
R1=ANSYS(1,1)/TARGET(1,1)
R2=ANSYS(2,1)/TARGET(2,1)
R3=ANSYS(3,1)/TARGET(3,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3
*END
MACRO
SAVE,TABLE_1
RESUME,MODEL
/PREP7
ET,1,SOLID186
VMESH,ALL
NSEL,S,LOC,X,0                ! BOUNDARY CONDITIONS
D,ALL,UX,0
NSEL,S,LOC,Y,0
D,ALL,UY,0
NSEL,S,LOC,Z,0
D,ALL,UZ,0
ALLS
FINISH
/SOLU
NSEL,S,LOC,X,1
D,ALL,UX,UAPP
NSEL,S,LOC,Y,1
D,ALL,UY,UAPP
```

```
NSEL,S,LOC,Z,1
D,ALL,UZ,UAPP
ALLS
NLGEOM,ON                    ! NON-LINEAR SOLUTION
NROPT,UNSYM
AUTOTS,OFF
SOLCONTROL,ON
CNVTOL,F,1.0,1E-5
NSUBST,100,100,100
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH
MACRO
SAVE,TABLE_2
RESUME,TABLE_1
/COM,
/OUT,vm253,vrt
/COM,--------------- VM253 RESULTS COMPARISON -------------------
/COM,
/COM, EPSV  |  TARGET PRESSURE  |  Mechanical APDL |  RATIO  |
/COM,
/COM,SOLID185 RESULTS COMPARISON
*VWRITE,LABEL(1),TARGET(1,1),ANSYS(1,1),RATIO(1,1)
(1X,A8,'   ',F10.4,'   ',F14.4,'   ',1F14.4)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,SOLID186 RESULTS COMPARISON
*VWRITE,LABEL(1),TARGET(1,1),ANSYS(1,1),RATIO(1,1)
(1X,A8,'   ',F10.4,'   ',F14.4,'   ',1F14.4)
/COM,------------------------------------------------------------
/OUT
FINISH
*LIST,vm253,vrt
/DELETE,TABLE_1
/DELETE,TABLE_2
```

VM254 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM254
/TITLE, VM254 CAMPBELL DIAGRAMS AND CRITICAL SPEEDS USING SYMMETRIC ORTHOTROPIC BEARINGS
/COM,   REF: "THE DYNAMICS OF ROTOR-BEARING SYSTEMS USING FINITE ELEMENTS"
/COM,   JOURNAL OF ENG. FOR INDUSTRY - MAY 1976, PG: 598-600
C***    USING PIPE16
/COM
/OUT,SCRATCH
/PREP7
*DIM,SPIN,,6                           ! SPIN VELOCITY (RPM)
SPIN(1) = 1000.
SPIN(2) = 20000.
SPIN(3) = 40000.
SPIN(4) = 60000.
SPIN(5) = 80000.
SPIN(6) = 100000.
RO = 7806                                        ! MATERIAL : STEEL
PEX = 2.078E+11
PGXY = 1.E+14                           ! NO SHEAR
MP,EX,1,PEX
MP,PRXY,1,0.3
MP,DENS,1,RO
MP,GXY,1,PGXY

ET,1,PIPE16                                      ! ELEMENT TYPE # 1: SHAFT
NBDIAM = 18                                      ! SHAFT SECTION PROPERTIES
```

```
*DIM,DIAM,ARRAY,NBDIAM
DIAM(1) = 1.02E-2
DIAM(2) = 2.04E-2
DIAM(3) = 1.52E-2
DIAM(4) = 4.06E-2
DIAM(5) = DIAM(4)
DIAM(6) = 6.6E-2
DIAM(7) = DIAM(6)
DIAM(8) = 5.08E-2
DIAM(9) = DIAM(8)
DIAM(10) = 2.54E-2
DIAM(11) = DIAM(10)
DIAM(12) = 3.04E-2
DIAM(13) = DIAM(12)
DIAM(14) = 2.54E-2
DIAM(15) = DIAM(14)
DIAM(16) = 7.62E-2
DIAM(17) = 4.06E-2
DIAM(18) = DIAM(17)
*DO,I,1,NBDIAM
   R,I,DIAM(I),DIAM(I)/2
*ENDDO
R,7,DIAM(7),(DIAM(7)-3.04E-2)/2
R,8,DIAM(8),(DIAM(8)-3.56E-2)/2
R,18,DIAM(18),(DIAM(18)-3.04E-2)/2

ET,2,MASS21                                    ! ELEMENT TYPE # 2: MASS
R,20,1.401,1.401,1.401,0.002,0.00136,0.00136

ET,3,COMBI214                                  ! ELEMENT TYPE # 3: BEARING ELEMENT
KEYOPT,3,2,1                                   ! YZ PLANE
KEYOPT,3,3,0                                   ! ELEMENT IS SYMMETRIC
R,30,3.503E+7,3.503E+7,-8.756E+6,-8.756E+6,,   ! REAL CONSTANTS ( K11,K22,K12,K21) NO DAMPING

ET,4,COMBI214
KEYOPT,4,2,1                                   ! YZ PLANE
KEYOPT,4,3,0                                   ! ELEMENT IS SYMMETRIC
R,40,3.503E+7,3.503E+7,-8.756E+6,-8.756E+6,,   ! REAL CONSTANTS ( K11,K22,K12,K21) NO DAMPING

/COM, NODES
N,1 ,0.
N,2 ,1.27E-2
N,3 ,5.08E-2
N,4 ,7.62E-2
N,5 ,8.89E-2
N,6 ,10.16E-2
N,7 ,10.67E-2
N,8 ,11.43E-2
N,9 ,12.7E-2
N,10,13.46E-2
N,11,16.51E-2
N,12,19.05E-2
N,13,22.86E-2
N,14,26.67E-2
N,15,28.7E-2
N,16,30.48E-2
N,17,31.5E-2
N,18,34.54E-2
N,19,35.5E-2

BRG = 0.1                               ! BEARING "LENGTH" FOR VISUALISATION
N,20,16.51E-2,BRG
N,22,28.7E-2,BRG

/COM, ELEMENTS
/COM, SHAFT
TYPE,1
MAT,1
*DO,I,1,NBDIAM
REAL,I
   E,I,I+1
*ENDDO
```

```
/COM, DISK
TYPE,2
REAL,20
E,5

/COM, BEARINGS
TYPE,3
REAL,30
E,11,20
TYPE,4
REAL,40
E,15,22
ALLSEL,ALL
FINI
/SOLU
D,ALL,UX                                      ! NO TRACTION AND TORSION
D,ALL,ROTX
D,20,ALL                                      ! SECOND NODES OF BEARING
D,22,ALL

/COM, MODAL
RATIO = 4*ATAN(1)/30
ANTYPE,MODAL
CORIOLIS,ON,,,ON
NBF = 20
MODOPT,DAMP,NBF,,,ON
*DO,I,1,6
   OMEGA,SPIN(I)*RATIO                       ! UNIT FOR OMEGA IS RAD/SEC
   MXPAND,NBF
   SOLVE
*ENDDO
FINI

/POST1
/OUT,
PRCAMP,,1.,RPM
PLCAMP,,1.,RPM
*GET,F1,CAMP,1,FREQ,6
*GET,F2,CAMP,2,FREQ,6
*GET,F3,CAMP,3,FREQ,6
*GET,F4,CAMP,4,FREQ,6
*DIM,LABEL,CHAR,1,4
*DIM,VALUE,ARRAY,4,3

LABEL(1,1) = 'WHIRL BW'
LABEL(1,2) = 'WHIRL FW'
LABEL(1,3) = 'WHIRL BW'
LABEL(1,4) = 'WHIRL FW'
*VFILL,VALUE(1,1),DATA,10747
*VFILL,VALUE(1,2),DATA,F1*60
*VFILL,VALUE(1,3),DATA,ABS((F1*60)/10747)
*VFILL,VALUE(2,1),DATA,19665
*VFILL,VALUE(2,2),DATA,F2*60
*VFILL,VALUE(2,3),DATA,ABS((F2*60)/19665)
*VFILL,VALUE(3,1),DATA,39077
*VFILL,VALUE(3,2),DATA,F3*60
*VFILL,VALUE(3,3),DATA,ABS((F3*60)/39077)
*VFILL,VALUE(4,1),DATA,47549
*VFILL,VALUE(4,2),DATA,F4*60
*VFILL,VALUE(4,3),DATA,ABS((F4*60)/47549)
SAVE,TABLE_1
FINI
/CLEAR,NOSTART


!**********************************************************************


C***    USING PIPE288
/OUT,SCRATCH
/PREP7
```

```
*DIM,SPIN,,6                           ! SPIN VELOCITY (RPM)
SPIN(1) = 1000.
SPIN(2) = 20000.
SPIN(3) = 40000.
SPIN(4) = 60000.
SPIN(5) = 80000.
SPIN(6) = 100000.
RO = 7806                                        ! MATERIAL : STEEL
PEX = 2.078E+11
PGXY = 1.E+14                            ! NO SHEAR
MP,EX,1,PEX
MP,PRXY,1,0.3
MP,DENS,1,RO
MP,GXY,1,PGXY

ET,1,PIPE288                                      ! ELEMENT TYPE # 1: SHAFT
KEYOPT,1,3,3
KEYOPT,1,4,2
NBDIAM = 18                                      ! SHAFT SECTION PROPERTIES
*DIM,DIAM,ARRAY,NBDIAM
DIAM(1) = 1.02E-2
DIAM(2) = 2.04E-2
DIAM(3) = 1.52E-2
DIAM(4) = 4.06E-2
DIAM(5) = DIAM(4)
DIAM(6) = 6.6E-2
DIAM(7) = DIAM(6)
DIAM(8) = 5.08E-2
DIAM(9) = DIAM(8)
DIAM(10) = 2.54E-2
DIAM(11) = DIAM(10)
DIAM(12) = 3.04E-2
DIAM(13) = DIAM(12)
DIAM(14) = 2.54E-2
DIAM(15) = DIAM(14)
DIAM(16) = 7.62E-2
DIAM(17) = 4.06E-2
DIAM(18) = DIAM(17)
*DO,I,1,NBDIAM
SECTYPE,I,PIPE
   SECDATA,DIAM(I),DIAM(I)/2
*ENDDO
SLIST

SECTYPE,7,PIPE
SECDATA,DIAM(7),(DIAM(7)-3.04E-2)/2
SECTYPE,8,PIPE
SECDATA,DIAM(8),(DIAM(8)-3.56E-2)/2
SECTYPE,18,PIPE
SECDATA,DIAM(18),(DIAM(18)-3.04E-2)/2

ET,2,MASS21                                    ! ELEMENT TYPE # 2: MASS
R,20,1.401,1.401,1.401,0.002,0.00136,0.00136

ET,3,COMBI214                                  ! ELEMENT TYPE # 3: BEARING ELEMENT
KEYOPT,3,2,1                                   ! YZ PLANE
KEYOPT,3,3,0                                   ! ELEMENT IS SYMMETRIC
R,30,3.503E+7,3.503E+7,-8.756E+6,-8.756E+6,,   ! REAL CONSTANTS ( K11,K22,K12,K21) NO DAMPING

ET,4,COMBI214
KEYOPT,4,2,1                                   ! YZ PLANE
KEYOPT,4,3,0                                   ! ELEMENT IS SYMMETRIC
R,40,3.503E+7,3.503E+7,-8.756E+6,-8.756E+6,,   ! REAL CONSTANTS ( K11,K22,K12,K21) NO DAMPING

/COM, NODES
N,1 ,0.
N,2 ,1.27E-2
N,3 ,5.08E-2
N,4 ,7.62E-2
N,5 ,8.89E-2
N,6 ,10.16E-2
N,7 ,10.67E-2
```

```
N,8 ,11.43E-2
N,9 ,12.7E-2
N,10,13.46E-2
N,11,16.51E-2
N,12,19.05E-2
N,13,22.86E-2
N,14,26.67E-2
N,15,28.7E-2
N,16,30.48E-2
N,17,31.5E-2
N,18,34.54E-2
N,19,35.5E-2

BRG = 0.1                               ! BEARING "LENGTH" FOR VISUALISATION
N,20,16.51E-2,BRG
N,22,28.7E-2,BRG

/COM, ELEMENTS
/COM, SHAFT
TYPE,1
MAT,1
*DO,I,1,NBDIAM
SECNUM,I
   E,I,I+1
*ENDDO

/COM, DISK
TYPE,2
REAL,20
E,5

/COM, BEARINGS
TYPE,3
REAL,30
E,11,20
TYPE,4
REAL,40
E,15,22
ALLSEL,ALL
FINI
/SOLU
D,ALL,UX                                      ! NO TRACTION AND TORSION
D,ALL,ROTX
D,20,ALL                                      ! SECOND NODES OF BEARING
D,22,ALL

/COM, MODAL
RATIO = 4*ATAN(1)/30
ANTYPE,MODAL
CORIOLIS,ON,,,ON
NBF = 10
MODOPT,QRDAMP,NBF,,,ON
*DO,I,1,6
   OMEGA,SPIN(I)*RATIO                       ! UNIT FOR OMEGA IS RAD/SEC
   MXPAND,NBF
   SOLVE
*ENDDO
FINI

/POST1
/OUT,
PRCAMP,,1.,RPM,,,,,
PLCAMP,,1.,RPM,,,,,
*GET,F1,CAMP,1,FREQ,6
*GET,F2,CAMP,2,FREQ,6
*GET,F3,CAMP,3,FREQ,6
*GET,F4,CAMP,4,FREQ,6
*DIM,LABEL,CHAR,1,4
*DIM,VALUE,ARRAY,4,3

LABEL(1,1) = 'WHIRL BW'
LABEL(1,2) = 'WHIRL FW'
```

```
LABEL(1,3) = 'WHIRL BW'
LABEL(1,4) = 'WHIRL FW'
*VFILL,VALUE(1,1),DATA,10747
*VFILL,VALUE(1,2),DATA,F1*60
*VFILL,VALUE(1,3),DATA,ABS((F1*60)/10747)
*VFILL,VALUE(2,1),DATA,19665
*VFILL,VALUE(2,2),DATA,F2*60
*VFILL,VALUE(2,3),DATA,ABS((F2*60)/19665)
*VFILL,VALUE(3,1),DATA,39077
*VFILL,VALUE(3,2),DATA,F3*60
*VFILL,VALUE(3,3),DATA,ABS((F3*60)/39077)
*VFILL,VALUE(4,1),DATA,47549
*VFILL,VALUE(4,2),DATA,F4*60
*VFILL,VALUE(4,3),DATA,ABS((F4*60)/47549)
SAVE,TABLE_2
FINI
/CLEAR,NOSTART



/NOPR
/COM
/OUT,vm254,vrt
/COM,------------ VM254 RESULTS COMPARISON --------------
/COM,
/COM,          |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING PIPE16
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,3),VALUE(3,1),VALUE(3,2),VALUE(3,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,4),VALUE(4,1),VALUE(4,2),VALUE(4,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
RESUME,TABLE_2
/COM,USING PIPE288
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,3),VALUE(3,1),VALUE(3,2),VALUE(3,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,4),VALUE(4,1),VALUE(4,2),VALUE(4,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM,----------------------------------------------------------
/OUT,
FINISH
*LIST,vm254,vrt
```

VM255 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM255
/TITLE,VM255,DELAMINATION OF DOUBLE CANTILEVER BEAM USING DEBONDING
/COM,   REF: ALFANO, G. AND CRISFIELD, M. A.,
/COM,   "FINITE ELEMENT INTERFACE MODELS FOR THE DELAMINATION ANALYSIS
/COM,   OF LAMINATED COMPOSITES: MECHANICAL AND COMPUTATIONAL ISSUES"
/COM,   INT. J. NUMER. METH. ENGNG 2001, 50:1701-1736.
/PREP7
ET,1,PLANE182              !* 2D 4-NODE STRUCTURAL SOLID ELEMENT
KEYOPT,1,1,2               !* ENHANCE STRAIN FORMULATION
```

```
KEYOPT,1,3,2                !* PLANE STRAIN
ET,2,PLANE182
KEYOPT,2,1,2
KEYOPT,2,3,2
ET,3,TARGE169               !* 2D TARGET ELEMENT
ET,4,CONTA171               !* 2D CONTACT ELEMENT
KEYOPT,4,12,5               !* BONDED ALWAYS CONTACT
MP,EX,1,1.353E5             !* E11 = 135.3 GPA
MP,EY,1,9.0E3               !* E22 =   9.0 GPA
MP,EZ,1,9.0E3               !* E33 =   9.0 GPA
MP,GXY,1,5.2E3              !* G12 =   5.2 GPA
MP,PRXY,1,0.24
MP,PRXZ,1,0.24
MP,PRYZ,1,0.46
KOPEN  = 1.E6
TB,CZM,2,1,1,CBDE
TBDATA,1,1.7,0.28,,,1.E-8
RECTNG,0,100,0,1.5          !* DEFINE AREAS
RECTNG,0,100,0,-1.5
LSEL,S,LINE,,2,8,2          !* DEFINE LINE DIVISION
LESIZE,ALL,0.75
LSEL,INVE
LESIZE,ALL, , ,200
ALLSEL,ALL
TYPE,1                      !* MESH AREA 2
MAT,1
LOCAL,11,0,0,0,0
ESYS,11
AMESH,2
CSYS,0
TYPE,2                      !* MESH AREA 1
ESYS,11
AMESH,1
CSYS,0
NSEL,S,LOC,X,30,100
TYPE,3
MAT,2
REAL,3
ESEL,S,TYPE,,2
NSLE,S
NSEL,R,LOC,Y
ESURF                       !* TARGET ELEMENTS
TYPE,4
REAL,3
RMODIF,3,3,-KOPEN
RMODIF,3,12,-KOPEN
ESEL,S,TYPE,,1
NSLE,S
NSEL,R,LOC,Y
NSEL,R,LOC,X,30,100
ESURF                       !* CONTACT ELEMENTS
ALLSEL,ALL
NSEL,S,LOC,X,100            !* APPLY CONSTRAINTS
D,ALL,ALL
NSEL,ALL
FINISH
/SOLU
ESEL,S,TYPE,,2
NSLE,S
NSEL,R,LOC,X
NSEL,R,LOC,Y,1.5            !* APPLY DISPLACEMENT LOADING ON TOP
D,ALL,UY,10
NSEL,ALL
ESEL,ALL
ESEL,S,TYPE,,1
NSLE,S
NSEL,R,LOC,X
NSEL,R,LOC,Y,-1.5           !* APPLY DISPLACEMENT LOADING ON BOTTOM
D,ALL,UY,-10
NSEL,ALL
ESEL,ALL
NLGEOM,ON
```

```
TIME,1
NSUBST,100,100,100
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE                        !* PERFORM SOLUTION
FINISH
/POST26
NSEL,S,LOC,Y,1.5
NSEL,R,LOC,X,0
/OUT,
*GET,NTOP,NODE,0,NUM,MAX
NSEL,ALL
NSOL,2,NTOP,U,Y,UY
RFORCE,3,NTOP,F,Y,FY
PROD,4,3, , ,RF, , ,20
/TITLE,VM255, DCB: REACTION AT TOP NODE VERSES PRESCRIBED DISPLACEMENT
/AXLAB,X,DISP U (mm)
/AXLAB,Y,REACTION FORCE R (N)
/YRANGE,0,60
XVAR,2
PLVAR,4
PRVAR,UY,RF
*GET,TMAX,VARI,4,EXTREM,TMAX   !* TIME CORRESPONDING TO MAX RFORCE
FINISH
/POST1
SET, , , , ,TMAX               !* RETRIEVE RESULTS AT TMAX
NSEL,S,NODE, ,NTOP             !* SELECT NODE NTOP
*GET,RF_NTOP,NODE,NTOP,RF,FY   !* FY RFORCE AT NODE NTOP
*GET,UY_NTOP,NODE,NTOP,U,Y     !* DISP AT NODE NTOP CORRESPONDING TO RFORCE
RF_MAX = RF_NTOP*20            !* PLANE STRAIN OPTION AND WIDTH = 20 mm
SET,LAST                       !* RETRIEVE RESULTS AT LAST SUBSTEP
*GET,RF_END,NODE,NTOP,RF,FY    !* FY RFORCE AT NODE NTOP AT LAST SUBSTEP
*GET,UY_END,NODE,NTOP,U,Y      !* DISP AT NODE NTOP CORRESPONDING TO RFORCE
RF_END = RF_END*20             !* PLANE STRAIN OPTION AND WIDTH = 20 mm
*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
*DIM,VALUE2,,2,3
LABEL(1,1) = 'RFORCE','DISP '
LABEL(1,2) = 'FY (N)','UY (mm)'
*VFILL,VALUE(1,1),DATA,50.0,1.5
*VFILL,VALUE(1,2),DATA,RF_MAX,UY_NTOP
*VFILL,VALUE(1,3),DATA,ABS(RF_MAX/50.0),ABS(UY_NTOP/1.5)
*VFILL,VALUE2(1,1),DATA,24.0,10.0
*VFILL,VALUE2(1,2),DATA,RF_END,UY_END
*VFILL,VALUE2(1,3),DATA,ABS(RF_END/24.0),ABS(UY_END/10.0)
/COM
/OUT,vm255,vrt
/COM,------------------- VM255 RESULTS COMPARISON --------------
/COM,
/COM,                  |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,MAX RFORCE AND CORRESPONDING DISP USING DEBONDING:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
/COM,
/COM,RFORCE CORRESPONDING TO DISP U = 10.0 USING DEBONDING:
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm255,vrt
```

VM256 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
```

```
/VERIFY,VM256
/COM,   VERIFICATION MANUAL FOR FRACTURE MECHANCIS, REL 11.0
/TITLE,VM256 FRACTURE MECHANICS STRESS INTENSITY  - CRACK IN A 2D PLATE
/COM    REFERENCE: BROWN AND SRAWLEY, ASTM SPECIAL TECHNICAL PUBLICATION NO. 410.
/COM    ****** CRACK IN 2-DIMENSIONS USING 2-D PLANE183 ELEMENT  ******
/PREP7
ET,1,PLANE183,,,2              ! PLANE183 (PLANE STRAIN)
MP,EX,1,30E6
MP,NUXY,1,0.3
K,1                           ! DEFINE KEYPOINTS AND LINE SEGMENTS
K,2,4
K,3,4,5
K,4,-1,5
K,5,-1
L,1,2
L,2,3
LESIZE,2,,,4
L,3,4
LESIZE,3,,,4
L,4,5,
LESIZE,4,,,6,.2
L,5,1
ESIZE,,5
KSCON,1,.15,0,8               ! DEFINE CRACK TIP ELEMENT SIZE, NO SINGULAR ELEMENTS
AL,1,2,3,4,5
DL,1,1,SYMM                   ! APPLY SOLID MODEL BOUNDARY CONDITIONS
DL,4,1,SYMM
SFL,3,PRES,-.5641895
AMESH,1
OUTPR,ALL
FINISH
/SOLU
ANTYPE,STATIC
OUTRES,ALL,ALL
NSEL,S,LOC,X,0,10
NSEL,R,LOC,Y,0
D,ALL,UY,0
ALLSEL,ALL
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0
D,ALL,UX,0
ALLSEL,ALL
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0
CM,CRACKTIP,NODE             ! DEFINE CRACK TIP NODE COMPONENT
ALLSEL,ALL
CINT,NEW,1                   ! DEFINE CRACK ID
CINT,TYPE,SIFS               ! DEFINE CRACK TYPE
CINT,CTNC,CRACKTIP           ! DEFINE CRACK TIP NODE COMPONENT
CINT,SYMM,ON                 ! SYMMETRY ON
CINT,NCON,6                  ! NUMBER OF COUNTOURS
CINT,NORM,0,2                ! DEFINE CRACK PLANE NORMAL
CINT,LIST
ALLSEL,ALL
/OUT,SCRATCH
SOLVE
FINI
/POST1
/OUT,
PRCINT,1,1,K1                  ! PRINT K VALUES
*GET,K,CINT,1,CTIP,1,,5,,K1    ! GET K VALUE FOR CRACK TIP NODE
*STATUS,K
/OUT,SCRATCH
*DIM,LABEL,CHAR,1,
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI ',
*VFILL,VALUE(1,1),DATA,1.0249     ! STRESS INTENSITY VALUE OBTAINED FROM REFERENCE
*VFILL,VALUE(1,2),DATA,K
*VFILL,VALUE(1,3),DATA,ABS(K/1.0249)
SAVE,TABLE_1
FINISH
/CLEAR, NOSTART                ! CLEAR DATABASE FOR 2ND SOLUTION
```

```
/OUT,


/COM ************* CRACK IN 3D PLATE USING SOLID 185 ELEMENT ******************* C

/PREP7
SMRT,OFF
/TITLE, VM256, FRACTURE MECHANICS STRESS INTENSITY  - CRACK IN A FINITE WIDTH PLATE
/COM,     ****** CRACK IN 3-DIMENSIONS USING SOLID185
/COM,
ET,1,SOLID185          ! SOLID 185 ELEMENT
ET,2,SOLID185          ! ELEMENTS AROUND THE CRACK TIP
MP,EX,1,3E7
MP,NUXY,1,0.3
CSYS,1                 ! CYLINDRICAL COORDINATE SYSTEM
N,1
NGEN,9,20,1
N,11,0.8
N,171,0.8,180
FILL,11,171,7,31,20
CSYS,0                ! CARTESIAN COORDINATE SYSTEM
FILL,1,11,9,2,1,9,20,3
N,15,4
N,75,4,5
FILL,15,75,2,35,20
N,155,-1,5
FILL,75,155,3,95,20
N,172,-1
FILL,155,172,5,177,-1,,,.15
FILL,11,15,3,,,7,20,3
NGEN,2,200,1,177,,,,.25
/OUT,SCRATCH
E,2,22,1,1,202,222,201,201
EGEN,8,20,-1
E,2,3,23,22,202,203,223,222
EGEN,8,20,-1
EGEN,9,1,-8
EGEN,5,1,73,78
E,171,151,173,172,371,351,373,372
E,151,131,174,173,351,331,374,373
E,131,132,175,174,331,332,375,374
EGEN,3,1,-1
E,134,135,155,177,334,335,355,377
TYPE,2
EMODIF,1                    ! MODIFY ELEMENTS 1 TO 8 FROM TYPE,1 TO TYPE,2
*REPEAT,8,1
NUMMRG,NODE                 ! MERGE COINCIDENT NODES
ALLSEL,ALL
/OUT,
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0
NLIST
CM,CRACKTIP,NODE            ! CRACK TIP NODE COMPONENT
ALLSEL,ALL
NSEL,S,LOC,X,-1
DSYM,SYMM,X                 ! SYMMETRY BOUNDARY CONDITIONS
NSEL,S,LOC,X,0,4
NSEL,R,LOC,Y,0
DSYM,SYMM,Y                 ! SYMMETRY BOUNDARY CONDITIONS
ALLSEL,ALL
D,ALL,UZ,0
ALLSEL,ALL
NSEL,S,LOC,Y,5
SF,ALL,PRES,-0.5641895      ! SURFACE PRESSURE
ALLSEL,ALL
FINI
/SOLU
AUTOTS,ON
NSUBST,10
OUTRES,ALL,ALL
CINT,NEW,1                   ! CRACK ID
CINT,TYPE,SIFS              ! DEFINE CRACK TYPE
```

```
CINT,CTNC,CRACKTIP,NODE(-1,0,0)    !DEFINE CRACK TIP COMPONENT
CINT,NCON,6                   ! NO OF CONTOURS
CINT,SYMM,ON                  ! SYMMETRY ON
CINT,NORM,0,2                 ! CRACK PLANE NORMAL
CINT,LIST
ALLSEL,ALL
SAVE
/NERR,0,,,,
/OUT,SCRATCH
SOLVE
FINI
/POST1
/OUT,
PRCINT,1,1,K1                  ! PRINT K VALUES
*GET,K,CINT,1,CTIP,NODE(0,0,0),,5,,K1    ! GET K VALUE FOR CRACK TIP NODE
*STATUS,K
*DIM,LABEL,CHAR,1,
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI ',
*VFILL,VALUE(1,1),DATA,1.0249     ! STRESS INTENSITY VALUE OBTAINED FROM REFERENCE
*VFILL,VALUE(1,2),DATA,K
*VFILL,VALUE(1,3),DATA,ABS(K/1.0249)
SAVE,TABLE_2
FINISH
/CLEAR, NOSTART                ! CLEAR DATABASE FOR 3RD SOLUTION
/OUT,


/COM ************* CRACK IN 3D PLATE USING SOLID 186 ELEMENT ******************* C


/PREP7
SMRT,OFF
/TITLE,VM256 FRACTURE MECHANICS STRESS INTENSITY  - CRACK IN A FINITE WIDTH PLATE
/COM,     ****** CRACK IN 3-DIMENSIONS USING SOLID186
/COM,
ET,1,PLANE183
ET,2,186                      ! SOLID ELEMENT 186
MP,EX,1,30E6
MP,NUXY,1,0.3
K,1                           ! DEFINE KEYPOINTS AND LINE SEGMENTS
K,2,4
K,3,4,5
K,4,-1,5
K,5,-1
L,1,2
L,2,3
LESIZE,2,,,4
L,3,4
LESIZE,3,,,4
L,4,5,
LESIZE,4,,,6,.2
L,5,1
ESIZE,,5
KSCON,1,.15,0,8               ! DEFINE CRACK TIP ELEMENT SIZE, NO SINGULAR ELEMENTS
AL,1,2,3,4,5
AMESH,1

TYPE,2
ESIZE,,2
VEXT,1,,,0,0,0.25
ALLSEL
ESEL,S,ENAME,,183
ACLEAR,1
ALLSEL

/OUT,
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0
NLIST
CM,CRACKTIP,NODE             ! CRACK TIP NODE COMPONENT
ALLSEL,ALL
```

```
NSEL,S,LOC,X,-1
DSYM,SYMM,X                 ! SYMMETRY BOUNDARY CONDITIONS
NSEL,S,LOC,X,0,4
NSEL,R,LOC,Y,0
DSYM,SYMM,Y                 ! SYMMETRY BOUNDARY CONDITIONS
ALLSEL,ALL
D,ALL,UZ,0
ALLSEL,ALL
NSEL,S,LOC,Y,5
SF,ALL,PRES,-0.5641895      ! SURFACE PRESSURE
ALLSEL,ALL
FINI
/SOLU
AUTOTS,ON
NSUBST,10
OUTRES,ALL,ALL
CINT,NEW,1                    ! CRACK ID
CINT,TYPE,SIFS               ! DEFINE CRACK TYPE
CINT,CTNC,CRACKTIP,NODE(-1,0,0)     !DEFINE CRACK TIP COMPONENT
CINT,NCON,6                   ! NO OF CONTOURS
CINT,SYMM,ON                  ! SYMMETRY ON
CINT,NORM,0,2                 ! CRACK PLANE NORMAL
CINT,LIST
ALLSEL,ALL
SAVE
/NERR,0,,,,
/OUT,SCRATCH
SOLVE
FINI
/POST1
/OUT,
PRCINT,1,1,K1                  ! PRINT K VALUES
*GET,K,CINT,1,CTIP,NODE(0,0,0),,5,,K1    ! GET K VALUE FOR CRACK TIP NODE
*STATUS,K
*DIM,LABEL,CHAR,1,
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI ',
*VFILL,VALUE(1,1),DATA,1.0249     ! STRESS INTENSITY VALUE OBTAINED FROM REFERENCE
*VFILL,VALUE(1,2),DATA,K
*VFILL,VALUE(1,3),DATA,ABS(K/1.0249)
SAVE,TABLE_3
FINISH
RESUME,TABLE_1

/COM
/OUT,vm256,vrt
/COM,------------------- VM256 RESULTS COMPARISON --------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM, ****************************************
/COM,  USING PLANE 183 ELEMENT (2-D ANALYSIS)
/COM, *****************************************
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM, *****************************************
/COM,  USING SOLID 185 ELEMENT (3-D ANALYSIS)
/COM, *****************************************
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM, *******************************************************
/COM,  USING SOLID 186 ELEMENT - SURFACE CRACK (3-D ANALYSIS)
```

```
/COM, ********************************************************
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/NOPR
/COM,
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm256,vrt
```

VM257 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM257
/TITLE,VM257,SWING COMPRISING TWO RIGID LINKS AND A BEAM WITH MIDSPAN MASS
/COM    O.A. BAUCHAU. G. DAMILANO AND N.J. THERON
/COM    NUMERICAL INTEGRATION OF NON-LINEAR ELASTIC MULTI-BODY SYSTEMS
/COM    INTERNATIONAL JOURNAL FOR NUMERICAL METHODS IN  ENGINEERING,
/COM    VOL. 38, 2727-2751 (1995)
C***  PERFORM ANALYSIS USING MPC184 RIGID LINKS
/PREP7
MP,EX,1,73E9              ! 73 GN/M^2
MP,NUXY,1,0.3
MP,DENS,1,2700            ! KG/M^3
K,1,0,0.36,0
K,2,0,0,0
K,3,0.72,0,0
K,4,0.72+0.36,0.36
L,1,2
L,2,3
L,3,4
ET,1,BEAM188              ! 3D LINEAR FINITE STRAIN BEAM
ET,2,MPC184               ! RIGID LINK
ET,3,MASS21               ! 3DMASS ELEMENT
KEYOPT,3,3,2              ! 3D MASS WITHOUT ROTARY INERTIA
R,3,0.5                   ! 0.5 KG
SECTYPE, 1, BEAM, RECT
SECDATA,1E-3,5E-3         ! 1 MM X 5 MM CROSS SECTION
TYPE,1
MAT,1
SECNUM,1
LESIZE,2, , ,4
LMESH,2                   ! DEFORMABLE BEAM
TYPE,2
MAT,2
SECNUM,2
LESIZE,1, , ,1            ! RIGID LINK
LMESH,1
TYPE,2
MAT,2
SECNUM,2
LESIZE,3, , ,1
LMESH,3                   ! RIGID LINK
NDMID = NODE(0.72/2,0,0)  ! NODE AT BEAM MIDSPAN
NDB   = NODE(0.72/4,0,0)  ! NODE AT LOCATION B
TYPE,3
REAL,3
E,NDMID                   ! MASS AT BEAM MIDSPAN
NSEL,S,LOC,Y,0.36
D,ALL,ALL
DDELE,ALL,ROTZ
ALLSEL,ALL
NDA = NODE(0,0,0)         ! NODE AT LOCATION A
NDE = NODE(0.72,0,0)      ! NODE AT LOCATION E
D, NDA, UZ, 0.0, ,, ,ROTX,ROTY
D, NDE, UZ, 0.0, ,, ,ROTX,ROTY
ALLSEL
```

```
FINISH
SAVE
C*** PERFORM SOLUTION USING HHT ALGORITHM WITH RESPONSE FREQ
/SOLU
*DIM,FXMID,TABLE,4,1,1
FXMID(1,0,1) = 0.0          !  TIME VALUES
FXMID(2,0,1) = 0.128
FXMID(3,0,1) = 0.256
FXMID(4,0,1) = 1.0
FXMID(1,1,1) = 0.0          !  FX IMPULSE LOAD VALUES
FXMID(2,1,1) = 2.0
FXMID(3,1,1) = 0.0
FXMID(4,1,1) = 0.0
F,NDMID,FX,%FXMID%          ! APPLY TABULAR LOADS
ANTYPE,TRANS
TRNOPT,FULL,,,,,HHT
TINTP,0.3                   ! 30% DAMPING
EQSLV,PCG
NLGEOM,ON                   ! LARGE DEFLECTION
AUTOTS,ON                   ! AUTO TIME STEPPING
OUTRES,ALL,-100             ! SAVE ALL RESULTS
KBC,0                       ! RAMPED LOADING
TOT_TIME = 1.0
TIME,TOT_TIME
NSUBST,1000,10E5,1000
CNVTOL,F                    ! FORCE CONVERGENCE CHECK
CNVTOL,M, , , ,1E-3         ! MOMENT CONVERGENCE CHECK
CNVTOL,U                    ! DISPLACEMENT CONVERGENCE CHECK
CNVTOL,ROT                  ! ROTATION CONVERGENCE CHECK
/OUT,scratch
SOLVE
/OUT
FINISH
/AUTO,1
/DIST,  1, 0
/REPLO
/VIEW,1,,,1
/ANG,1
/POST1
/PLOPTS,INFO,0
/PLOPTS,LEG1,0
/PLOPTS,LEG2,0
/PLOPTS,LEG3,0
/PLOPTS,FRAME,0
/PLOPTS,MINM,0
/PLOPTS,TITLE,0
/PLOPTS,FILE,0
/PLOPTS,LOGO,0
/PLOPTS,WINS,1
/PLOPTS,WP,0
/PLOPTS,DATE,0
/TRIAD,OFF
*DO,JJ,0,10
SET, , , , ,JJ/10
*IF,JJ,EQ,10,THEN
/PLOPTS,TITLE,1
/TITLE,SWING:MOTION AND DEFORMATION OF BEAM AND MOTION OF LINKS,AT 0.1 S
*ENDIF
PLNSOL,U,SUM
/NOERASE
*ENDDO
/ERASE
/POST26
NSOL,2,NDB,U,X
NSOL,3,NDB,U,Y
/TITLE,SWING:TIME HISTORY OF DISP COMPS OF POINT B IN THE I1&I2 DIRECTIONS
PLVAR,2,3                       ! COMPARE THIS PLOT WITH FIGURE 15. IN REFERENCE
!PRVAR,2,3
ESOL,4,2,3,F,X                  ! AXIAL FORCE AT POINT B
/TITLE,SWING:TIME HISTORY OF AXIAL FORCE IN THE BEAM, AT POINT B
PLVAR,4                         ! COMPARE THIS PLOT WITH FIGURE 16. IN REFERENCE
*GET,FMAX,VARI,4,EXTREM,VMAX    ! MAX AXIAL FORCE AT POINT B CORRESPONDING TO EVENT-X IN REF.
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*GET,TMAX,VARI,4,EXTREM,TMAX   ! TIME CORRESPONDING TO EVENT-X IN REFERENCE
FINISH
/POST1
SET, , , , ,TMAX               ! RETRIEVE RESULTS AT TMAX
*GET,UY_NDB,NODE,NDB,U,X       ! UX DISP AT POINT B CORRESPONDING TO EVENT-X IN REFERENCE
*GET,UX_NDB,NODE,NDB,U,Y       ! UY DISP AT POINT B CORRESPONDING TO EVENT-X IN REFERENCE
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'TIME','DISP','DISP','FORCE'
LABEL(1,2) = '   (sec)','UY (m)','UX (m)','FX (N)'
*VFILL,VALUE(1,1),DATA,0.641,0.28,0.075,112.7
*VFILL,VALUE(1,2),DATA,TMAX,UY_NDB,UX_NDB,FMAX
*VFILL,VALUE(1,3),DATA,ABS(TMAX/0.641),ABS(UY_NDB/0.28),ABS(UX_NDB/0.075),ABS(FMAX/112.7)
FINISH
SAVE,TABLE_1
/CLEAR,NOSTART
C***  PERFORM ANALYSIS USING TARGET RIGID LINKS
/PREP7
MP,EX,1,73E9               ! 73 GN/M^2
MP,NUXY,1,0.3
MP,DENS,1,2700             ! KG/M^3
K,1,0,0.36,0
K,2,0,0,0
K,3,0.72,0,0
K,4,0.72+0.36,0.36
L,1,2
L,2,3
L,3,4
ET,1,BEAM188               ! 3D LINEAR FINITE STRAIN BEAM
ET,11,TARGE170             ! TARGET ELEMENT
KEYOPT,11,2,1              ! TARGET MODELED AS A RIGID BODY
KEYOPT,11,4,111            ! DO NOT CONSTRAIN ROTATIONS
ET,3,MASS21                ! 3DMASS ELEMENT
KEYOPT,3,3,2               ! 3D MASS WITHOUT ROTARY INERTIA
R,3,0.5                    ! 0.5 KG
SECTYPE, 1, BEAM, RECT
SECDATA,1E-3,5E-3          ! 1MM X 5 MM CROSS SECTION
TYPE,1
MAT, 1
SECNUM,1
LESIZE,2, , ,4
LMESH,2                    ! DEFORMABLE BEAM
TYPE,11
REAL,11
LESIZE,1, , ,1
LMESH,1
TSHAP,PILO
TYPE,11
E,6
TYPE,11
REAL,12
LESIZE,3, , ,1
LMESH,3
TSHAP,PILO
TYPE,11
REAL,12
E,7
NDMID = NODE(0.72/2,0,0)   ! NODE AT BEAM MIDSPAN
NDB   = NODE(0.72/4,0,0)   ! NODE AT LOCATION B
TYPE,3
REAL,3
E,NDMID                    ! MASS AT BEAM MIDSPAN
NSEL,S,LOC,Y,0.36
D,ALL,ALL
DDELE,ALL,ROTZ
ALLSEL,ALL
NDA = NODE(0,0,0)          ! NODE AT LOCATION A
NDE = NODE(0.72,0,0)       ! NODE AT LOCATION E
D, NDA, UZ, 0.0, ,, ,ROTX,ROTY
D, NDE, UZ, 0.0, ,, ,ROTX,ROTY
FINISH
SAVE
```

```
C*** PERFORM SOLUTION USING HHT ALGORITHM WITH RESPONSE FREQ
/SOLU
*DIM,FXMID,TABLE,4,1,1
FXMID(1,0,1) = 0.0          !  TIME VALUES
FXMID(2,0,1) = 0.128
FXMID(3,0,1) = 0.256
FXMID(4,0,1) = 1.0
FXMID(1,1,1) = 0.0          !  FX IMPULSE LOAD VALUES
FXMID(2,1,1) = 2.0
FXMID(3,1,1) = 0.0
FXMID(4,1,1) = 0.0
F,NDMID,FX,%FXMID%          ! APPLY TABULAR LOADS
ANTYPE,TRANS
TRNOPT,FULL,,,,,HHT
TINTP,0.3                   ! 30% DAMPING
NLGEOM,ON                   ! LARGE DEFLECTION
EQSLV,PCG
AUTOTS,ON                   ! AUTO TIME STEPPING
OUTRES,ALL,-100             ! SAVE ONLY 100 RESULTS
KBC,0                       ! RAMPED LOADING
TOT_TIME = 1.0
TIME,TOT_TIME
NSUBST,1000,1000,1000
CNVTOL,U                    ! DISPLACEMENT CONVERGENCE CHECK
CNVTOL,ROT                  ! ROTATION CONVERGENCE CHECK
CNVTOL,F                    ! FORCE CONVERGENCE CHECK
CNVTOL,M, , , ,0.01         ! MOMENT CONVERGENCE CHECK
PRED,OFF
LNSRCH,OFF
/OUT,scratch
SOLVE
FINISH
/DIST,1,0
/AUTO,1
/REPLO
/VIEW,1,,,1
/ANG,1
/POST1
/PLOPTS,INFO,0
/PLOPTS,LEG1,0
/PLOPTS,LEG2,0
/PLOPTS,LEG3,0
/PLOPTS,FRAME,0
/PLOPTS,MINM,0
/PLOPTS,TITLE,0
/PLOPTS,FILE,0
/PLOPTS,LOGO,0
/PLOPTS,WINS,1
/PLOPTS,WP,0
/PLOPTS,DATE,0
/TRIAD,OFF
*DO,JJ,0,10
SET, , , , ,JJ/10
*IF,JJ,EQ,10,THEN
/PLOPTS,TITLE,1
/TITLE,SWING:MOTION AND DEFORMATION OF BEAM AND MOTION OF LINKS,AT 0.1 S
*ENDIF
PLNSOL,U,SUM
/NOERASE
*ENDDO
/ERASE
/POST26
NSOL,2,NDB,U,X
NSOL,3,NDB,U,Y
/TITLE,SWING:TIME HISTORY OF DISP COMPS OF POINT B IN THE I1&I2 DIRECTIONS
PLVAR,2,3                       ! COMPARE THIS PLOT WITH FIGURE 15. IN REFERENCE
!PRVAR,2,3
ESOL,4,2,3,F,X                  ! AXIAL FORCE AT POINT B
/TITLE,SWING:TIME HISTORY OF AXIAL FORCE IN THE BEAM, AT POINT B
PLVAR,4                         ! COMPARE THIS PLOT WITH FIGURE 16. IN REFERENCE
*GET,FMAX,VARI,4,EXTREM,VMAX    ! MAX AXIAL FORCE AT POINT B CORRESPONDING TO EVENT-X IN REF.
*GET,TMAX,VARI,4,EXTREM,TMAX    ! TIME CORRESPONDING TO EVENT-X IN REFERENCE
```

```
FINISH
/POST1
SET, , , , ,TMAX                 ! RETRIEVE RESULTS AT TMAX
*GET,UY_NDB,NODE,NDB,U,X         ! UX DISP AT POINT B CORRESPONDING TO EVENT-X IN REFERENCE
*GET,UX_NDB,NODE,NDB,U,Y         ! UY DISP AT POINT B CORRESPONDING TO EVENT-X IN REFERENCE
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'TIME','DISP','DISP','FORCE'
LABEL(1,2) = '   (sec)','UY (m)','UX (m)','FX (N)'
*VFILL,VALUE(1,1),DATA,0.641,0.28,0.075,112.7
*VFILL,VALUE(1,2),DATA,TMAX,UY_NDB,UX_NDB,FMAX
*VFILL,VALUE(1,3),DATA,ABS(TMAX/0.641),ABS(UY_NDB/0.28),ABS(UX_NDB/0.075),ABS(FMAX/112.7)
FINISH
SAVE,TABLE_2
RESUME,TABLE_1
/COM
/OUT,vm257,vrt
/COM,------------------- VM257 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,RESULTS USING MPC184 RIGID LINKS
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,RESULTS USING TARGET RIGID LINKS
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,-----------------------------------------------------------
/COM,
/OUT
FINISH
*LIST,vm257,vrt
/DELETE,TABLE_1
/DELETE,TABLE_2
```

VM258 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM258
/TITLE,VM258,SPIN-UP MANEUVER OF A FLEXIBLE BEAM
/COM,   J.C. SIMO AND L. VU-QUOC
/COM    ON THE DYNAMICS IN SPACE OF RODS UNDERGOING LARGE MOTIONS-
/COM,   -A GEOMETRICALLY EXACT APPROACH
/COM,   COMPUTER METHODS IN APPLIED MECHANICS AND ENGINEERING, VOL. 66,
/COM,   125-161 (1988.
/PREP7
ET,1,189 !3D QUADRATIC FINITE STRAIN BEAM
ET,2,184,16 !JOINT ELEMENT TYPE GENERAL
ET,3,184,6 !JOINT ELEMENT TYPE REVOLUTE
KEYOPT,3,4,1    !Z-AXIS REVOLUTE JOINT
N,1,0.0,0.0 !NODES FOR CANTILEVER BEAM
N,9,10.0,0.0
FILL,1,9
SECT,1,GENB,ELASTIC         !NONLINEAR GENERAL BEAM SECTION (ELASTIC)
BSAX,0.0,0.0 !BEAM SECTION AXIAL STIFFNESS (AXIAL STRAIN/AXIAL FORCE)
BSAX,1.0,2.8E7
BSM1,0.0,0.0 !BEAM SECTION BENDING STIFFNESS FOR PLANE XZ(CURVATURE/BENDING MOMENT)
BSM1,1.0,1.4E4
BSM2,0.0,0.0 !BEAM SECTION BENDING STIFFNESS FOR PLANE XY(CURVATURE/BENDING MOMENT)
BSM2,1.0,1.4E4
BSTQ,0.0,0.0 !BEAM SECTION TORSION STIFFNESS (TWIST/TORQUE)
BSTQ,1.0,1.4E4
BSS1,0.0,0.0 !BEAM SECTION SHEAR STIFFNESS FOR PLANE XZ (SHEAR STRAIN/TRANSVERSE SHEAR FORCE)
BSS1,1.0,1.0E7
```

```
BSS2,0.0,0.0 !BEAM SECTION SHEAR STIFFNESS FOR PLANE XY (SHEAR STRAIN/ TRANSVERSE SHEAR FORCE)
BSS2,1.0,1.0E7
BSMD,1.2 !BEAM SECTION MASS DENSITY (MASS/LENGTH)
TYPE,1  !BEAM ELEMENT DEFINITION
SECNUM,1
EN,1,1,3,2
ENGEN,1,4,2,1
SECTYPE,2,JOIN,GENE,GENE !GENERAL JOINT SECTION
SECJOIN,                        !LOCAL COORDINATE SYSTEM=GLOBAL CARTESIAN (DEFAULT)
TYPE,2                  !GENERAL JOINT ELEMENT DEFINITION
SECNUM,2
EN,201,1,9
SECTYPE,3,JOIN,REVO,REVO !REVOLUTE JOINT SECTION
SECJOIN,                        !LOCAL COORDINATE SYSTEM=GLOBAL CARTESIAN(DEFAULT)
TYPE,3                  !REVOLUTE JOINT ELEMENT DEFINITION
SECNUM,3
EN,301, ,1                      !GROUNDED JOINT ELEMENT
C***DEFINE ROTATION ANGLE AS A FUNCTION OF TIME
*DIM,FUNC1,TABLE,3001,1,1
!FIRST TABULAR LOAD: (6/15)*(((TIME*TIME)/2)+((15/(2*PI))^2)*(COS((2*TIME*PI)/15)-1))
FUNC1(0,0,1) = 0.0
FUNC1(0,1,1) = 0.0
PI = ACOS(-1.0)
OM = (2.0*PI)/15.0
A  = 0.4
B  = 45.0/(2.0*PI*PI)
*DO,II,1,3001
 T1 = (II-1)*0.005
 FUNC1(II,0,1) = T1             !TIME
 T2 = A*((T1*T1)/2.0)
 T3 = B*(COS(OM*T1)-1.0)
 FUNC1(II,1,1) = T2 + T3        !VALUE
*END DO
!SECOND TABULAR LOAD: 6*TIME-45
*DIM,FUNC2,TABLE,2,1,1
FUNC2(0,0,1) = 0.0
FUNC2(0,1,1) = 0.0
FUNC2(1,0,1) = 15.0             !TIME VALUES
FUNC2(2,0,1) = 30.0
FUNC2(1,1,1) = 45               !ROTATION VALUES
FUNC2(2,1,1) = 135.0
FINISH
C*** PERFORM SOLUTION USING HHT ALGORITHM
/SOLU
ANTYPE,TRANS                 !TRANSIENT ANALYSIS
NLGEOM,ON                 !LARGE DEFLECTION
! LOAD STEP 1--ROTATION WITH ANGULAR ACCELERATION (SMALL CENTRIFUGAL FORCE)
DJ,301,ROTZ,%FUNC1%             !APPLY FIRST TABULAR LOAD
TRNOPT,FULL, , , , ,HHT         !HHT TIME INTEGRATION SCHEME
TINTP,0.1          !10% NUMERICAL DAMPING
TIME,10
AUTOTS,ON          !AUTO TIME STEPPING
MIDTOL,ON,2          !MIDSTEP RESIDUAL CHECK
DELTIM,0.005,0.002,0.02
OUTRES,ALL,2                    !WRITE RESULTS EVERY 2 SUBSTEPS
/OUT,SCRATCH
SOLVE
/OUT
TIME,15
! LOAD STEP 2--ROTATION WITH ANGULAR ACCELERATION (INTERMEDIATE CENTRIFUGAL FORCE)
DELTIM,0.005,0.005,0.01
OUTRES,ALL,2
/OUT,SCRATCH
SOLVE
/OUT
! LOAD STEP 3--STEADY MOTION AT CONSTANT ANGULAR VELOCITY
DJ,301,ROTZ,%FUNC2%             !APPLY SECOND TABULAR LOAD
TIME,18
OUTRES,ALL,2
/OUT,SCRATCH
SOLVE
/OUT
```

```
FINISH
! EXTRACT TIME POINTS FROM Mechanical APDL RESULTS CLOSEST TO THE REFERENCE TIME DATA
*DIM,TIME2,ARRAY,12
/POST1
*DO,K,1,12,1
 T = K*1.5
 SET,NEAR, , , ,T
 *GET,TIME2(K),ACTIVE,0,SET,TIME
*END DO
FINISH
/POST26
ESOL,2,201,9,SMISC,61,U1        !AXIAL DISPLACEMENT OF BEAM TIP
ESOL,3,201,9,SMISC,62,U2        !TRANSVERSE DISPLACEMENT OF BEAM TIP
NSOL,4,9,ROT,Z,ROTZ9            !ROTATION OF BEAM BASE
NSOL,5,1,ROT,Z,ROTZ1            !ROTATION OF BEAM TIP
! ROTATION OF BEAM TIP RELATIVE TO BASE--CONVERTED TO DEGREES
ADD,6,5,4,,ROTZ, , ,57.2957795131,-57.2957795131,0
/OUT
/TITLE,SPIN-UP OF A FLEXIBLE BEAM: ROTATION ANGLE VS. TIME
/AXLAB,Y,ROTATION ANGLE
PLVAR,5
/TITLE, TIME HISTORY OF AXIAL DISPLACEMENT OF BEAM TIP
/AXLAB,Y,AXIAL DISPLACEMENT
PLVAR,2                         !COMPARE THIS PLOT WITH FIGURE 6 IN REFERENCE
/TITLE,TIME HISTORY OF TRANSVERSE DISPLACEMENT OF BEAM TIP
/AXLAB,Y,TRANSVERSE DISPLACEMENT
PLVAR,3                         !COMPARE THIS PLOT WITH FIGURE 6 IN REFERENCE
/TITLE,TIME HISTORY OF RELATIVE ROTATION OF BEAM TIP
/AXLAB,Y,RELATIVE ROTATION
PLVAR,6                         !COMPARE THIS PLOT WITH FIGURE 6 IN REFERENCE

*GET,UXMIN,VARI,2,EXTREM,VMIN   ! MIN AXIAL DISPLACEMENT AT BEAM TIP
*GET,TXMIN,VARI,2,EXTREM,TMIN   ! TIME CORRESPONDING TO MIN AXIAL DISPLACEMENT

*GET,UYMIN,VARI,3,EXTREM,VMIN   ! MIN TRANSVERSE DISPLACEMENT AT BEAM TIP
*GET,TYMIN,VARI,3,EXTREM,TMIN   ! TIME CORRESPONDING TO MIN TRANSVERSE  DISPLACEMENT

*GET,ROTZMAX,VARI,6,EXTREM,VMAX ! MAX RELATIVE ROTATION
*GET,TZMAX,VARI,6,EXTREM,TMAX   ! TIME CORRESPONDING TO MAXIMUM RELATIVE ROTATION

*GET,UXMAX,VARI,2,EXTREM,VMAX   ! MAX STRETCH
*GET,TXMAX,VARI,2,EXTREM,TMAX   ! TIME CORRESPONDING TO MAX STRETCH

*DIM,LABEL1,CHAR,2,2
*DIM,VALUE1,,2,3
LABEL1(1,1) = 'TIME','TIP DISP'
LABEL1(1,2) = '   (sec)','UX '
*VFILL,VALUE1(1,1),DATA,6.7,-0.019
*VFILL,VALUE1(1,2),DATA,TXMIN,UXMIN
*VFILL,VALUE1(1,3),DATA,ABS(TXMIN/6.7),ABS(UXMIN/(-0.019))
FINISH
SAVE,TABLE_1
/POST26
*DIM,LABEL2,CHAR,2,2
*DIM,VALUE2,,2,3
LABEL2(1,1) = 'TIME','TIP DISP'
LABEL2(1,2) = '   (sec)','UY '
*VFILL,VALUE2(1,1),DATA,6.85,-0.575
*VFILL,VALUE2(1,2),DATA,TYMIN,UYMIN
*VFILL,VALUE2(1,3),DATA,ABS(TYMIN/6.85),ABS(UYMIN/(-0.575))
FINISH
SAVE,TABLE_2
/POST26
*DIM,LABEL3,CHAR,2,2
*DIM,VALUE3,,2,3
LABEL3(1,1) = 'TIME','REL'
LABEL3(1,2) = '   (sec)','ROTZ(deg)'
*VFILL,VALUE3(1,1),DATA,6.7,4.424
*VFILL,VALUE3(1,2),DATA,TZMAX,ROTZMAX
*VFILL,VALUE3(1,3),DATA,ABS(TZMAX/6.7),ABS(ROTZMAX/4.424)
FINISH
SAVE,TABLE_3
```

```
/POST26
*DIM,LABEL4,CHAR,2,2
*DIM,VALUE4,,2,3
LABEL4(1,1) = 'TIME','STRETCH'
LABEL4(1,2) = '   (sec)','UX'
*VFILL,VALUE4(1,1),DATA,16,5.14E-4
*VFILL,VALUE4(1,2),DATA,TXMAX,UXMAX
*VFILL,VALUE4(1,3),DATA,ABS(TXMAX/16),ABS(UXMAX/5.14E-4)
FINISH
SAVE,TABLE_4


RESUME,TABLE_1
/COM
/OUT,vm258,vrt
/COM,------------------- VM258 RESULTS COMPARISON --------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,PEAK AXIAL DISPLACEMENT
*VWRITE,LABEL1(1,1),LABEL1(1,2),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM,PEAK TRANSVERSE DISPLACEMENT
*VWRITE,LABEL2(1,1),LABEL2(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM,PEAK RELATIVE ROTATION
*VWRITE,LABEL3(1,1),LABEL3(1,2),VALUE3(1,1),VALUE3(1,2),VALUE3(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/NOPR
RESUME,TABLE_4
/GOPR
/COM,
/COM,STEADY-STATE STRETCH
*VWRITE,LABEL4(1,1),LABEL4(1,2),VALUE4(1,1),VALUE4(1,2),VALUE4(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',1F15.3)
/COM,----------------------------------------------------------
/COM,
/OUT
FINISH
*LIST,vm258,vrt
/DELETE,TABLE_1
/DELETE,TABLE_2
/DELETE,TABLE_3
/DELETE,TABLE_4
```

VM259 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM259
/COM,  VERIFICATION MANUAL FOR SPRS ANALYSIS WITH MISSING MASS AND RIGID RESPONSES, REL 12.0
/TITLE,VM259,MISSING MASS WITH RIGID RESPONSES EFFECTS IN SPECTRUM ANALYSIS FOR BM3 PIPING MODEL
/COM, REFERENCE: " REEVALUATION OF REGULATORY GUIDANCE ON MODAL RESPONSE COMBINATION
/COM,              METHODS FOR SEISMIC RESPONSE SPECTRUM ANALYSIS"
/COM,              R.MORANTE,Y.WANG, BROOKHAVEN NATIONAL LABORATORY,DECEMBER 1999
/COM,              U.S. NUCLEAR REGULATORY COMMISSION
/OUT,SCRATCH
/FILNAME,MODEL
/PREP7
YOUNGMODULUS = 2.9e+7     ! YOUNG'S MODULUS
NU = 0.3                               ! POISSON RATIO
```

```
SHEARMODULUS = YOUNGMODULUS/(2*(1+NU))    ! SHEAR MODULUS
ET,1,PIPE16
R, 1, 3.500, 0.2160               ! OUTER DIAMETER, WALL THICKNESS
MP,EX,  1, YOUNGMODULUS
MP,NUXY,1, NU
MP,GXY ,1, SHEARMODULUS
MP,DENS,1, 1.043e-3
ET,2,PIPE16
R, 2, 4.500, 0.2370               ! OUTER DIAMETER, WALL THICKNESS
MP,EX,  2, YOUNGMODULUS
MP,NUXY,2, NU
MP,GXY ,2, SHEARMODULUS
MP,DENS,2, 1.107e-3
ET,3,PIPE16
R, 3, 8.625, 0.3220                ! OUTER DIAMETER, WALL THICKNESS
MP,EX,  3, YOUNGMODULUS
MP,NUXY,3, NU
MP,GXY ,3, SHEARMODULUS
MP,DENS,3, 1.253e-3
ET,4,PIPE18
R, 4, 3.500, 0.2160,  4.500        ! OUTER DIAMETER, WALL THICKNESS, RADIUS OF CURVATURE
MP,EX,  4, YOUNGMODULUS
MP,NUXY,4, NU
MP,GXY ,4, SHEARMODULUS
MP,DENS,4, 1.043e-3
ET,5,PIPE18
R, 5, 4.500, 0.2370,  6.000        ! OUTER DIAMETER, WALL THICKNESS, RADIUS OF CURVATURE
MP,EX,  5, YOUNGMODULUS
MP,NUXY,5, NU
MP,GXY ,5, SHEARMODULUS
MP,DENS,5, 1.107e-3
ET,6,PIPE18
R, 6, 8.625, 0.3220, 12.000       ! OUTER DIAMETER, WALL THICKNESS, RADIUS OF CURVATURE
MP,EX,  6, YOUNGMODULUS
MP,NUXY,6, NU
MP,GXY ,6, SHEARMODULUS
MP,DENS,6, 1.253e-3
ET,7,COMBIN14,,1     ! UX DEGREE OF FREEDOM
ET,8,COMBIN14,,2     ! UY DEGREE OF FREEDOM
ET,9,COMBIN14,,3     ! UZ DEGREE OF FREEDOM
R, 7, 1.e+5                 ! STIFFNESS
R, 8, 1.e+8                 ! STIFFNESS
R, 9, 1.e+11                ! STIFFNESS
/COM, ANCHORS
ET,10,COMBIN14,,4     ! ROTX DEGREE OF FREEDOM
ET,11,COMBIN14,,5     ! ROTY DEGREE OF FREEDOM
ET,12,COMBIN14,,6     ! ROTZ DEGREE OF FREEDOM
R,10, 1.e+20

N,  1,
N,  2,  15.000,
N,  3,  19.500,   -4.500
N,  4,  19.500, -180.000
N,  5,  19.500, -199.500
N,  6,  19.500, -204.000,   4.500
N,  7,  19.500, -204.000, 139.500
N,  8,  24.000, -204.000, 144.000
N,  9,  96.000, -204.000, 144.000
N, 10, 254.000, -204.000, 144.000
N, 11, 333.000, -204.000, 144.000
N, 12, 411.000, -204.000, 144.000
N, 13, 483.000, -204.000, 144.000
N, 14, 487.500, -204.000, 148.500
N, 15, 487.500, -204.000, 192.000
N, 16, 487.500, -204.000, 235.500
N, 17, 492.000, -204.000, 240.000
N, 18, 575.000, -204.000, 240.000
N, 19, 723.000, -204.000, 240.000
N, 20, 727.500, -208.500, 240.000
N, 21, 727.500, -264.000, 240.000
N, 22, 727.500, -264.000, 205.000
N, 23, 727.500, -264.000, 190.000
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N, 24, 733.500, -264.000, 184.000
N, 25, 753.500, -264.000, 184.000
N, 26, 845.500, -264.000, 184.000
N, 27, 851.500, -264.000, 178.000
N, 28, 851.500, -264.000, 160.000
N, 29, 851.500, -264.000, 142.000
N, 30, 851.500, -270.000, 136.000
N, 31, 851.500, -360.000, 136.000
N, 32, 727.500, -264.000, 255.000
N, 33, 727.500, -264.000, 270.000
N, 34, 727.500, -264.000, 306.000
N, 35, 727.500, -264.000, 414.000
N, 36, 739.500, -264.000, 426.000
N, 37, 847.500, -264.000, 426.000
N, 38, 955.500, -264.000, 426.000
/COM, NODES FOR CURVATURE
N, 203,  15.000,   -4.500
N, 506,  19.500, -199.500,   4.500
N, 708,  24.000, -204.000, 139.500
N,1314, 483.000, -204.000, 148.500
N,1617, 492.000, -204.000, 235.500
N,1920, 723.000, -208.500, 240.000
N,2324, 733.500, -264.000, 190.000
N,2627, 845.500, -264.000, 178.000
N,2930, 851.500, -270.000, 142.000
N,3536, 739.500, -264.000, 414.000
/COM, NODES FOR ELASTIC SUPPORT
DIST = 50.0       ! VISUALIZATION
N,10001,        -DIST
N,20001,             ,          DIST
N,30001,             ,              , -DIST
N,10004,  19.500+DIST, -180.000
N,30004,  19.500     , -180.000     , -DIST
N,20007,  19.500     , -204.000+DIST, 139.500
N,20011, 333.000     , -204.000+DIST, 144.000
N,30011, 333.000     , -204.000     , 144.000-DIST
N,10015, 487.500-DIST, -204.000     , 192.000
N,20017, 492.000     , -204.000-DIST, 240.000
N,30017, 492.000     , -204.000     , 240.000-DIST
N,10023, 727.500-DIST, -264.000     , 190.000
N,20023, 727.500     , -264.000+DIST, 190.000
N,10031, 851.500+DIST, -360.000     , 136.000
N,20031, 851.500     , -360.000-DIST, 136.000
N,30031, 851.500     , -360.000     , 136.000-DIST
N,20036, 739.500     , -264.000-DIST, 426.000
N,30036, 739.500     , -264.000     , 426.000-DIST
N,10038, 955.500+DIST, -264.000     , 426.000
N,20038, 955.500     , -264.000-DIST, 426.000
N,30038, 955.500     , -264.000     , 426.000-DIST
/COM,  STRAIGHT PIPE ELEMENTS
TYPE,1
REAL,1
MAT,1
E, 1, 2
E, 3, 4
E, 4, 5
E, 6, 7
E, 8, 9
E, 9,10
E,10,11
E,11,12
E,12,13
E,14,15
E,15,16
E,17,18
E,18,19
E,20,21
TYPE,2
REAL,2
MAT,2
E,21,22
E,22,23
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E,24,25
E,25,26
E,27,28
E,28,29
E,30,31
TYPE,3
REAL,3
MAT,3
E,21,32
E,32,33
E,33,34
E,34,35
E,36,37
E,37,38
/COM, CURVED PIPE ELEMENTS
TYPE,4
REAL,4
MAT,4
E,2,3,203
E,5,6,506
E,7,8,708
E,13,14,1314
E,16,17,1617
E,19,20,1920
TYPE,5
REAL,5
MAT,5
E,23,24,2324
E,26,27,2627
E,29,30,2930
TYPE,6
REAL,6
MAT,6
E,35,36,3536
/COM,  ELASTIC SUPPORTS AND ANCHORS
TYPE,7
REAL,8
E, 4,10004
REAL,7
E,15,10015
REAL,7
E,23,10023
REAL,9
E, 1,10001
E,31,10031
E,38,10038
TYPE,8
REAL,8
E, 7,20007
REAL,8
E,11,20011
REAL,8
E,17,20017
REAL,8
E,23,20023
REAL,8
E,36,20036
REAL,9
E, 1,20001
E,31,20031
E,38,20038
TYPE,9
REAL,8
E, 4,30004
REAL,7
E,11,30011
REAL,7
E,17,30017
REAL,7
E,36,30036
REAL,9
E, 1,30001
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E,31,30031
E,38,30038
TYPE,10
REAL,10
E, 1,10001
E,31,10031
E,38,10038
TYPE,11
REAL,10
E, 1,20001
E,31,20031
E,38,20038
TYPE,12
REAL,10
E, 1,30001
E,31,30031
E,38,30038
NSEL,S,NODE,,10000,40000
D,ALL,ALL,
ALLSEL,ALL
SAVE,MODEL,DB
FINI
/CLEAR,NOSTART
/FILNAME,CASE1
RESUME,MODEL,DB
FINI
/OUT,
/COM,
/COM,  MODAL ANALYSIS WITH LUMPED MASS
/COM,
/OUT,SCRATCH
/SOLU
ANTYPE,MODAL
MODOPT,LANB,14
LUMPM,ON     ! LUMPED MASS MATRIX FORMULATION
MXPAND,14,,,YES
SOLVE
SAVE
*DIM,LABEL,,14
*DIM,FREQ_ANS,,14      ! FREQUENCIES OBTAINED FROM Mechanical APDL
*DIM,FREQ_EXP,,14          ! FREQUENCIES FROM REFERENCE
*DIM,FREQ_ERR,,14
*DO,I,1,14
LABEL(I)=I
*ENDDO
*DO,I,1,14
*GET,FREQ_ANS(I),MODE,I,FREQ
*ENDDO
*VFILL,FREQ_EXP,DATA,2.91,4.39,5.52,5.70,6.98,7.34,7.88,10.30,11.06,11.23
*VFILL,FREQ_EXP(11),DATA,11.50,12.43,13.88,16.12
*STAT,FREQ_ANS
*STAT,FREQ_EXP
*DO,I,1,14
FREQ_ERR(I)= ABS(FREQ_ANS(I)/(FREQ_EXP(I)))
*ENDDO
SAVE,TABLE_1
FINI
/OUT,
/COM,
/COM,  SPECTRUM ANALYSIS WITH MISSING MASS
/COM,
/OUT,SCRATCH
/SOLU
ANTYPE,SPECTRUM
SPOPT,SPRS,,
SVTYP,2,386.4
FREQ    , 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.00
SV, 0.01, 0.06, 0.13, 0.13, 0.20, 0.35, 0.39, 0.37, 0.41, 0.76
FREQ    , 1.10, 1.20, 1.30, 1.40, 1.50, 1.60, 1.70, 1.80, 1.90
SV, 0.01, 0.64, 0.59, 0.91, 1.03, 1.46, 0.95, 0.91, 1.61, 1.92
FREQ    , 2.00, 2.10, 2.20, 2.30, 2.40, 2.50, 2.60, 2.70, 2.80
SV, 0.01, 1.57, 1.18, 2.65, 2.85, 3.26, 4.47, 4.75, 5.29, 7.44
```

```
FREQ    , 2.90, 3.00, 3.15, 3.30, 3.45, 3.60, 3.80, 4.00, 4.20
SV, 0.01, 4.27, 4.61, 4.13, 3.96, 4.05, 2.44, 2.09, 2.29, 1.52
FREQ    , 4.40, 4.60, 4.80, 5.00, 5.25, 5.50, 5.75, 6.00, 6.25
SV, 0.01, 1.34, 1.37, 1.36, 1.31, 1.69, 1.27, 1.04, 0.76, 0.76
FREQ    , 6.50, 6.75, 7.00, 7.25, 7.50, 7.75, 8.00, 8.50, 9.00
SV, 0.01, 0.69, 0.70, 0.74, 0.70, 0.67, 0.66, 0.61, 0.75, 0.60
FREQ    , 9.50,10.00,10.50,11.00,11.50,12.00,12.50,13.00,13.50
SV, 0.01, 0.69, 0.61, 0.70, 0.59, 0.61, 0.56, 0.59, 0.59, 0.59
FREQ    ,14.00,14.50,15.00,16.00,17.00,18.00,20.00,22.00,25.00
SV, 0.01, 0.58, 0.59, 0.58, 0.55, 0.56, 0.55, 0.55, 0.55, 0.54
FREQ    ,28.00,31.00,34.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
SV, 0.01, 0.54, 0.54, 0.54, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
SVPLOT,OFF,0.01
SED,1,0,0                       ! EXCITATION IN X DIRECTION
SRSS,0.001,disp                  ! SRSS MODE COMBINATION METHOD
MMASS,ON,0.54                    ! MISSING MASS ON WITH ZPA VALUE OF 0.54
SOLVE
SAVE
FINI
/POST1
/COM, TOTAL RESPONSE OF THE STRUCTURE
/INPUT,CASE1,mcom
/OUT,
*GET,RF10001_1,NODE,10001,RF,FX
*GET,RF20001_1,NODE,20001,RF,FY
*GET,RF30001_1,NODE,30001,RF,FZ
*GET,RF10031_1,NODE,10031,RF,FX
*GET,RF20031_1,NODE,20031,RF,FY
*GET,RF30031_1,NODE,30031,RF,FZ
/OUT,SCRATCH
*DIM,LABEL,CHAR,1,6
*DIM,VALUE,,6,3
LABEL(1,1) = 'FX1'
LABEL(1,2) = 'FY1'
LABEL(1,3) = 'FZ1'
LABEL(1,4) = 'FX31'
LABEL(1,5) = 'FY31'
LABEL(1,6) = 'FZ31'
/COM,
/COM,  REACTION FORCES OBTAINED FROM REFERENCE AND FROM Mechanical APDL FOR NODES 1 AND 31
/COM,
*VFILL,VALUE(1,1),DATA,43.71*1.10            ! FX AT NODE 1 WITH SRSS COMBINATION
*VFILL,VALUE(1,2),DATA,RF10001_1               ! FX AT NODE 10001 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(1,3),DATA,ABS(RF10001_1/(43.71*1.10))
*VFILL,VALUE(2,1),DATA,4.36*1.26               ! FY AT NODE 1 WITH SRSS COMBINATION
*VFILL,VALUE(2,2),DATA,RF20001_1               ! FY AT NODE 20001 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(2,3),DATA,ABS(RF20001_1/(4.36*1.26))
*VFILL,VALUE(3,1),DATA,1.60*4.74               ! FZ AT NODE 1 WITH SRSS COMBINATION
*VFILL,VALUE(3,2),DATA,RF30001_1               ! FZ AT NODE 30001 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(3,3),DATA,ABS(RF30001_1/(4.74*1.60))
*VFILL,VALUE(4,1),DATA,55.05*0.92              ! FX AT NODE 31 WITH SRSS COMBINATION
*VFILL,VALUE(4,2),DATA,RF10031_1               ! FX AT NODE 10031 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(4,3),DATA,ABS(RF10031_1/(55.05*0.92))
*VFILL,VALUE(5,1),DATA,14.17*1.75              ! FY AT NODE 31 WITH SRSS COMBINATION
*VFILL,VALUE(5,2),DATA,RF20031_1               ! FY AT NODE 20031 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(5,3),DATA,ABS(RF20031_1/(14.17*1.75))
*VFILL,VALUE(6,1),DATA,16.08*1.97             ! FZ AT NODE 31 WITH SRSS COMBINATION
*VFILL,VALUE(6,2),DATA,RF30031_1              ! FZ AT NODE 30031 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(6,3),DATA,ABS(RF30031_1/(16.08*1.97))
SAVE,TABLE_2
FINISH
/CLEAR,NOSTART
/OUT,
/COM,
/COM,  SPECTRUM ANALYSIS WITH RIGID RESPONSES AND MISSING MASS (USING LINDLEY METHOD)
/COM,
/OUT,SCRATCH
/FILNAME,CASE2
RESUME,MODEL,DB
FINI
/SOLU
ANTYPE,MODAL
```

```
MODOPT,LANB,14
LUMPM,ON                                  ! LUMPED MASS MATRIX FORMULATION
MXPAND,14,,,YES
SOLVE
SAVE,
FINI
/SOLU
ANTYPE,SPECTRUM
SPOPT,SPRS,,
SVTYP,2,386.4
FREQ    , 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.00
SV, 0.01, 0.06, 0.13, 0.13, 0.20, 0.35, 0.39, 0.37, 0.41, 0.76
FREQ    , 1.10, 1.20, 1.30, 1.40, 1.50, 1.60, 1.70, 1.80, 1.90
SV, 0.01, 0.64, 0.59, 0.91, 1.03, 1.46, 0.95, 0.91, 1.61, 1.92
FREQ    , 2.00, 2.10, 2.20, 2.30, 2.40, 2.50, 2.60, 2.70, 2.80
SV, 0.01, 1.57, 1.18, 2.65, 2.85, 3.26, 4.47, 4.75, 5.29, 7.44
FREQ    , 2.90, 3.00, 3.15, 3.30, 3.45, 3.60, 3.80, 4.00, 4.20
SV, 0.01, 4.27, 4.61, 4.13, 3.96, 4.05, 2.44, 2.09, 2.29, 1.52
FREQ    , 4.40, 4.60, 4.80, 5.00, 5.25, 5.50, 5.75, 6.00, 6.25
SV, 0.01, 1.34, 1.37, 1.36, 1.31, 1.69, 1.27, 1.04, 0.76, 0.76
FREQ    , 6.50, 6.75, 7.00, 7.25, 7.50, 7.75, 8.00, 8.50, 9.00
SV, 0.01, 0.69, 0.70, 0.74, 0.70, 0.67, 0.66, 0.61, 0.75, 0.60
FREQ    , 9.50,10.00,10.50,11.00,11.50,12.00,12.50,13.00,13.50
SV, 0.01, 0.69, 0.61, 0.70, 0.59, 0.61, 0.56, 0.59, 0.59, 0.59
FREQ    ,14.00,14.50,15.00,16.00,17.00,18.00,20.00,22.00,25.00
SV, 0.01, 0.58, 0.59, 0.58, 0.55, 0.56, 0.55, 0.55, 0.55, 0.54
FREQ    ,28.00,31.00,34.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
SV, 0.01, 0.54, 0.54, 0.54, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
SVPLOT,OFF,0.01
SED,1,0,0                               ! EXCITATION IN X DIRECTION
SRSS,0.001,DISP                            ! SRSS MODE COMBINATION METHOD
MMASS,ON,0.54                              ! MISSING MASS ON WITH ZPA = 0.54
RIGRESP,ON,LINDLEY,0.54                    ! RIGID RESPONSE USING LINDLEY METHOD
SOLVE
SAVE
FINI
/POST1
/COM, TOTAL RESPONSE OF THE STRUCTURE
/INPUT,CASE2,mcom
/OUT,
*GET,RF10001_2,NODE,10001,RF,FX
*GET,RF20001_2,NODE,20001,RF,FY
*GET,RF30001_2,NODE,30001,RF,FZ
*GET,RF10031_2,NODE,10031,RF,FX
*GET,RF20031_2,NODE,20031,RF,FY
*GET,RF30031_2,NODE,30031,RF,FZ
/OUT,SCRATCH
*DIM,LABEL,CHAR,1,6
*DIM,VALUE,,6,3
LABEL(1,1) = 'FX1'
LABEL(1,2) = 'FY1'
LABEL(1,3) = 'FZ1'
LABEL(1,4) = 'FX31'
LABEL(1,5) = 'FY31'
LABEL(1,6) = 'FZ31'
/COM,
/COM,  REACTION FORCES OBTAINED FROM REFERENCE AND FROM Mechanical APDL FOR NODES 1 AND 31
/COM,
*VFILL,VALUE(1,1),DATA,43.71*1.06                 ! FX AT NODE 1 WITH SRSS COMBINATION
*VFILL,VALUE(1,2),DATA,RF10001_2                  ! FX AT NODE 10001 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(1,3),DATA,ABS(RF10001_2/(43.71*1.06))
*VFILL,VALUE(2,1),DATA,4.36*0.85                  ! FY AT NODE 1 WITH SRSS COMBINATION
*VFILL,VALUE(2,2),DATA,RF20001_2                  ! FY AT NODE 20001 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(2,3),DATA,ABS(RF20001_2/(4.36*0.85))
*VFILL,VALUE(3,1),DATA,1.60*2.21                  ! FZ AT NODE 1 WITH SRSS COMBINATION
*VFILL,VALUE(3,2),DATA,RF30001_2                  ! FZ AT NODE 30001 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(3,3),DATA,ABS(RF30001_2/(2.21*1.60))
*VFILL,VALUE(4,1),DATA,55.05*1.02                 ! FX AT NODE 31 WITH SRSS COMBINATION
*VFILL,VALUE(4,2),DATA,RF10031_2                  ! FX AT NODE 10031 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(4,3),DATA,ABS(RF10031_2/(55.05*1.02))
*VFILL,VALUE(5,1),DATA,14.17*1.26                 ! FY AT NODE 31 WITH SRSS COMBINATION
*VFILL,VALUE(5,2),DATA,RF20031_2                  ! FY AT NODE 20031 OBTAINED FROM Mechanical APDL
```

```
*VFILL,VALUE(5,3),DATA,ABS(RF20031_2/(14.17*1.26))
*VFILL,VALUE(6,1),DATA,16.08*1.43                ! FZ AT NODE 31 WITH SRSS COMBINATION
*VFILL,VALUE(6,2),DATA,RF30031_2                 ! FZ AT NODE 30031 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(6,3),DATA,ABS(RF30031_2/(16.08*1.43))
SAVE,TABLE_3
FINISH
/CLEAR,NOSTART
/OUT,
/COM,
/COM,  SPECTRUM ANALYSIS WITH RIGID RESPONSES AND MISSING MASS (GUPTA METHOD)
/COM,
/OUT,SCRATCH
/FILNAME,CASE3
RESUME,MODEL,DB
FINI
/SOLU
ANTYPE,MODAL
MODOPT,LANB,14
LUMPM,ON                                     ! LUMPED MASS MATRIX FORMULATION
MXPAND,14,,,YES
SOLVE
SAVE
FINI
/SOLU
ANTYPE,SPECTRUM
SPOPT,SPRS,,
SVTYP,2,386.4
FREQ    , 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.00
SV, 0.01, 0.06, 0.13, 0.13, 0.20, 0.35, 0.39, 0.37, 0.41, 0.76
FREQ    , 1.10, 1.20, 1.30, 1.40, 1.50, 1.60, 1.70, 1.80, 1.90
SV, 0.01, 0.64, 0.59, 0.91, 1.03, 1.46, 0.95, 0.91, 1.61, 1.92
FREQ    , 2.00, 2.10, 2.20, 2.30, 2.40, 2.50, 2.60, 2.70, 2.80
SV, 0.01, 1.57, 1.18, 2.65, 2.85, 3.26, 4.47, 4.75, 5.29, 7.44
FREQ    , 2.90, 3.00, 3.15, 3.30, 3.45, 3.60, 3.80, 4.00, 4.20
SV, 0.01, 4.27, 4.61, 4.13, 3.96, 4.05, 2.44, 2.09, 2.29, 1.52
FREQ    , 4.40, 4.60, 4.80, 5.00, 5.25, 5.50, 5.75, 6.00, 6.25
SV, 0.01, 1.34, 1.37, 1.36, 1.31, 1.69, 1.27, 1.04, 0.76, 0.76
FREQ    , 6.50, 6.75, 7.00, 7.25, 7.50, 7.75, 8.00, 8.50, 9.00
SV, 0.01, 0.69, 0.70, 0.74, 0.70, 0.67, 0.66, 0.61, 0.75, 0.60
FREQ    , 9.50,10.00,10.50,11.00,11.50,12.00,12.50,13.00,13.50
SV, 0.01, 0.69, 0.61, 0.70, 0.59, 0.61, 0.56, 0.59, 0.59, 0.59
FREQ    ,14.00,14.50,15.00,16.00,17.00,18.00,20.00,22.00,25.00
SV, 0.01, 0.58, 0.59, 0.58, 0.55, 0.56, 0.55, 0.55, 0.55, 0.54
FREQ    ,28.00,31.00,34.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
SV, 0.01, 0.54, 0.54, 0.54, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
SVPLOT,OFF,0.01
SED,1,0,0                                  ! EXCITATION IN X DIRECTION
SRSS,0.001,DISP                            ! SRSS MODE COMBINATION
MMASS,ON,0.54                              ! MISSING MASS ON WITH ZPA VALUE OF 0.54
RIGRESP,ON,GUPTA,2.8,6.0                   ! RIGID RESPONSE ON WITH GUPTA METHOD
SOLVE
SAVE
FINI
/POST1
/COM, TOTAL RESPONSE OF THE STRUCTURE
/INPUT,CASE3,mcom
/OUT,
*GET,RF10001_3,NODE,10001,RF,FX
*GET,RF20001_3,NODE,20001,RF,FY
*GET,RF30001_3,NODE,30001,RF,FZ
*GET,RF10031_3,NODE,10031,RF,FX
*GET,RF20031_3,NODE,20031,RF,FY
*GET,RF30031_3,NODE,30031,RF,FZ
/OUT,SCRATCH
*DIM,LABEL,CHAR,1,6
*DIM,VALUE,,6,3
LABEL(1,1) = 'FX1'
LABEL(1,2) = 'FY1'
LABEL(1,3) = 'FZ1'
LABEL(1,4) = 'FX31'
LABEL(1,5) = 'FY31'
LABEL(1,6) = 'FZ31'
```

```
/COM,
/COM,  REACTION FORCES OBTAINED FROM REFERENCE AND FROM Mechanical APDL FOR NODES 1 AND 31
/COM,
*VFILL,VALUE(1,1),DATA,45.43                     ! FX AT NODE 1 WITH SRSS COMBINATION
*VFILL,VALUE(1,2),DATA,RF10001_3                 ! FX AT NODE 10001 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(1,3),DATA,ABS(RF10001_3/(45.43))
*VFILL,VALUE(2,1),DATA,3.08                      ! FY AT NODE 1 WITH SRSS COMBINATION
*VFILL,VALUE(2,2),DATA,RF20001_3                 ! FY AT NODE 20001 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(2,3),DATA,ABS(RF20001_3/(3.08))
*VFILL,VALUE(3,1),DATA,1.34                      ! FZ AT NODE 1 WITH SRSS COMBINATION
*VFILL,VALUE(3,2),DATA,RF30001_3                 ! FZ AT NODE 30001 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(3,3),DATA,ABS(RF30001_3/(1.34))
*VFILL,VALUE(4,1),DATA,56.06                     ! FX AT NODE 31 WITH SRSS COMBINATION
*VFILL,VALUE(4,2),DATA,RF10031_3                 ! FX AT NODE 10031 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(4,3),DATA,ABS(RF10031_3/(56.06))
*VFILL,VALUE(5,1),DATA,14.19                     ! FY AT NODE 31 WITH SRSS COMBINATION
*VFILL,VALUE(5,2),DATA,RF20031_3                 ! FY AT NODE 20031 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(5,3),DATA,ABS(RF20031_3/(14.19))
*VFILL,VALUE(6,1),DATA,13.95                     ! FZ AT NODE 31 WITH SRSS COMBINATION
*VFILL,VALUE(6,2),DATA,RF30031_3                 ! FZ AT NODE 30031 OBTAINED FROM Mechanical APDL
*VFILL,VALUE(6,3),DATA,ABS(RF30031_3/(13.95))
SAVE,TABLE_4
FINISH
RESUME,TABLE_1
/COM,
/OUT,vm259,vrt
/COM,
/COM, ------------------------ VM259 RESULTS COMPARISON --------------------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
/COM, ==================================
/COM,   FREQUENCIES FROM MODAL ANALYSIS
/COM, ==================================
*VWRITE,LABEL(1),FREQ_EXP(1),FREQ_ANS(1),FREQ_ERR(1)
(1X,F3.0,4X,F10.4,4X,F14.4,4X,F15.3)
/COM,
/COM,
/NOPR,
RESUME,TABLE_2
/GOPR
/COM,
/COM,
/COM, ======================================
/COM,  SPECTRUM ANALYSIS WITH MISSING MASS
/COM, ======================================
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,3),VALUE(3,1),VALUE(3,2),VALUE(3,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,4),VALUE(4,1),VALUE(4,2),VALUE(4,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,5),VALUE(5,1),VALUE(5,2),VALUE(5,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,6),VALUE(6,1),VALUE(6,2),VALUE(6,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM,
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM, ===================================================================
/COM,  SPECTRUM ANALYSIS WITH MISSING MASS AND RIGID RESPONSES (LINDLEY)
/COM, ===================================================================
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
```

```
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,3),VALUE(3,1),VALUE(3,2),VALUE(3,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,4),VALUE(4,1),VALUE(4,2),VALUE(4,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,5),VALUE(5,1),VALUE(5,2),VALUE(5,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,6),VALUE(6,1),VALUE(6,2),VALUE(6,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/NOPR
RESUME,TABLE_4
/GOPR
/COM,
/COM, ==================================================================
/COM,  SPECTRUM ANALYSIS WITH MISSING MASS AND RIGID RESPONSES (GUPTA)
/COM, ===================================================================
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,3),VALUE(3,1),VALUE(3,2),VALUE(3,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,4),VALUE(4,1),VALUE(4,2),VALUE(4,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,5),VALUE(5,1),VALUE(5,2),VALUE(5,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,6),VALUE(6,1),VALUE(6,2),VALUE(6,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/NOPR
/COM,
/COM,-------------------------------------------------------------------------------------------
/OUT
*LIST,vm259,vrt
FINISH
```

VM260 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM260
/OUT,SCRATCH
/COM, VERFICATION MANUAL FOR TWO DIMENSIONAL CONSOLIDATION PROBLEM
/TITLE,VM260,TWO DIMENSIONAL CONSOLIDATION SETTLEMENT UNDER A RECTANGULAR LOAD
C*** USING CPT212
/COM, REFERENCE: " A.T-F,SCHIFFMAN,ET AL.,AN ANALYSIS OF CONSOLIDATION THEORIES
/COM,    JOURNAL OF SOLID MECHANICS AND FOUNDATION DIVISION,1969,PG:285-312
/COM,
/PREP7
W=1      ! RECTANGULAR LOAD HALF-WIDTH
E=1000      ! YOUNG'S MODULUS
A=4      ! REFINEMENT COEFFICIENT
R=100      ! LOADING
ET,1,CPT212      ! 2D 4 NODE COUPLED PORE PRESSURE ELEMENT
KEYOPT,1,3,2      ! PLANE STRAIN CONDISTIONS
RECT,0,6*W,0,-9*W     ! AREA 6*W BY 9*W
LESIZE,3,,,12*A/W     ! 12*A ELEMENTS ON HORIZONTAL EDGES
LESIZE,4,,,18*A/W     ! 18*A ELEMENTS ON VERTICAL EDGES
AMAP,1,1,2,3,4

MP,EX,1,E
MP,NUXY,1,0
BULK = 0
FPX = 0.267E-8      ! SOLID PERMEABILITY
ONE = 1.0
TB,PM,1,,,PERM
```

```
TBDATA,1,FPX,FPX,FPX    ! PERMEABILITY COEFFICIENTS
TB,PM,1,,,BIOT
TBDATA,1,ONE     ! BIOT COEFFICIENT

NSEL,S,LOC,Y,-9*W
D,ALL,UX,0
D,ALL,UY,0     ! BOTTOM SURFACE FIXED
ALLSEL,ALL
NSEL,S,LOC,X,0
D,ALL,UX,0     ! SYMMETRY BOUNDARY CONDITION
ALLSEL,ALL
NSEL,S,LOC,X,6*W
D,ALL,UX,0     ! ROLLER BOUNDARY CONDITION
ALLSEL,ALL
NSEL,S,LOC,Y,0
D,ALL,PRES,0     ! PERMEABLE TOP SURFACE
ALLSEL,ALL

CVC = E*FPX     ! COEFFICIENT OF CONSOLIDATION
TV = 0.1     ! TIME FACTOR STEP
TT = TV*W*W/CVC     ! CRITICAL TIME
FINI

/SOLU
NROPT,UNSYMM     ! NEWTON RAPHSON WITH UNSYMMETRIC MATRICES
OUTRES,ALL,ALL
TIME,TT
NSUBS,10,10,10
KBC,1      ! STEP LOAD
NSEL,S,LOC,Y,0
NSEL,R,LOC,X,0,W
SF,ALL,PRES,R
ALLSEL,ALL
SOLVE

TIME,10*TT
NSUBS,90,90,90
SOLVE
FINI

/POST1
*DIM,LABEL1,CHAR,11,3
*DIM,LABEL2,CHAR,15,3
*DIM,VALUE1,,11,3
*DIM,VALUE2,,15,3

LABEL1(1,1) = 'CPT212  ','','','','','',''
LABEL1(8,1) = '','',''
LABEL1(1,2) = 'P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y='
LABEL1(8,2) = 'P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y='
LABEL1(1,3) = '0.0','0.5','1.0','1.5','2.0','2.5','3.0'
LABEL1(8,3) = '3.5','4.0','4.5','5.0',

LABEL2(1,1) = 'CPT212  ','','','','','',''
LABEL2(8,1) = '','','','','','',''
LABEL2(15,1) = ''
LABEL2(1,2) = 'P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y='
LABEL2(8,2) = 'P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y='
LABEL2(15,2) = 'P/R at Y='
LABEL2(1,3) = '0.01','0.02','0.03','0.05','0.09','0.1','0.2'
LABEL2(8,3) = '0.3','0.4','0.5','0.6','0.7','0.8','0.9',
LABEL2(15,3) = '1.0'

/COM, PORE PRESSURE VERSUS DEPTH
VALUE1(1,1)=0
VALUE1(2,1)=0.635
VALUE1(3,1)=0.57
VALUE1(4,1)=0.44
VALUE1(5,1)=0.35
VALUE1(6,1)=0.295
VALUE1(7,1)=0.26
VALUE1(8,1)=0.236
```

```
VALUE1(9,1)=0.22
VALUE1(10,1)=0.208
VALUE1(11,1)=0.2
SET,1,10
VALUE1(1,2)=0
VALUE1(1,3)=1
*DO,I,2,11
N1=NODE(0,-(I-1)*0.5,0)
*GET,P,NODE,N1,PRES
VALUE1(I,2)=P/R
VALUE1(I,3)=ABS(VALUE1(I,1)/VALUE1(I,2))
*ENDDO

N1 = NODE(0,-0.5,0)
/COM, PORE PRESSURE VERSUS TIME
VALUE2(1,1)=0.77
VALUE2(2,1)=0.8
VALUE2(3,1)=0.79
VALUE2(4,1)=0.73
VALUE2(5,1)=0.615
VALUE2(6,1)=0.59
VALUE2(7,1)=0.42
VALUE2(8,1)=0.33
VALUE2(9,1)=0.27
VALUE2(10,1)=0.23
VALUE2(11,1)=0.20
VALUE2(12,1)=0.175
VALUE2(13,1)=0.16
VALUE2(14,1)=0.145
VALUE2(15,1)=0.135
SET,1,1
VALUE2(1,2)=PRES(N1)/R
SET,1,2
VALUE2(2,2)=PRES(N1)/R
SET,1,3
VALUE2(3,2)=PRES(N1)/R
SET,1,5
VALUE2(4,2)=PRES(N1)/R
SET,1,9
VALUE2(5,2)=PRES(N1)/R
SET,1,10
VALUE2(6,2)=PRES(N1)/R
*DO,I,1,9
SET,2,10*I
VALUE2(I+6,2)= PRES(N1)/R
*ENDDO
*DO,I,1,15
VALUE2(I,3)= VALUE2(I,1)/VALUE2(I,2)
*ENDDO
SAVE,INF1
FINISH
/CLEAR,NOSTART
/OUT,SCRATCH




/TITLE,VM260,TWO DIMENSIONAL CONSOLIDATION SETTLEMENT UNDER A RECTANGULAR LOAD
C*** USING CPT213
/PREP7
W=1       ! RECTANGULAR LOAD HALF-WIDTH
E=1000       ! YOUNG'S MODULUS
A=4       ! REFINEMENT COEFFICIENT
R=100       ! LOADING
ET,1,CPT213      ! 2D 8 NODE COUPLED PORE PRESSURE ELEMENT
KEYOPT,1,3,2      ! PLANE STRAIN CONDISTIONS
RECT,0,6*W,0,-9*W     ! AREA 6*W BY 9*W
LESIZE,3,,,6*A/W     ! 6*A ELEMENTS ON HORIZONTAL EDGES
LESIZE,4,,,9*A/W     ! 9*A ELEMENTS ON VERTICAL EDGES
AMAP,1,1,2,3,4

MP,EX,1,E
```

```
MP,NUXY,1,0
BULK = 0
FPX = 0.267E-8      ! SOLID PERMEABILITY
ONE = 1.0
TB,PM,1,,,PERM
TBDATA,1,FPX,FPX,FPX     ! PERMEABILITY COEFFICIENTS
TB,PM,1,,,BIOT
TBDATA,1,ONE      ! BIOT COEFFICIENT

NSEL,S,LOC,Y,-9*W
D,ALL,UX,0
D,ALL,UY,0      ! BOTTOM SURFACE FIXED
ALLSEL,ALL
NSEL,S,LOC,X,0
D,ALL,UX,0      ! SYMMETRY BOUNDARY CONDITION
ALLSEL,ALL
NSEL,S,LOC,X,6*W
D,ALL,UX,0      ! ROLLER BOUNDARY CONDITION
ALLSEL,ALL
NSEL,S,LOC,Y,0
D,ALL,PRES,0      ! PERMEABLE TOP SURFACE
ALLSEL,ALL

CVC = E*FPX      ! COEFFICIENT OF CONSOLIDATION
TV = 0.1      ! TIME FACTOR STEP
TT = TV*W*W/CVC      ! CRITICAL TIME
FINI

/SOLU
NROPT,UNSYMM      ! NEWTON RAPHSON WITH UNSYMMETRIC MATRICES
OUTRES,ALL,ALL
TIME,TT
NSUBS,10,10,10
KBC,1       ! STEP LOAD
NSEL,S,LOC,Y,0
NSEL,R,LOC,X,0,W
SF,ALL,PRES,R
ALLSEL,ALL
SOLVE

TIME,10*TT
NSUBS,90,90,90
SOLVE
FINI

/POST1
*DIM,LABEL1,CHAR,11,3
*DIM,LABEL2,CHAR,15,3
*DIM,VALUE1,,11,3
*DIM,VALUE2,,15,3

LABEL1(1,1) = 'CPT213  ','','','','','',''
LABEL1(8,1) = '','',''
LABEL1(1,2) = 'P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y='
LABEL1(8,2) = 'P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y='
LABEL1(1,3) = '0.0','0.5','1.0','1.5','2.0','2.5','3.0'
LABEL1(8,3) = '3.5','4.0','4.5','5.0',

LABEL2(1,1) = 'CPT213  ','','','','','',''
LABEL2(8,1) = '','','','','','',''
LABEL2(15,1) = ''
LABEL2(1,2) = 'P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y='
LABEL2(8,2) = 'P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y=','P/R at Y='
LABEL2(15,2) = 'P/R at Y='
LABEL2(1,3) = '0.01','0.02','0.03','0.05','0.09','0.1','0.2'
LABEL2(8,3) = '0.3','0.4','0.5','0.6','0.7','0.8','0.9',
LABEL2(15,3) = '1.0'

/COM, PORE PRESSURE VERSUS DEPTH
VALUE1(1,1)=0
VALUE1(2,1)=0.635
VALUE1(3,1)=0.57
```

```
VALUE1(4,1)=0.44
VALUE1(5,1)=0.35
VALUE1(6,1)=0.295
VALUE1(7,1)=0.26
VALUE1(8,1)=0.236
VALUE1(9,1)=0.22
VALUE1(10,1)=0.208
VALUE1(11,1)=0.2
SET,1,10
VALUE1(1,2)=0
VALUE1(1,3)=1
*DO,I,2,11
N1=NODE(0,-(I-1)*0.5,0)
*GET,P,NODE,N1,PRES
VALUE1(I,2)=P/R
VALUE1(I,3)=ABS(VALUE1(I,1)/VALUE1(I,2))
*ENDDO

N1 = NODE(0,-0.5,0)
/COM, PORE PRESSURE VERSUS TIME
VALUE2(1,1)=0.77
VALUE2(2,1)=0.8
VALUE2(3,1)=0.79
VALUE2(4,1)=0.73
VALUE2(5,1)=0.615
VALUE2(6,1)=0.59
VALUE2(7,1)=0.42
VALUE2(8,1)=0.33
VALUE2(9,1)=0.27
VALUE2(10,1)=0.23
VALUE2(11,1)=0.20
VALUE2(12,1)=0.175
VALUE2(13,1)=0.16
VALUE2(14,1)=0.145
VALUE2(15,1)=0.135
SET,1,1
VALUE2(1,2)=PRES(N1)/R
SET,1,2
VALUE2(2,2)=PRES(N1)/R
SET,1,3
VALUE2(3,2)=PRES(N1)/R
SET,1,5
VALUE2(4,2)=PRES(N1)/R
SET,1,9
VALUE2(5,2)=PRES(N1)/R
SET,1,10
VALUE2(6,2)=PRES(N1)/R
*DO,I,1,9
SET,2,10*I
VALUE2(I+6,2)= PRES(N1)/R
*ENDDO
*DO,I,1,15
VALUE2(I,3)= VALUE2(I,1)/VALUE2(I,2)
*ENDDO
SAVE,INF2

RESUME,INF1
/COM
/OUT,vm260,vrt
/COM,----- VM260 RESULTS COMPARISON - PORE PRESSURE VERSUS DEPTH ---------
/COM,
/COM,Y=DEPTH
/COM,P=PORE PRESSURE
/COM,R=EXTERNAL LOADING
/COM,
/COM,                              |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL1(1,1),LABEL1(1,2),LABEL1(1,3),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A8,A11,A11,'  ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/NOPR
RESUME,INF2
```

```
*VWRITE,LABEL1(1,1),LABEL1(1,2),LABEL1(1,3),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A8,A11,A11,'  ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,----------------------------------------------------------------------
RESUME,INF1
/COM,
/COM,Y=DEPTH
/COM,P=PORE PRESSURE
/COM,R=EXTERNAL LOADING
/COM,
/COM,----- VM260 RESULTS COMPARISON - PORE PRESSURE VERSUS TIME  ----------
/COM,
/COM,                               |   TARGET    |   Mechanical APDL    |   RATIO
/COM,
*VWRITE,LABEL2(1,1),LABEL2(1,2),LABEL2(1,3),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A11,A11,'  ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/NOPR
RESUME,INF2
*VWRITE,LABEL2(1,1),LABEL2(1,2),LABEL2(1,3),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A11,A11,'  ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,----------------------------------------------------------------------
/OUT
*LIST,vm260,vrt
FINISH
/DELETE,INF1
/DELETE,INF2
```

VM261 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM261
/COM, VERIFICATION MANUAL FOR ROTATING BEAM WITH INTERNAL VISCOUS DAMPING
/TITLE,VM261,ROTATING BEAM WITH INTERNAL VISCOUS DAMPING
/COM,  REFERENCE: " FINITE ELEMENT SIMULATION OF ROTOR-BEARING SYSTEMS
/COM,                WITH INTERNAL DAMPING",ASME JOURNAL OF ENGINEERING
/COM,                FOR POWER, E.S.ZORZI AND H.D.NELSON, 1976
/COM,
/COM,
/COM, ROTATING BEAM WITH UNDAMPED ISOTROPIC SUPPORTS
/COM,
/COM,
/OUT,SCRATCH
/PREP7
/COM, BEAM DIMENSIONS
LENGTH = 1.27     ! LENGTH OF THE BEAM IN METERS
DIA  = 0.1016     ! DIAMETER OF THE BEAM IN METERS
PI      = ACOS(-1)
/COM, MATERIAL PROPERTIES FOR STEEL
E  = 2.1E+11    ! YOUNG'S MODULUS FOR STEEL IN PA
DENS    = 7800     ! DENSITY IN KG/M^3
SHEARM = E*1000     ! NO SHEAR
PROPD  = 2.0E-04          ! INTERNAL VISCOUS DAMPING
KB  = 1.75E+07     ! STIFFNESS FOR BEARING IN N/M
/COM, MODEL
ET,1,BEAM188
SECTYPE,1,BEAM,CSOLID
SECDATA,DIA/2
MP,EX,1,E
MP,GXY,1,SHEARM
MP,DENS,1,DENS
MP,NUXY,1,0.3
MP,BETD,1,2.0E-04
TYPE,1
SECNUM,1
MAT,1
K,1,0,0,0
K,2,LENGTH,0,0
L,1,2
```

```
LESIZE,1,,,5
LMESH,1
ALLSEL,ALL
CM,SHAFT,ELEM    ! CREATING COMPONENT FOR BEAM ELEMENTS
ALLSEL,ALL
/COM, BEARING ELEMENTS
ET,2,COMBI214
KEYOPT,2,2,1    ! YZ PLANE
REAL,2
R,2,KB,KB     ! STIFFNESS ALONG Y AND Z DIRECTION
RMORE,,,,
N,101,0,0,0
N,102,LENGTH,0,0
TYPE,2
MAT,2
E,1,101
E,2,102
ALLSEL,ALL
/COM, CONSTRAINTS
D,101,ALL,0
D,102,ALL,0
D,ALL,UX,,,,,ROTX
ALLSEL,ALL
FINI
/COM, COMPLEX MODAL SOLVE WITH QRDAMP
/SOLU
ANTYPE,MODAL
MODOPT,QRDAMP,6,,,ON,
QRDOPT,ON                   ! REUSE OF NORMAL MODES FOR QRDAMP SOLVE
MXPAND,6
CORIOLIS,ON,,,ON,ON   ! GYROSCOPIC DAMPING AND ROTATING DAMPING
CMOMEGA,SHAFT,0,0,0   ! 1ST LOAD STEP
SOLVE
CMOMEGA,SHAFT,130,0,0   ! 2ND LOAD STEP
SOLVE
CMOMEGA,SHAFT,261,0,0   ! 3RD LOAD STEP
SOLVE
CMOMEGA,SHAFT,392,0,0   ! 4TH LOAD STEP
SOLVE
CMOMEGA,SHAFT,539.25,0,0  ! 5TH LOAD STEP
SOLVE
CMOMEGA,SHAFT,654,0,0   ! 6TH LOAD STEP
SOLVE
CMOMEGA,SHAFT,785,0,0   ! 7TH LOAD STEP
SOLVE
CMOMEGA,SHAFT,916,0,0   ! 8TH LOAD STEP
SOLVE
CMOMEGA,SHAFT,1047,0,0   ! 9TH LOAD STEP
SOLVE
CMOMEGA,SHAFT,1178,0,0   ! 10TH LOAD STEP
SOLVE
CMOMEGA,SHAFT,1309,0,0   ! 11TH LOAD STEP
SOLVE
CMOMEGA,SHAFT,1444,0,0   ! 12TH LOAD STEP
SOLVE
CMOMEGA,SHAFT,1570,0,0   ! 13TH LOAD STEP
SOLVE
FINI
/POST1
SET,5,1
*GET,RFREQ1,ACTIVE,0,SET,FREQ  ! REAL FREQUENCY AFTER FIRST CRITICAL SPEED
SET,12,4
*GET,RFREQ2,ACTIVE,0,SET,FREQ  ! REAL FREQUENCY AFTER SECOND CRITICAL SPEED
SET,5,1,,1
*GET,IFREQ1,ACTIVE,0,SET,FREQ  ! IMAGINARY FREQUENCY AFTER FIRST CRITICAL SPEED
SET,12,4,,1
*GET,IFREQ2,ACTIVE,0,SET,FREQ  ! IMAGINARY FREQUENCY AFTER SECOND CRITICAL SPEED
/OUT,
PRCAMP,ON,1,RPM,,SHAFT   ! CRITICAL SPEEDS
*GET,VCRIC1_1,CAMP,1,VCRI
*GET,VCRIC4_1,CAMP,4,VCRI
PRCAMP,ON,,RPM,,SHAFT,2   ! LOGARITHMIC DECREMENT
```

```
/OUT,SCRATCH
/COM, COMPUTING INSTABILITY FROM Mechanical APDL
UFREQ1_1 = 2*PI*(RFREQ1/IFREQ1) ! COMPUTING LOGARITHMIC DECREMENT AFTER FIRST CRITICAL SPEED
UFREQ4_1 = 2*PI*(RFREQ2/IFREQ2) ! COMPUTING LOGARITHMIC DECREMENT AFTER SECOND CRITICAL SPEED
*DIM,LABEL,CHAR,1,4
*DIM,VALUE,,4,3
LABEL(1,1) = 'VCRIC1'
LABEL(1,2) = 'VCRIC2'
LABEL(1,3) = 'UFREQ1'
LABEL(1,4) = 'UFREQ2'
/COM, CRITICAL SPEEDS OBTAINED FROM Mechanical APDL AND REFERENCE
/COM, UNSTABLE MODES ARE OBTAINED FROM 1ST FORWARD AND 2ND FORWARD MODES
/COM,
/OUT,SCRATCH
*VFILL,VALUE(1,1),DATA,4950  ! 1ST FORWARD CRITICAL SPEED - REFERENCE
*VFILL,VALUE(1,2),DATA,VCRIC1_1     ! 1ST FORWARD CRITICAL SPEED - Mechanical APDL
*VFILL,VALUE(1,3),DATA,ABS(VCRIC1_1/4950)
*VFILL,VALUE(2,1),DATA,10500  ! 2ND FORWARD CRITICAL SPEED - REFERENCE
*VFILL,VALUE(2,2),DATA,VCRIC4_1     ! 2ND FORWARD CRITICAL SPEED - Mechanical APDL
*VFILL,VALUE(2,3),DATA,ABS(VCRIC4_1/10500)
*VFILL,VALUE(3,1),DATA,0.001  ! UNSTABLE FREQUENCY NEAR 5000 RPM - REFERENCE (FIG 3)
*VFILL,VALUE(3,2),DATA,UFREQ1_1 ! FROM Mechanical APDL
*VFILL,VALUE(3,3),DATA,ABS(UFREQ1_1/0.0010)
*VFILL,VALUE(4,1),DATA,0.0103  ! UNSTABLE FREQUENCY NEAR 13,500 RPM - REFERENCE (FIG 3)
*VFILL,VALUE(4,2),DATA,UFREQ4_1 ! FROM Mechanical APDL
*VFILL,VALUE(4,3),DATA,ABS(UFREQ4_1/0.0103)
SAVE,TABLE_1
FINISH
RESUME,TABLE_1
/COM,
/OUT,vm261,vrt
/COM,
/COM, ----------------------VM261 RESULTS COMPARISON------------------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM, CRITICAL SPEEDS
/COM, ---------------
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM, LOGARITHMIC DECREMENT FOR UNSTABLE FREQUENCIES
/COM, ----------------------------------------------
/COM,
*VWRITE,LABEL(1,3),VALUE(3,1),VALUE(3,2),VALUE(3,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,4),VALUE(4,1),VALUE(4,2),VALUE(4,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM, ----------------------------------------------------------------------------
/OUT,
*LIST,vm261,vrt
FINISH
```

VM262 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM262
/COM,VERFICATION MANUAL FOR TWO DIMENSIONAL THERMAL FRACTURAL PROBLEM
/TITLE,VM262,TWO DIMENSIONAL FRACTURAL PROBLEM UNDER THERMAL LOAD
/COM, REFERENCE: "W.K.WILSON, ET AL., THE USE OF THE J-INTEGRAL IN THERMAL STRESS CRACK PROBLEMS
/COM,             INTERNATIONAL JOURNAL OF FRACTURE, 1979,PG:377-387
/COM,
/OUT,SCRATCH
/PREP7
A=1                    ! CRACK LENGTH
```

```
W=2*A                   ! WIDTH
L=4*W                   ! LENGTH
L2=L/2                  ! HALF OF LENGTH
E=1E5                   ! YOUNG'S MODULUS
NU=0.3                  ! POISSONS RATIO
T0=10                   ! TEMPERATURES AT THE RIGHT SIDE
ALPHA=1e-4              ! SECANT COEFFICIENTS OF THERMAL EXPANSION

MP,EX,1,E
MP,NUXY,1,NU
MP,ALPX,1,ALPHA         ! THERMAL MATERIAL PROPERTIES
MP,REFT,1,0             ! REFERENCE TEMPERATURE FOR ELEMENTs

K,1,
K,2,W/2
K,3,W/2,A
K,4,W/2,L2
K,5,-W/2,L2
K,6,-W/2,A
K,7,-W/2
A,1,2,3,6,7
A,3,4,5,6

ET,1,PLANE182
KEYOPT,1,3,2             ! PLANE STRAIN

ESIZE,A/6
KSCON,1,A/12,1,8
AMESH,1
ESIZE,W/6
AMESH,2

NSEL,S,LOC,X,0,W/2       ! SYMMETRICAL CONDITIONS
NSEL,R,LOC,Y,0
D,ALL,UY,0
NSEL,ALL

NSEL,S,LOC,Y,L2          ! TOP EDGE FIXED
D,ALL,UY,0
D,ALL,UX,0
NSEL,ALL
FINISH

/SOLU
ANTYPE,STATIC
OUTRES,CINT,ALL
CNVTOL,F,1,0.001
CNVTOL,U,1,0.001
TIME,1.0

NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0
CM,CRACK1,NODE
ALLSEL

*GET,NNODE,NODE,0,COUNT
*DO,I,1,NNODE
  TN=2*T0/W*NX(I)
  BF,I,TEMP,TN           ! APPLY TEMPERATURE LOADING
*ENDDO
ALLSEL

CINT,NEW,1
CINT,NAME,CRACK1         !CRACK ID
CINT,NCON,6              !NUMBER OF COUNTOURS
CINT,SYMM,ON             !SYMMETRICAL CONDITION
CINT,NORM,,
CINT,LIST
ALLSEL
/OUT,
SOLVE
FINISH
```

```
/OUT,SCRATCH
/POST1
PRCINT,1
*GET,J1,CINT,1,CTIP,1,,1
*GET,J2,CINT,1,CTIP,1,,2
*GET,J3,CINT,1,CTIP,1,,3
*GET,J4,CINT,1,CTIP,1,,4
*GET,J5,CINT,1,CTIP,1,,5
*GET,J6,CINT,1,CTIP,1,,6
JC1=ABS(J2+J3+J4+J5+J6)/5
K1=SQRT(JC1*E/(1-NU*NU))
/COM, Mechanical APDL RESULTS
*STAT,K1
/COM, EXPECTED RESULTS FROM REFERENCE PAPER
S0=E*ALPHA*T0/(1-NU)
K1_EXPECT=0.5*S0*SQRT(3.1416*A)
*STAT,K1_EXPECT
*DIM,LABEL,CHAR,1,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'K1'
*VFILL,VALUE(1,1),DATA,K1_EXPECT
*VFILL,VALUE(1,2),DATA,K1
*VFILL,VALUE(1,3),DATA,ABS(K1/K1_EXPECT)
SAVE,TABLE_1
FINISH
RESUME,TABLE_1
/COM,
/OUT,vm262,vrt
/COM,
/COM,
/COM, ----------------------VM262 RESULTS COMPARISON-----------------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL   |  RATIO
/COM,
/COM,   STRESS-INTENSITY
/COM,  --------------------
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM, -----------------------------------------------------------------------
/OUT,
*LIST,vm262,vrt
FINISH
```

VM263 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM263
/TITLE,VM263,CRITICAL SPEEDS FOR ROTOR-BEARING SYSTEM WITH AXISYMMETRIC ELEMENTS
C*** USING SOLID272
/COM,  REF: "THE DYNAMICS OF ROTOR-BEARING SYSTEMS USING FINITE ELEMENTS"
/COM,        JOURNAL OF ENG. FOR INDUSTRY - MAY 1976
/COM,
/OUT,SCRATCH

/PREP7
*DIM,SPIN,,7
SPIN(1) = 0
SPIN(2) = 10000
SPIN(3) = 20000
SPIN(4) = 40000
SPIN(5) = 60000
SPIN(6) = 80000
SPIN(7) = 100000
MP,EX,1,2.078e+11
MP,DENS,1,7806
```

```
MP,NUXY,1,0.33
ET,1,SOLID272,,3          ! 3 CIRCUMFERENTIAL NODES
TYPE,1
NBDIAM = 18           ! SHAFT SECTION PROPERTIES
*DIM,DIAM,ARRAY,NBDIAM
DIAM(1) = 1.02E-2
DIAM(2) = 2.04E-2
DIAM(3) = 1.52E-2
DIAM(4) = 4.06E-2
DIAM(5) = DIAM(4)
DIAM(6) = 6.6E-2
DIAM(7) = DIAM(6)
DIAM(8) = 5.08E-2
DIAM(9) = DIAM(8)
DIAM(10) = 2.54E-2
DIAM(11) = DIAM(10)
DIAM(12) = 3.04E-2
DIAM(13) = DIAM(12)
DIAM(14) = 2.54E-2
DIAM(15) = DIAM(14)
DIAM(16) = 7.62E-2
DIAM(17) = 4.06E-2
DIAM(18) = DIAM(17)

/COM, MODELING SHAFT ELEMENTS
K,1,,,,
K,2,,DIAM(1)/2,,
K,3,1.27E-2,DIAM(1)/2,,
K,4,1.27E-2,0,0
A,1,2,3,4

K,5,1.27E-2,DIAM(2)/2,0
K,6,5.08E-2,DIAM(2)/2,0
K,7,5.08E-2,DIAM(3)/2,0
K,8,5.08E-2,0,0
A,4,3,5,6,7,8

K,9,7.62E-2,DIAM(3)/2,0
K,10,7.62E-2,0,0
A,8,7,9,10

K,11,7.62E-2,DIAM(4)/2
K,12,8.89E-2,DIAM(4)/2
K,13,8.89E-2,0,0
A,10,9,11,12,13

K,14,10.16E-2,DIAM(5)/2
K,15,10.16E-2,0,0
A,13,12,14,15

K,16,10.16E-2,DIAM(6)/2
K,17,10.67E-2,DIAM(6)/2
K,18,10.67E-2,3.04E-2/2
K,19,10.67E-2,0,0
A,15,14,16,17,18,19

K,20,11.43E-2,DIAM(7)/2
K,21,11.43E-2,DIAM(8)/2
K,22,11.43E-2,3.56E-2/2
K,23,11.43E-2,3.04E-2/2
A,18,17,20,21,22,23

K,24,12.7E-2,DIAM(8)/2,0
K,25,12.7E-2,3.56E-2/2,0
A,22,21,24,25

K,26,12.7E-2,0,0
K,27,13.46E-2,DIAM(9)/2
K,28,13.46E-2,DIAM(10)/2
K,29,13.46E-2,0,0
A,26,25,24,27,28,29
```

```
K,30,16.51E-2,DIAM(10)/2
K,31,16.51E-2,0,0
A,29,28,30,31

K,32,19.05E-02,DIAM(11)/2
K,33,19.05E-02,0,0
A,31,30,32,33

K,34,19.05E-2,DIAM(12)/2
K,35,22.86E-02,DIAM(12)/2
K,36,22.86E-02,0,0
A,33,32,34,35,36

K,37,26.67E-2,DIAM(13)/2
K,38,26.67E-2,DIAM(14)/2
K,39,26.67E-2,0,0
A,36,35,37,38,39

K,40,28.7E-2,DIAM(14)/2,0
K,41,28.7E-2,0,0
A,39,38,40,41

K,42,30.48E-2,DIAM(15)/2,0
K,43,30.48E-2,0,0
A,41,40,42,43

K,44,30.48E-2,DIAM(16)/2
K,45,31.5E-2,DIAM(16)/2
K,46,31.5E-2,DIAM(17)/2
K,47,31.5E-2,0,0
A,43,42,44,45,46,47

K,48,34.54E-2,DIAM(17)/2,,
K,49,34.54E-2,3.04E-2/2,,
K,50,34.54E-2,0,0
A,47,46,48,49,50

K,51,35.5E-2,DIAM(18)/2
K,52,35.5E-2,3.04E-2/2
A,49,48,51,52
ESIZE,0.5E-2
SECT,1,AXIS
SECDATA,1,0,0,0,1,0,0
AMESH,ALL

/COM, MODELING DISC ELEMENT
ET,2,SOLID272,,3
TYPE,2
MP,EX,2,2.078E11
MP,DENS,2,7806
MP,NUXY,2,0.33
TH = 0.028            ! THICKNESS OF THE DISC
RADD = 0.0495           ! OUTER RADIUS OF THE DISC
RADS = 0.0203           ! INNER RADIUS OF THE DISC
K,100,8.89E-2-(TH/2),RADS,0
K,101,8.89E-2-(TH/2),RADD,0
K,102,8.89E-2+(TH/2),RADD,0
K,103,8.89E-2+(TH/2),RADS,0
A,100,101,102,103
TYPE,2
MAT,2
AMESH,19
SECT,2,AXIS
SECDATA,1,0,0,0,1,0,0
ALLSEL,ALL

/COM, GENERATING AXISYMMETRIC SOLID ELEMENTS FOR DISC AND SHAFT
NAXIS
ALLSEL,ALL
NUMMRG,NODE
NUMMRG,KP
ALLSEL,ALL
```

```
/COM, MODELING SYMMETRIC BEARINGS
ET,3,COMBIN14
KEYOPT,3,2,2          ! BEARING IN Y DIRECTION
ET,5,COMBIN14
KEYOPT,5,2,3          ! BEARING IN Z DIRECTION
R,3,4.378E+7
R,5,4.378E+7
DIST = 0.000          ! FOR VISUALIZATION
N,10000,16.51E-2,DIST,0
N,20000,16.51E-2,0,DIST
N,10001,28.70E-2,DIST,0
N,20001,28.70E-2,0,DIST
TYPE,3
REAL,3
E,NODE(16.51E-02,0,0),10000
E,NODE(28.70E-02,0,0),10001
TYPE,5
REAL,5
E,NODE(16.51E-02,0,0),20000
E,NODE(28.70E-02,0,0),20001

/COM, CONSTRAINING ALL BEARING NODES
D,10000,ALL,0
D,10001,ALL,0
D,20000,ALL,0
D,20001,ALL,0
ALLSEL,ALL

/COM, SUPPRESSING AXIAL MOTION IN THE SHAFT
NSEL,S,LOC,Y,0
NSEL,R,LOC,Z,0
D,ALL,UX,0
NSEL,ALL
FINI

/COM, PERFORMING CAMPBELL ANALYSIS USING QRDAMP EIGEN SOLVER
/SOLU
ANTYPE,MODAL
MODOPT,DAMP,25,1.0,,                ! COMPUTE COMPLEX EIGEN MODES USING DAMP SOLVER
MXPAND,25,,,YES           ! EXPAND ALL THE MODES WITH STRESS CALCULATION ON
CORIOLIS,ON,,,ON           ! CORIOLIS ON IN A STATIONARY REFERENCE FRAME
RATIO = 4*ATAN(1)/30         ! CONVERT RPM INTO RADIANS/SECOND
*DO,I,1,7
OMEGA,SPIN(I)*RATIO          ! SOLVE FOR DIFFERENT ROTATIONAL VELOCITY
SOLVE
*ENDDO
FINI
/POST1
/OUT,
PRCAMP,ON,2.0,RPM           ! PRINT CAMPBELL VALUES FOR SLOPE = 2.0 IN RPM
PLCAMP,,2.,RPM
*GET,CRIC1,CAMP,1,VCRI,,,
*GET,CRIC2,CAMP,2,VCRI,,,
*GET,CRIC3,CAMP,3,VCRI,,,
*GET,CRIC4,CAMP,4,VCRI,,,
*GET,CRIC5,CAMP,5,VCRI,,,
*GET,CRIC6,CAMP,6,VCRI,,,

PRCAMP,ON,4.,RPM               ! PRINT CAMPBELL VALUES FOR SLOPE = 4.0 IN RPM
PLCAMP,,4.,RPM
*GET,CRIC7,CAMP,1,VCRI,,,
*GET,CRIC8,CAMP,2,VCRI,,,
*GET,CRIC9,CAMP,3,VCRI,,,
*GET,CRIC10,CAMP,4,VCRI,,,
*GET,CRIC11,CAMP,5,VCRI,,,
*GET,CRIC12,CAMP,6,VCRI,,,


/OUT,SCRATCH
*DIM,LABEL,CHAR,1,12
*DIM,VALUE,,12,3
```

```
LABEL(1,1) = 'CRIC1'
LABEL(1,2) = 'CRIC2'
LABEL(1,3) = 'CRIC3'
LABEL(1,4) = 'CRIC4'
LABEL(1,5) = 'CRIC5'
LABEL(1,6) = 'CRIC6'
LABEL(1,7) = 'CRIC7'
LABEL(1,8) = 'CRIC8'
LABEL(1,9) = 'CRIC9'
LABEL(1,10) = 'CRIC10'
LABEL(1,11) = 'CRIC11'
LABEL(1,12) = 'CRIC12'
/COM,
/COM, WHIRL SPEEDS OBTAINED FOR SLOPE = 2.0 (REFERENCE RESULTS FOR WHIRL RATIO 1/2)
/COM,
*VFILL,VALUE(1,1),DATA,7929                   ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/2
*VFILL,VALUE(1,2),DATA,CRIC1
*VFILL,VALUE(1,3),DATA,ABS(CRIC1/7929)
*VFILL,VALUE(2,1),DATA,8350                   ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/2
*VFILL,VALUE(2,2),DATA,CRIC2
*VFILL,VALUE(2,3),DATA,ABS(CRIC2/8350)
*VFILL,VALUE(3,1),DATA,23760                   ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/2
*VFILL,VALUE(3,2),DATA,CRIC3
*VFILL,VALUE(3,3),DATA,ABS(CRIC3/23760)
*VFILL,VALUE(4,1),DATA,24602                   ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/2
*VFILL,VALUE(4,2),DATA,CRIC4
*VFILL,VALUE(4,3),DATA,ABS(CRIC4/24602)
*VFILL,VALUE(5,1),DATA,34820                   ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/2
*VFILL,VALUE(5,2),DATA,CRIC5
*VFILL,VALUE(5,3),DATA,ABS(CRIC5/34820)
*VFILL,VALUE(6,1),DATA,42776                   ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/2
*VFILL,VALUE(6,2),DATA,CRIC6
*VFILL,VALUE(6,3),DATA,ABS(CRIC6/42776)
/COM,
/COM, WHIRL SPEEDS OBTAINED FOR SLOPE = 4.0 (REFERENCE RESULTS FOR WHIRL RATIO 1/4)
/COM,
*VFILL,VALUE(7,1),DATA,4015                    ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(7,2),DATA,CRIC7
*VFILL,VALUE(7,3),DATA,ABS(CRIC7/4015)
*VFILL,VALUE(8,1),DATA,4120.25                 ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(8,2),DATA,CRIC8
*VFILL,VALUE(8,3),DATA,ABS(CRIC8/4120)
*VFILL,VALUE(9,1),DATA,11989.25                ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(9,2),DATA,CRIC9
*VFILL,VALUE(9,3),DATA,ABS(CRIC9/11989)
*VFILL,VALUE(10,1),DATA,12200                  ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(10,2),DATA,CRIC10
*VFILL,VALUE(10,3),DATA,ABS(CRIC10/12200)
*VFILL,VALUE(11,1),DATA,18184.25               ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(11,2),DATA,CRIC11
*VFILL,VALUE(11,3),DATA,ABS(CRIC11/18184)
*VFILL,VALUE(12,1),DATA,20162.25               ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(12,2),DATA,CRIC12
*VFILL,VALUE(12,3),DATA,ABS(CRIC12/20162)
SAVE,INF1
FINISH
/CLEAR,NOSTART
```

```
/TITLE,VM263,CRITICAL SPEEDS FOR ROTOR-BEARING SYSTEM WITH AXISYMMETRIC ELEMENTS
C*** USING SOLID273
/PREP7
*DIM,SPIN,,7
SPIN(1) = 0
SPIN(2) = 10000
SPIN(3) = 20000
SPIN(4) = 40000
SPIN(5) = 60000
SPIN(6) = 80000
SPIN(7) = 100000
```

```
MP,EX,1,2.078e+11
MP,DENS,1,7806
MP,NUXY,1,0.33
ET,1,SOLID273,,3          ! 3 CIRCUMFERENTIAL NODES
TYPE,1
NBDIAM = 18           ! SHAFT SECTION PROPERTIES
*DIM,DIAM,ARRAY,NBDIAM
DIAM(1) = 1.02E-2
DIAM(2) = 2.04E-2
DIAM(3) = 1.52E-2
DIAM(4) = 4.06E-2
DIAM(5) = DIAM(4)
DIAM(6) = 6.6E-2
DIAM(7) = DIAM(6)
DIAM(8) = 5.08E-2
DIAM(9) = DIAM(8)
DIAM(10) = 2.54E-2
DIAM(11) = DIAM(10)
DIAM(12) = 3.04E-2
DIAM(13) = DIAM(12)
DIAM(14) = 2.54E-2
DIAM(15) = DIAM(14)
DIAM(16) = 7.62E-2
DIAM(17) = 4.06E-2
DIAM(18) = DIAM(17)

/COM, MODELING SHAFT ELEMENTS
K,1,,,,
K,2,,DIAM(1)/2,,
K,3,1.27E-2,DIAM(1)/2,,
K,4,1.27E-2,0,0
A,1,2,3,4

K,5,1.27E-2,DIAM(2)/2,0
K,6,5.08E-2,DIAM(2)/2,0
K,7,5.08E-2,DIAM(3)/2,0
K,8,5.08E-2,0,0
A,4,3,5,6,7,8

K,9,7.62E-2,DIAM(3)/2,0
K,10,7.62E-2,0,0
A,8,7,9,10

K,11,7.62E-2,DIAM(4)/2
K,12,8.89E-2,DIAM(4)/2
K,13,8.89E-2,0,0
A,10,9,11,12,13

K,14,10.16E-2,DIAM(5)/2
K,15,10.16E-2,0,0
A,13,12,14,15

K,16,10.16E-2,DIAM(6)/2
K,17,10.67E-2,DIAM(6)/2
K,18,10.67E-2,3.04E-2/2
K,19,10.67E-2,0,0
A,15,14,16,17,18,19

K,20,11.43E-2,DIAM(7)/2
K,21,11.43E-2,DIAM(8)/2
K,22,11.43E-2,3.56E-2/2
K,23,11.43E-2,3.04E-2/2
A,18,17,20,21,22,23

K,24,12.7E-2,DIAM(8)/2,0
K,25,12.7E-2,3.56E-2/2,0
A,22,21,24,25

K,26,12.7E-2,0,0
K,27,13.46E-2,DIAM(9)/2
K,28,13.46E-2,DIAM(10)/2
K,29,13.46E-2,0,0
```

```
A,26,25,24,27,28,29

K,30,16.51E-2,DIAM(10)/2
K,31,16.51E-2,0,0
A,29,28,30,31

K,32,19.05E-02,DIAM(11)/2
K,33,19.05E-02,0,0
A,31,30,32,33

K,34,19.05E-2,DIAM(12)/2
K,35,22.86E-02,DIAM(12)/2
K,36,22.86E-02,0,0
A,33,32,34,35,36

K,37,26.67E-2,DIAM(13)/2
K,38,26.67E-2,DIAM(14)/2
K,39,26.67E-2,0,0
A,36,35,37,38,39

K,40,28.7E-2,DIAM(14)/2,0
K,41,28.7E-2,0,0
A,39,38,40,41

K,42,30.48E-2,DIAM(15)/2,0
K,43,30.48E-2,0,0
A,41,40,42,43

K,44,30.48E-2,DIAM(16)/2
K,45,31.5E-2,DIAM(16)/2
K,46,31.5E-2,DIAM(17)/2
K,47,31.5E-2,0,0
A,43,42,44,45,46,47

K,48,34.54E-2,DIAM(17)/2,,
K,49,34.54E-2,3.04E-2/2,,
K,50,34.54E-2,0,0
A,47,46,48,49,50

K,51,35.5E-2,DIAM(18)/2
K,52,35.5E-2,3.04E-2/2
A,49,48,51,52
ESIZE,0.015
SECT,1,AXIS
SECDATA,1,0,0,0,1,0,0
AMESH,ALL

/COM, MODELING DISC ELEMENT
ET,2,SOLID273,,3
TYPE,2
MP,EX,2,2.078E11
MP,DENS,2,7806
MP,NUXY,2,0.33
TH = 0.028           ! THICKNESS OF THE DISC
RADD = 0.0495          ! OUTER RADIUS OF THE DISC
RADS = 0.0203          ! INNER RADIUS OF THE DISC
K,100,8.89E-2-(TH/2),RADS,0
K,101,8.89E-2-(TH/2),RADD,0
K,102,8.89E-2+(TH/2),RADD,0
K,103,8.89E-2+(TH/2),RADS,0
A,100,101,102,103
TYPE,2
MAT,2
ESIZE,1
AMESH,19
SECT,2,AXIS
SECDATA,1,0,0,0,1,0,0
ALLSEL,ALL

/COM, GENERATING AXISYMMETRIC SOLID ELEMENTS FOR DISC AND SHAFT
NAXIS
ALLSEL,ALL
```

```
NUMMRG,NODE
NUMMRG,KP
ALLSEL,ALL

/COM, MODELING SYMMETRIC BEARINGS
ET,3,COMBIN14
KEYOPT,3,2,2          ! BEARING IN Y DIRECTION
ET,5,COMBIN14
KEYOPT,5,2,3          ! BEARING IN Z DIRECTION
R,3,4.378E+7
R,5,4.378E+7
DIST = 0.000          ! FOR VISUALIZATION
N,10000,16.51E-2,DIST,0
N,20000,16.51E-2,0,DIST
N,10001,28.70E-2,DIST,0
N,20001,28.70E-2,0,DIST
TYPE,3
REAL,3
E,NODE(16.51E-02,0,0),10000
E,NODE(28.70E-02,0,0),10001
TYPE,5
REAL,5
E,NODE(16.51E-02,0,0),20000
E,NODE(28.70E-02,0,0),20001

/COM, CONSTRAINING ALL BEARING NODES
D,10000,ALL,0
D,10001,ALL,0
D,20000,ALL,0
D,20001,ALL,0
ALLSEL,ALL

/COM, SUPPRESSING AXIAL MOTION IN THE SHAFT
NSEL,S,LOC,Y,0
NSEL,R,LOC,Z,0
D,ALL,UX,0
NSEL,ALL
FINI

/COM, PERFORMING CAMPBELL ANALYSIS USING QRDAMP EIGEN SOLVER
/SOLU
ANTYPE,MODAL
MODOPT,DAMP,25,1.0,,               ! COMPUTE COMPLEX EIGEN MODES USING DAMP SOLVER
MXPAND,25,,,YES          ! EXPAND ALL THE MODES WITH STRESS CALCULATION ON
CORIOLIS,ON,,,ON          ! CORIOLIS ON IN A STATIONARY REFERENCE FRAME
RATIO = 4*ATAN(1)/30         ! CONVERT RPM INTO RADIANS/SECOND
*DO,I,1,7
OMEGA,SPIN(I)*RATIO         ! SOLVE FOR DIFFERENT ROTATIONAL VELOCITY
SOLVE
*ENDDO
FINI
/POST1
/OUT,
PRCAMP,ON,2.0,RPM          ! PRINT CAMPBELL VALUES FOR SLOPE = 2.0 IN RPM
PLCAMP,,2.,RPM
*GET,CRIC1,CAMP,1,VCRI,,,
*GET,CRIC2,CAMP,2,VCRI,,,
*GET,CRIC3,CAMP,3,VCRI,,,
*GET,CRIC4,CAMP,4,VCRI,,,
*GET,CRIC5,CAMP,5,VCRI,,,
*GET,CRIC6,CAMP,6,VCRI,,,

PRCAMP,ON,4.,RPM              ! PRINT CAMPBELL VALUES FOR SLOPE = 4.0 IN RPM
PLCAMP,,4.,RPM
*GET,CRIC7,CAMP,1,VCRI,,,
*GET,CRIC8,CAMP,2,VCRI,,,
*GET,CRIC9,CAMP,3,VCRI,,,
*GET,CRIC10,CAMP,4,VCRI,,,
*GET,CRIC11,CAMP,5,VCRI,,,
*GET,CRIC12,CAMP,6,VCRI,,,
```

```
/OUT,SCRATCH
*DIM,LABEL,CHAR,1,12
*DIM,VALUE,,12,3
LABEL(1,1) = 'CRIC1'
LABEL(1,2) = 'CRIC2'
LABEL(1,3) = 'CRIC3'
LABEL(1,4) = 'CRIC4'
LABEL(1,5) = 'CRIC5'
LABEL(1,6) = 'CRIC6'
LABEL(1,7) = 'CRIC7'
LABEL(1,8) = 'CRIC8'
LABEL(1,9) = 'CRIC9'
LABEL(1,10) = 'CRIC10'
LABEL(1,11) = 'CRIC11'
LABEL(1,12) = 'CRIC12'
/COM,
/COM, WHIRL SPEEDS OBTAINED FOR SLOPE = 2.0 (REFERENCE RESULTS FOR WHIRL RATIO 1/2)
/COM,
*VFILL,VALUE(1,1),DATA,7929                   ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/2
*VFILL,VALUE(1,2),DATA,CRIC1
*VFILL,VALUE(1,3),DATA,ABS(CRIC1/7929)
*VFILL,VALUE(2,1),DATA,8350                   ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/2
*VFILL,VALUE(2,2),DATA,CRIC2
*VFILL,VALUE(2,3),DATA,ABS(CRIC2/8350)
*VFILL,VALUE(3,1),DATA,23760                   ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/2
*VFILL,VALUE(3,2),DATA,CRIC3
*VFILL,VALUE(3,3),DATA,ABS(CRIC3/23760)
*VFILL,VALUE(4,1),DATA,24602                   ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/2
*VFILL,VALUE(4,2),DATA,CRIC4
*VFILL,VALUE(4,3),DATA,ABS(CRIC4/24602)
*VFILL,VALUE(5,1),DATA,34820                   ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/2
*VFILL,VALUE(5,2),DATA,CRIC5
*VFILL,VALUE(5,3),DATA,ABS(CRIC5/34820)
*VFILL,VALUE(6,1),DATA,42776                   ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/2
*VFILL,VALUE(6,2),DATA,CRIC6
*VFILL,VALUE(6,3),DATA,ABS(CRIC6/42776)
/COM,
/COM, WHIRL SPEEDS OBTAINED FOR SLOPE = 4.0 (REFERENCE RESULTS FOR WHIRL RATIO 1/4)
/COM,
*VFILL,VALUE(7,1),DATA,4015                    ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(7,2),DATA,CRIC7
*VFILL,VALUE(7,3),DATA,ABS(CRIC7/4015)
*VFILL,VALUE(8,1),DATA,4120.25                 ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(8,2),DATA,CRIC8
*VFILL,VALUE(8,3),DATA,ABS(CRIC8/4120)
*VFILL,VALUE(9,1),DATA,11989.25                ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(9,2),DATA,CRIC9
*VFILL,VALUE(9,3),DATA,ABS(CRIC9/11989)
*VFILL,VALUE(10,1),DATA,12200                  ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(10,2),DATA,CRIC10
*VFILL,VALUE(10,3),DATA,ABS(CRIC10/12200)
*VFILL,VALUE(11,1),DATA,18184.25               ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(11,2),DATA,CRIC11
*VFILL,VALUE(11,3),DATA,ABS(CRIC11/18184)
*VFILL,VALUE(12,1),DATA,20162.25               ! CRITICAL SPEED VALUE OBTAINED FROM REFERENCE/4
*VFILL,VALUE(12,2),DATA,CRIC12
*VFILL,VALUE(12,3),DATA,ABS(CRIC12/20162)
SAVE,INF2
FINISH
/CLEAR,NOSTART

RESUME,INF1
/COM
/OUT,vm263,vrt
/COM,------------ vm263 RESULTS COMPARISON --------------
/COM,
/COM,        |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM, -------------------------------------
/COM, WHIRL SPEEDS WITH SLOPE = 2.0
/COM, -------------------------------------
/COM, ---------------SOLID272---------------
```

```
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,3),VALUE(3,1),VALUE(3,2),VALUE(3,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,4),VALUE(4,1),VALUE(4,2),VALUE(4,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,5),VALUE(5,1),VALUE(5,2),VALUE(5,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,6),VALUE(6,1),VALUE(6,2),VALUE(6,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM, ---------------SOLID273---------------
/NOPR
RESUME,INF2
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,3),VALUE(3,1),VALUE(3,2),VALUE(3,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,4),VALUE(4,1),VALUE(4,2),VALUE(4,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,5),VALUE(5,1),VALUE(5,2),VALUE(5,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,6),VALUE(6,1),VALUE(6,2),VALUE(6,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
RESUME,INF1
/COM, -------------------------------------
/COM, WHIRL SPEEDS WITH SLOPE = 4.0
/COM, -------------------------------------
/COM, ---------------SOLID272---------------
*VWRITE,LABEL(1,7),VALUE(7,1),VALUE(7,2),VALUE(7,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,8),VALUE(8,1),VALUE(8,2),VALUE(8,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,9),VALUE(9,1),VALUE(9,2),VALUE(9,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,10),VALUE(10,1),VALUE(10,2),VALUE(10,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,11),VALUE(11,1),VALUE(11,2),VALUE(11,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,12),VALUE(12,1),VALUE(12,2),VALUE(12,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM
/COM, ---------------SOLID273---------------
/NOPR
RESUME,INF2
*VWRITE,LABEL(1,7),VALUE(7,1),VALUE(7,2),VALUE(7,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,8),VALUE(8,1),VALUE(8,2),VALUE(8,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,9),VALUE(9,1),VALUE(9,2),VALUE(9,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,10),VALUE(10,1),VALUE(10,2),VALUE(10,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,11),VALUE(11,1),VALUE(11,2),VALUE(11,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,12),VALUE(12,1),VALUE(12,2),VALUE(12,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM
/OUT
FINISH
*LIST,vm263,vrt
/DELETE,INF1
/DELETE,INF2
```

VM264 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM264
/COM,VERFICATION MANUAL FOR ONE-DIMENSIONAL CONSOLIDATION SETTLEMENT
/TITLE,VM264, ONE DIMENSIONAL CONSOLIDATION SETTLEMENT
C*** USING CPT213
/COM, REFERENCE: "K.TERZAGHI, THEORETICAL SOIL MECHANICS, WILEY, NEW YORK, 1942"
/COM,
/PREP7
ET,1,CPT213                 ! 2-D 8-NODE COUPLED PORE-PRESSURE ELEMENT
KEYOPT,1,3,2                ! PLANE STRAIN
H=-10                       ! DEPTH OF CONSOLIDATION (M)
W=1                         ! WIDTH OF ELEMENT (M)
RECTNG,0,W,0,H              ! GEOMETRY
ESIZE,W
AMESH,1
MP,EX,1,5.8E5               ! YOUNG'S MODULUS
MP,NUXY,1,0.0               ! POISSON'S RATIO
FPX=8.62E-3    ! PERMEABILITY
ONE=1.0
TB,PM,1,,,PERM
TBDATA,1,FPX,FPX,FPX
TB,PM,1,,,BIOT    ! BIOT COEFFICIENT
TBDATA,1,ONE
ALLSEL
D,ALL,UX                    !HORIZONTAL DOFS ARE CONSTRAINED
ALLSEL

NSEL,S,LOC,Y,H
D,ALL,UY,0                  !BOTTOM SURFACE IS CONSTRAINED IN Y DIRECTION
ALLSEL

NSEL,S,LOC,Y,0
D,ALL,PRES,0                ! PRESSURE DOF BLOCKED ON TOP SURFACE
ALLSEL

FINISH

/SOLU
ANTYPE,STATIC
NROPT,UNSYM
TIME,0.002

R=10                        ! LOADING
NSEL,S,LOC,Y,0
SF,ALL,PRES,R               ! APPLY EXTERNAL LOAD ON TOP SURFACE
ALLSEL

NSUBST,100,1000,10
KBC,1
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINISH

/POST1
SET,LAST
PRNS,PRESS
PLNS,PRESS
/OUT,
*DIM,LABEL,CHAR,10,2
*DIM,VALUE,,10,3

LABEL(1,1) = 'CPT213  ','','','','','',''
LABEL(8,1) = '','',''
LABEL(1,2) = '0.1','0.2','0.3','0.4','0.5','0.6','0.7'
LABEL(8,2) = '0.8','0.9','1.0'
```

```
VALUE(1,1)=0.18
VALUE(2,1)=0.35
VALUE(3,1)=0.50
VALUE(4,1)=0.63
VALUE(5,1)=0.74
VALUE(6,1)=0.82
VALUE(7,1)=0.89
VALUE(8,1)=0.93
VALUE(9,1)=0.94
VALUE(10,1)=0.95
/COM,
/COM, TARGET VALUE IS OBTAINED FROM FORMULA MENTIONED IN REFERENCE PAPER
/COM,
*DO,I,1,10
N1=NODE(0,-I,0)
*GET,P,NODE,N1,PRES
VALUE(I,2)=P/R
VALUE(I,3)=ABS(VALUE(I,2)/VALUE(I,1))
*ENDDO
SAVE,INF1
FINI
/CLEAR,NOSTART
/OUT,SCRATCH


/TITLE,VM264, ONE DIMENSIONAL CONSOLIDATION SETTLEMENT
C*** USING CPT215
/PREP7
ET,1,CPT215               ! 3-D 8-NODE COUPLED PORE-PRESSURE ELEMENT
H=-10                     ! DEPTH OF CONSOLIDATION (M)
W=1                       ! WIDTH AND DEPTH OF ELEMENT (M)
BLC4,0,0,W,H,W            ! GEOMETRY
ESIZE,W/4
VMESH,1
MP,EX,1,5.8E5             ! YOUNG'S MODULUS
MP,NUXY,1,0.0             ! POISSON'S RATIO
FPX=8.62E-3    ! PERMEABILITY
ONE=1.0
TB,PM,1,,,PERM
TBDATA,1,FPX,FPX,FPX
TB,PM,1,,,BIOT   ! BIOT COEFFICIENT
TBDATA,1,ONE
ALLSEL
D,ALL,UX                  ! HORIZONTAL DOFS ARE CONSTRAINED
D,ALL,UZ
ALLSEL

NSEL,S,LOC,Y,H
D,ALL,UY,0                ! BOTTOM SURFACE IS CONSTRAINED IN Y DIRECTION
ALLSEL

NSEL,S,LOC,Y,0
D,ALL,PRES,0              ! PRESSURE DOF BLOCKED ON TOP SURFACE
ALLSEL

FINISH

/SOLU
ANTYPE,STATIC
NROPT,UNSYM
CNVTOL,PRES,,1E-7
TIME,0.002

R=10                      ! LOADING
NSEL,S,LOC,Y,0
SF,ALL,PRES,R             ! APPLY EXTERNAL LOAD ON TOP SURFACE
ALLSEL

NSUBST,100,1000,10
KBC,1
OUTRES,ALL,ALL
SOLVE
```

```
FINISH

/POST1
SET,LAST
/VIEW,1,1,1,1
/ANG,1
PRNS,PRESS
PLNS,PRESS
/OUT,
*DIM,LABEL,CHAR,10,2
*DIM,VALUE,,10,3

LABEL(1,1) = 'CPT215  ','','','','','',''
LABEL(8,1) = '','',''
LABEL(1,2) = '0.1','0.2','0.3','0.4','0.5','0.6','0.7'
LABEL(8,2) = '0.8','0.9','1.0'

VALUE(1,1)=0.18
VALUE(2,1)=0.35
VALUE(3,1)=0.50
VALUE(4,1)=0.63
VALUE(5,1)=0.74
VALUE(6,1)=0.82
VALUE(7,1)=0.89
VALUE(8,1)=0.93
VALUE(9,1)=0.94
VALUE(10,1)=0.95
/COM,
/COM, TARGET VALUE IS OBTAINED FROM FORMULA MENTIONED IN REFERENCE PAPER
/COM,
*DO,I,1,10
N1=NODE(0,-I,0)
*GET,P,NODE,N1,PRES
VALUE(I,2)=P/R
VALUE(I,3)=ABS(VALUE(I,2)/VALUE(I,1))
*ENDDO
SAVE,INF2
FINI
/CLEAR,NOSTART
/OUT,SCRATCH



/TITLE,VM264, ONE DIMENSIONAL CONSOLIDATION SETTLEMENT
C*** USING CPT216
/PREP7
ET,1,CPT216               ! 3-D 20 NODE COUPLED PORE-PRESSURE ELEMENT
H=-10                     ! DEPTH OF CONSOLIDATION (M)
W=1                       ! WIDTH AND DEPTH OF ELEMENT (M)
BLC4,0,0,W,H,W            ! GEOMETRY
ESIZE,W
VMESH,1
MP,EX,1,5.8E5             ! YOUNG'S MODULUS
MP,NUXY,1,0.0             ! POISSON'S RATIO
FPX=8.62E-3    ! PERMEABILITY
ONE=1.0
TB,PM,1,,,PERM
TBDATA,1,FPX,FPX,FPX
TB,PM,1,,,BIOT   ! BIOT COEFFICIENT
TBDATA,1,ONE
ALLSEL
D,ALL,UX                  ! HORIZONTAL DOFS ARE CONSTRAINED
D,ALL,UZ
ALLSEL

NSEL,S,LOC,Y,H
D,ALL,UY,0                ! BOTTOM SURFACE IS CONSTRAINED IN Y DIRECTION
ALLSEL

NSEL,S,LOC,Y,0
D,ALL,PRES,0              ! PRESSURE DOF BLOCKED ON TOP SURFACE
ALLSEL
```

```
FINISH

/SOLU
ANTYPE,STATIC
NROPT,UNSYM
TIME,0.002

R=10                     ! LOADING
NSEL,S,LOC,Y,0
SF,ALL,PRES,R            ! APPLY EXTERNAL LOAD ON TOP SURFACE
ALLSEL

NSUBST,100,1000,10
KBC,1
OUTRES,ALL,ALL
SOLVE
FINISH

/POST1
SET,LAST
PRNS,PRESS
/VIEW,1,1,1,1
/ANG,1
PLNS,PRESS
/OUT,
*DIM,LABEL,CHAR,10,2
*DIM,VALUE,,10,3

LABEL(1,1) = 'CPT216  ','','','','','',''
LABEL(8,1) = '','',''
LABEL(1,2) = '0.1','0.2','0.3','0.4','0.5','0.6','0.7'
LABEL(8,2) = '0.8','0.9','1.0'

VALUE(1,1)=0.18
VALUE(2,1)=0.35
VALUE(3,1)=0.50
VALUE(4,1)=0.63
VALUE(5,1)=0.74
VALUE(6,1)=0.82
VALUE(7,1)=0.89
VALUE(8,1)=0.93
VALUE(9,1)=0.94
VALUE(10,1)=0.95
/COM,
/COM, TARGET VALUE IS OBTAINED FROM FORMULA MENTIONED IN REFERENCE PAPER
/COM,
*DO,I,1,10
N1=NODE(0,-I,0)
*GET,P,NODE,N1,PRES
VALUE(I,2)=P/R
VALUE(I,3)=ABS(VALUE(I,2)/VALUE(I,1))
*ENDDO
SAVE,INF3
FINI
/CLEAR,NOSTART
/OUT,SCRATCH



/TITLE,VM264, ONE DIMENSIONAL CONSOLIDATION SETTLEMENT
C*** USING CPT217
/PREP7
ET,1,CPT217              ! 3-D 10 NODE COUPLED PORE-PRESSURE ELEMENT
H=-10                    ! DEPTH OF CONSOLIDATION (M)
W=1                      ! WIDTH AND DEPTH OF ELEMENT (M)
BLC4,0,0,W,H,W           ! GEOMETRY
ESIZE,W
VMESH,1
MP,EX,1,5.8E5            ! YOUNG'S MODULUS
MP,NUXY,1,0.0            ! POISSON'S RATIO
FPX=8.62E-3    ! PERMEABILITY
```

```
ONE=1.0
TB,PM,1,,,PERM
TBDATA,1,FPX,FPX,FPX
TB,PM,1,,,BIOT   ! BIOT COEFFICIENT
TBDATA,1,ONE
ALLSEL
D,ALL,UX                ! HORIZONTAL DOFS ARE CONSTRAINED
D,ALL,UZ
ALLSEL

NSEL,S,LOC,Y,H
D,ALL,UY,0              ! BOTTOM SURFACE IS CONSTRAINED IN Y DIRECTION
ALLSEL

NSEL,S,LOC,Y,0
D,ALL,PRES,0            ! PRESSURE DOF BLOCKED ON TOP SURFACE
ALLSEL

FINISH

/SOLU
ANTYPE,STATIC
NROPT,UNSYM
TIME,0.002

R=10                    ! LOADING
NSEL,S,LOC,Y,0
SF,ALL,PRES,R           ! APPLY EXTERNAL LOAD ON TOP SURFACE
ALLSEL

NSUBST,100,1000,10
KBC,1
OUTRES,ALL,ALL
SOLVE
FINISH

/POST1
SET,LAST
PRNS,PRESS
/VIEW,1,1,1,1
/ANG,1
PLNS,PRESS
/OUT,
*DIM,LABEL,CHAR,10,2
*DIM,VALUE,,10,3

LABEL(1,1) = 'CPT217  ','','','','','',''
LABEL(8,1) = '','',''
LABEL(1,2) = '0.1','0.2','0.3','0.4','0.5','0.6','0.7'
LABEL(8,2) = '0.8','0.9','1.0'

VALUE(1,1)=0.18
VALUE(2,1)=0.35
VALUE(3,1)=0.50
VALUE(4,1)=0.63
VALUE(5,1)=0.74
VALUE(6,1)=0.82
VALUE(7,1)=0.89
VALUE(8,1)=0.93
VALUE(9,1)=0.94
VALUE(10,1)=0.95
/COM,
/COM, TARGET VALUE IS OBTAINED FROM FORMULA MENTIONED IN REFERENCE PAPER
/COM,
*DO,I,1,10
N1=NODE(0,-I,0)
*GET,P,NODE,N1,PRES
VALUE(I,2)=P/R
VALUE(I,3)=ABS(VALUE(I,2)/VALUE(I,1))
*ENDDO
SAVE,INF4
```

```
RESUME,INF1
/COM
/OUT,vm264,vrt
/COM,------------ vm264 RESULTS COMPARISON --------------
/COM,
/COM,        Y/H         |  TARGET   |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/NOPR
RESUME,INF2
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
RESUME,INF3
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
RESUME,INF4
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM-----------------------------------------------------
/OUT
FINISH
*LIST,vm264,vrt
/DELETE,INF1
/DELETE,INF2
/DELETE,INF3
/DELETE,INF4
```

VM265 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM265
/PREP7
/TITLE, VM265, ELASTIC ROD IMPACTING A RIGID WALL
C***     N.J. CARPENTER, R.L. TAYLOR AND M.G.KATONA,
C***     "LAGRANGE CONSTRAINTS FOR TRANSIENT FINITE ELEMENT SURFACE CONTACT"
C***     INTERNATIONAL JOURNAL FOR NUMERICAL METHODS IN ENGINEERING, VOL.32,103-128 (1991)
/PREP7
ANTYPE,TRANS                 ! NONLINEAR TRANSIENT DYNAMIC ANALYSIS
ET,1,SHELL181                ! 4-NODE STRUCTURAL SHELL
ET,3,CONTA177                ! 3D LINE-TO-SURFACE CONTACT
KEYOPT,3,2,4                 ! PURE LAGRANGE MULTIPLIER ON CONTACT NORMAL AND TANGENT
KEYOPT,3,7,4                 ! IMPACT CONSTRAINTS
ET,4,TARGE170                ! 3D TARGET SEGMENT
R,3                          ! REAL CONSTANT CONTACT PAIR
SECTYPE,1,SHELL              ! SHELL SECTION TYPE
SECDATA,1                    ! SHELL THICKNESS
MP,EX,1,3.0E7                ! YOUNG'S MODULUS [PSI]
MP,NUXY,1,0.3                ! POISSON'S RATIO
MP,DENS,1,0.73E-3            ! DENSITY  [LBF S^2/IN^4]
BLC4,-10.01,0.0,10.0,1.0     ! ROD GEOMETRY
TYPE,1
SECNUM,1
MAT,1
LESIZE,1,,,20                ! 20 ELEMENTS PER LENGTH
LESIZE,2,,,1
LESIZE,3,,,20
LESIZE,4,,,1
AMESH,1
N,1001,0,-0.5,-1.5           ! RIGID WALL
N,1002,0,-0.5,1.5
N,1003,0,1.5,1.5
N,1004,0,1.5,-1.5
REAL,3
TYPE,4
```

```
TSHAP,QUAD
E,1001,1002,1003,1004        ! TARGET ELEMENT
REAL,3
TYPE,3
ESEL,S,TYPE,,1
NSLE
NSEL,R,LOC,X,-0.01
ESURF                        ! CONTACT ON THE RIGHT SHELL EDGE
ALLSEL,ALL
NSEL,S,LOC,Y,0.0             ! BOUNDARY CONDITIONS
NSEL,U,LOC,X,-0.01           ! AVOID OVER CONSTRAINTS ON CONTACT NODE
D,ALL,UY
NSEL,ALL
NSEL,S,LOC,Y,1.0
NSEL,U,LOC,X,-0.01           ! AVOID OVER CONSTRAINTS ON CONTACT NODE
D,ALL,UY
NSEL,ALL
NSEL,U,LOC,X,-0.01           ! AVOID OVER CONSTRAINTS ON CONTACT NODE
D,ALL,UZ
D,ALL,ROTX
D,ALL,ROTY
D,ALL,ROTZ
NSEL,ALL
ESEL,S,TYPE,,1
NSLE
IC,ALL,UX,,202.2             ! INITIAL VELOCITY
ALLSEL,ALL
FINISH
/SOLU
NLGEOM,ON                    ! INLCUDE LARGE DEFLECTION EFFECTS
TRNOPT,FULL, , , , ,HHT      ! FULL METHOD WITH HHT ALGORITHM
TINTP,0.0                  ! NO NUMERICAL DAMPING
TIME,2.0E-4                  ! TIME TO ALLOW IMPACT AND RELEASE OF THE ROD
NSUB,89,89,89                ! UNIFORM TIME STEP INCREMENT OF 0.2226E-5 SEC
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINISH
/POST26
NUMVAR,20
NSOL,2,22,U,X,UX22           ! NODE ON THE ROD CONTACT SURFACE
NSOL,3,22,VEL,X,VX22
ESOL,4,22,2,SMISC,1,FORCE1
ESOL,5,22,22,SMISC,2,FORCE2
ADD,6,4,5,,FORCE             ! NORMAL CONTACT FORCE
ENERSOL,7,KENE               ! KINETIC ENERGY
ENERSOL,8,SENE               ! STRAIN ENERGY DENSITY
ADD,9,7,8,,TOTALENE          ! TOTAL ENERGY
/OUT,
PRVAR,2,3,6
PRVAR,7,8,9
/TITLE,CONTACT SURFACE DISPLACEMENT VERSUS TIME
/AXLAB,Y,AXIAL DISPLACEMENT
PLVAR,2                      ! COMPARE THIS PLOT WITH FIGURE 3a IN REFERENCE
/TITLE,CONTACT SURFACE VELOCITY VERSUS TIME
/AXLAB,Y,AXIAL VELOCITY
PLVAR,3                      ! COMPARE THIS PLOT WITH FIGURE 3b IN REFERENCE
/TITLE,NORMAL CONTACT FORCE VERSUS TIME
/AXLAB,Y,NORMAL CONTACT FORCE
PLVAR,6                      ! COMPARE THIS PLOT WITH FIGURE 3c IN REFERENCE
/TITLE,KINETIC ENERGY,STRAIN ENERGY AND TOTAL ENERGY VERSUS TIME
/AXLAB,Y,ENERGIES
PLVAR,7,8,9
FINI
/POST1
*GET,NSET,ACTIVE,0,SET,NSET  ! NUMBER OF SUBSTEPS
*DIM,AFORCE,ARRAY,NSET       ! ARRAY FOR NORMAL CONTACT FORCE
*DIM,ATIME,ARRAY,NSET        ! ARRAY FOR TIME
*DIM,ADISP,ARRAY,NSET        ! ARRAY FOR AXIAL DISPLACEMENT
*DIM,AVEL,ARRAY,NSET         ! ARRAY FOR AXIAL CENTER OF MASS VELOCITY
*DIM,VELN,ARRAY,42
*DO,I,1,NSET
```

```
 SET,1,I
 *GET,FORCE1,ELEM,22,SMISC,1
 *GET,FORCE2,ELEM,22,SMISC,2
 AFORCE(I)=FORCE1+FORCE2
 *GET,ATIME(I),ACTIVE,0,SET,TIME
 ADISP(I)=UX(22)
 *DO,J,1,42
  VELN(J)=VX(J)
 *ENDDO
 AVEL(I)=0
 *DO,J,3,21
  AVEL(I)=AVEL(I)+VELN(J)+VELN(J+21)
 *ENDDO
 AVEL(I)=AVEL(I)+0.5*VELN(1)+0.5*VELN(2)
 AVEL(I)=(AVEL(I)+0.5*VELN(22)+0.5*VELN(23))/40
*ENDDO
IFOUND=0
*DO,I,1,NSET
 *IF,AFORCE(I),NE,0,AND,IFOUND,EQ,0,THEN
  TIMP=ATIME(I-1)            ! IMPACT TIME
  UIMP=ADISP(I-1)            ! CONTACT SURFACE DISPLACEMENT AT IMPACT
  VIMP=AVEL(I-1)             ! CONTACT SURFACE VELOCITY AT IMPACT
  IMP_FORCE=AFORCE(I-1)      ! NORMAL CONTACT FORCE AT IMPACT
  IFOUND=1
 *ENDIF
 *IF, AFORCE(I),EQ,0,AND,IFOUND,EQ,1,THEN
  *IF, AFORCE(I+1),EQ,0,THEN
   TREL=ATIME(I)              ! RELEASE TIME
   UREL=ADISP(I)              ! CONTACT SURFACE DISPLACEMENT AT RELEASE
   VREL=AVEL(I)               ! CONTACT SURFACE VELOCITY AT RELEASE
   REL_FORCE=AFORCE(I)        ! NORMAL CONTACT FORCE AT RELEASE
   IFOUND=2
  *ENDIF
 *ENDIF
*ENDDO
*DIM,LABEL2,CHAR,4,2
*DIM,VALUE2,,4,3
LABEL2(1,1) = 'TIME,  ','X DISP, ','X VEL, ','FORCE, '
LABEL2(1,2) = 'sec      ','in      ','in/sec   ','lb   '
*VFILL,VALUE2(1,1),DATA,.494E-4,0.01,202.2,0
*VFILL,VALUE2(1,2),DATA,TIMP,UIMP,VIMP,IMP_FORCE
*VFILL,VALUE2(1,3),DATA,ABS(TIMP/.494E-4),ABS(UIMP/0.01),ABS(VIMP/202.2),1
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'TIME,  ','X DISP, ','X VEL, ','FORCE, '
LABEL(1,2) = 'sec      ','in      ','in/sec   ','lb   '
*VFILL,VALUE(1,1),DATA,0.148E-3,0.01,-202.2,0
*VFILL,VALUE(1,2),DATA,TREL,UREL,VREL,REL_FORCE
*VFILL,VALUE(1,3),DATA,ABS(TREL/.148E-3),ABS(UREL/0.01),ABS(VREL/(-202.2)),1
FINISH
/COM
/OUT,vm265,vrt
/COM,----------------- VM265 RESULTS COMPARISON -------------------
/COM,
/COM,
/COM,AT IMPACT         |  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL2(1,1),LABEL2(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,
/COM,
/COM,AT RELEASE        |  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.5,'  ',F14.5,'   ',1F15.3)
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vm265,vrt
```

VM266 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM266
/PREP7
/TITLE, VM266, 3D CROSSING BEAMS IN CONTACT WITH FRICTION
C***     G.ZAVARISE AND P. WRIGGERS
C***     "CONTACT WITH FRICTION BETWEEN BEAMS IN 3-D SPACE"
C***     INTERNATIONAL JOURNAL FOR NUMERICAL METHODS IN ENGINEERING, VOL.49,977-1006 (2000)
/PREP7
ANTYPE,0                        ! STATIC ANALYSIS
ET,1,BEAM188                    ! 3-D 2-NODE BEAM
KEYO,1,3,2                      ! QUADRATIC SHAPE FUNCTIONS ALONG THE LENGTH
ET,2,BEAM188                    ! 3-D 2-NODE BEAM
KEYO,2,3,2                      ! QUADRATIC SHAPE FUNCTIONS ALONG THE LENGTH
SECTYPE,1,BEAM,CTUBE            ! CIRCULAR TUBE SECTION TYPE FOR BEAMS
SECDATA,0.06,0.12793            ! INNER AND OUTER RADIUS
R,2,0.2,0.2                     ! RADIUS ON THE TARGET AND CONTACT SIDES
RMODIF,2,3,-1.0E+4              ! NORMAL CONTACT STIFFNESS-ABSOLUTE VALUE
RMODIF,2,12,-1.0E+4             ! TANGENTIAL CONTACT STIFFNESS-ABSOLUTE VALUE
ET,3,CONTA176                   ! 3D LINE-TO-LINE CONTACT
KEYOPT,3,2,1                    ! PENALTY FUNCTION
KEYOPT,3,3,1                    ! CROSSING BEAMS
ET,4,TARGE170                   ! 3D TARGET SEGMENT
MP,EX,1,1.0E+8                  ! YOUNG'S MODULUS
MP,NUXY,1,0.0                   ! POISSON'S RATIO
MP,MU,1,0.1                     ! FRICTION COEFFICIENT
K,1,0,0,0                       ! GEOMETRY OF BEAMS
K,2,14,0,0
K,3,4,-5,1
K,4,4,5,1
L,1,2
L,3,4
TYPE,1                          ! HORIZONTAL BEAM
MAT,1
SECNUM,1
LESIZE,1,,,16
LMESH,1
TYPE,2                          ! VERTICAL BEAM
MAT,1
SECNUM,1
LESIZE,2,,,9
LMESH,2
TYPE,3                          ! CONTACT ON HORIZONTAL BEAM
REAL,2
MAT,1
ESEL,S,TYPE,,1
NSLE
ESURF
TYPE,4                          ! TARGET ON VERTICAL BEAM
REAL,2
MAT,1
ESEL,S,TYPE,,2
NSLE
ESURF
ALLSEL,ALL
DK,2,ALL                        ! CLAMPED RIGHT END OF HORIZONTAL BEAM
DK,3,ALL                        ! CLAMPED BOTH ENDS OF VERTICAL BEAM
DK,4,ALL
DK,2,UX,0.18                    ! HORIZONTAL DISPLACEMENT OF RIGHT END
DK,2,UZ,1.8                     ! OUT-OF-PLANE DISPLACEMENT OF RIGHT END
FINI
/SOLU
NLGEOM,ON
NSUBST,60,100,60
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINI
```

```
/POST1
ESEL,S,ELEM,,30                 ! ELEMENT IN CONTACT
/OUT,
SET,1,30                        ! TIME WHEN CONTACT IS INITIATED
ETABLE,PRES3,CONT,PRES          ! NORMAL CONTACT FORCE AT SUBSTEP30
ETABLE,SFRIC3,CONT,SFRIC        ! FRICTIONAL CONTACT FORCE AT SUBSTEP30
*GET,NFORCE3,ETAB,1,ELEM,30     ! NORMAL CONTACT FORCE AT SUBSTEP30-COMPARE WITH STEP 3 IN REFERENCE
*GET,TFORCE3,ETAB,2,ELEM,30     ! FRICTIONAL CONTACT FORCE AT SUBSTEP30-COMPARE WITH STEP 3 IN REFERENCE
SET,1,40
ETABLE,PRES4,CONT,PRES          ! NORMAL CONTACT FORCE AT SUBSTEP40
ETABLE,SFRIC4,CONT,SFRIC        ! FRICTIONAL CONTACT FORCE AT SUBSTEP40
*GET,NFORCE4,ETAB,3,ELEM,30     ! NORMAL CONTACT FORCE AT SUBSTEP40-COMPARE WITH STEP 4 IN REFERENCE
*GET,TFORCE4,ETAB,4,ELEM,30     ! FRICTIONAL CONTACT FORCE AT SUBSTEP40-COMPARE WITH STEP 4 IN REFERENCE
SET,1,50
ETABLE,PRES5,CONT,PRES          ! NORMAL CONTACT FORCE AT SUBSTEP50
ETABLE,SFRIC5,CONT,SFRIC        ! FRICTIONAL CONTACT FORCE AT SUBSTEP50
*GET,NFORCE5,ETAB,5,ELEM,30     ! NORMAL CONTACT FORCE AT SUBSTEP50-COMPARE WITH STEP 5 IN REFERENCE
*GET,TFORCE5,ETAB,6,ELEM,30     ! FRICTIONAL CONTACT FORCE AT SUBSTEP50-COMPARE WITH STEP 5 IN REFERENCE
SET,1,60                        ! LAST SUBSTEP
ETABLE,PRES6,CONT,PRES          ! NORMAL CONTACT FORCE AT SUBSTEP60 (LAST)
ETABLE,SFRIC6,CONT,SFRIC        ! FRICTIONAL CONTACT FORCE AT SUBSTEP60(LAST)
*GET,NFORCE6,ETAB,7,ELEM,30     ! NORMAL CONTACT FORCE AT SUBSTEP60-COMPARE WITH STEP 6 IN REFERENCE
*GET,TFORCE6,ETAB,8,ELEM,30     ! FRICTIONAL CONTACT FORCE AT SUBSTEP60-COMPARE WITH STEP 6 IN REFERENCE
ESEL,ALL
*DIM,LABEL2,CHAR,4,1
*DIM,VALUE2,,4,3
LABEL2(1,1) = 'NFORCE3  ','NFORCE4 ','NFORCE5 ','NFORCE6 '
*VFILL,VALUE2(1,1),DATA,17.0,33.8,50.4,67.0
*VFILL,VALUE2(1,2),DATA,NFORCE3,NFORCE4,NFORCE5,NFORCE6
*VFILL,VALUE2(1,3),DATA,(NFORCE3/17.0),(NFORCE4/33.8),(NFORCE5/50.4),(NFORCE6/67.0)
*DIM,LABEL1,CHAR,4,1
*DIM,VALUE1,,4,3
LABEL1(1,1) = 'TFORCE3  ','TFORCE4 ','TFORCE5 ','TFORCE6 '
*VFILL,VALUE1(1,1),DATA,1.7,3.38,5.04,6.7
*VFILL,VALUE1(1,2),DATA,TFORCE3,TFORCE4,TFORCE5,TFORCE6
*VFILL,VALUE1(1,3),DATA,(TFORCE3/1.7),(TFORCE4/3.38),(TFORCE5/5.04),(TFORCE6/6.7)
FINISH
/COM
/OUT,vm266,vrt
/COM,----------------- VM266 RESULTS COMPARISON ---------------
/COM,
/COM,
/COM,FORCE-BASED CONTACT: K(3)=1
/COM,NORMAL-CONTACT FORCE   |  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL2(1),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A20,'   ',F10.4,'  ',F14.4,'    ',1F15.3)
/COM,
/COM,
/COM,TANG-CONTACT FORCE     |  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A20,'   ',F10.4,'  ',F14.4,'    ',1F15.3)
/COM,
/COM, -------------------------------------------------------
/OUT
FINISH
!
/CLEAR,NOSTART

/PREP7
ANTYPE,0                        ! STATIC ANALYSIS
ET,1,BEAM188                    ! 3-D 2-NODE BEAM
KEYO,1,3,2                      ! QUADRATIC SHAPE FUNCTIONS ALONG THE LENGTH
ET,2,BEAM188                    ! 3-D 2-NODE BEAM
KEYO,2,3,2                      ! QUADRATIC SHAPE FUNCTIONS ALONG THE LENGTH
SECTYPE,1,BEAM,CTUBE            ! CIRCULAR TUBE SECTION TYPE FOR BEAMS
SECDATA,0.06,0.12793            ! INNER AND OUTER RADIUS
R,2,0.2,0.2                     ! RADIUS ON THE TARGET AND CONTACT SIDES
T_RATIO=5.71425                 ! AREA RATIO TO CONVERT TO TRACTION CONTACT
T_STIFF=(-1.0E4)*T_RATIO        ! SCALED ABSOLUTE VALUE OF CONTACT STIFFNESS
RMODIF,2,3,T_STIFF              ! APPLY NORMAL CONTACT STIFFNESS-ABSOLUTE VALUE
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RMODIF,2,12,T_STIFF              ! APPLY TANGENTIAL CONTACT STIFFNESS-ABSOLUTE VALUE
ET,3,CONTA176                    ! 3D LINE-TO-LINE CONTACT
KEYOPT,3,2,1                     ! PENALTY FUNCTION
KEYOPT,3,3,3                     ! CROSSING BEAMS WITH TRACTION CONTACT
ET,4,TARGE170                    ! 3D TARGET SEGMENT
MP,EX,1,1.0E+8                   ! YOUNG'S MODULUS
MP,NUXY,1,0.0                    ! POISSON'S RATIO
MP,MU,1,0.1                      ! FRICTION COEFFICIENT
K,1,0,0,0                        ! GEOMETRY OF BEAMS
K,2,14,0,0
K,3,4,-5,1
K,4,4,5,1
L,1,2
L,3,4
TYPE,1                           ! HORIZONTAL BEAM
MAT,1
SECNUM,1
LESIZE,1,,,16
LMESH,1
TYPE,2                           ! VERTICAL BEAM
MAT,1
SECNUM,1
LESIZE,2,,,9
LMESH,2
TYPE,3                           ! CONTACT ON HORIZONTAL BEAM
REAL,2
MAT,1
ESEL,S,TYPE,,1
NSLE
ESURF
TYPE,4                           ! TARGET ON VERTICAL BEAM
REAL,2
MAT,1
ESEL,S,TYPE,,2
NSLE
ESURF
ALLSEL,ALL
DK,2,ALL                         ! CLAMPED RIGHT END OF HORIZONTAL BEAM
DK,3,ALL                         ! CLAMPED BOTH ENDS OF VERTICAL BEAM
DK,4,ALL
DK,2,UX,0.18                     ! HORIZONTAL DISPLACEMENT OF RIGHT END
DK,2,UZ,1.8                      ! OUT-OF-PLANE DISPLACEMENT OF RIGHT END
FINI
/SOLU
NLGEOM,ON
NSUBST,60,100,60
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINI
/POST1
ESEL,S,ELEM,,30                  ! ELEMENT IN CONTACT
/OUT,
SET,1,30                         ! TIME WHEN CONTACT IS INITIATED
ETABLE,PRES3,CONT,PRES           ! NORMAL CONTACT PRESSURE AT SUBSTEP30
ETABLE,SFRIC3,CONT,SFRIC         ! FRICTIONAL CONTACT PRESSURE AT SUBSTEP30
*GET,NPRES3,ETAB,1,ELEM,30       ! NORMAL CONTACT PRESSURE AT SUBSTEP30-COMPARE WITH STEP 3 IN REFERENCE
*GET,TPRES3,ETAB,2,ELEM,30       ! FRICTIONAL CONTACT PRESSURE AT SUBSTEP30-COMPARE WITH STEP 3 IN REFERENCE
SET,1,40
ETABLE,PRES4,CONT,PRES           ! NORMAL CONTACT PRESSURE AT SUBSTEP40
ETABLE,SFRIC4,CONT,SFRIC         ! FRICTIONAL CONTACT PRESSURE AT SUBSTEP40
*GET,NPRES4,ETAB,3,ELEM,30       ! NORMAL CONTACT PRESSURE AT SUBSTEP40-COMPARE WITH STEP 4 IN REFERENCE
*GET,TPRES4,ETAB,4,ELEM,30       ! FRICTIONAL CONTACT PRESSURE AT SUBSTEP40-COMPARE WITH STEP 4 IN REFERENCE
SET,1,50
ETABLE,PRES5,CONT,PRES           ! NORMAL CONTACT PRESSURE AT SUBSTEP50
ETABLE,SFRIC5,CONT,SFRIC         ! FRICTIONAL CONTACT PRESSURE AT SUBSTEP50
*GET,NPRES5,ETAB,5,ELEM,30       ! NORMAL CONTACT PRESSURE AT SUBSTEP50-COMPARE WITH STEP 5 IN REFERENCE
*GET,TPRES5,ETAB,6,ELEM,30       ! FRICTIONAL CONTACT PRESSURE AT SUBSTEP50-COMPARE WITH STEP 5 IN REFERENCE
SET,1,60                         ! LAST SUBSTEP
ETABLE,PRES6,CONT,PRES           ! NORMAL CONTACT PRESSURE AT SUBSTEP60 (LAST)
ETABLE,SFRIC6,CONT,SFRIC         ! FRICTIONAL CONTACT PRESSURE AT SUBSTEP60(LAST)
*GET,NPRES6,ETAB,7,ELEM,30       ! NORMAL CONTACT PRESSURE AT SUBSTEP60-COMPARE WITH STEP 6 IN REFERENCE
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*GET,TPRES6,ETAB,8,ELEM,30      ! FRICTIONAL CONTACT PRESSURE AT SUBSTEP60-COMPARE WITH STEP 6 IN REFERENCE
ESEL,ALL
*DIM,LABEL2,CHAR,4,1
*DIM,VALUE2,,4,3
LABEL2(1,1) = 'NPRES3  ','NPRES4 ','NPRES5 ','NPRES6 '
*VFILL,VALUE2(1,1),DATA,17.0*T_RATIO,33.8*T_RATIO,50.4*T_RATIO,67.0*T_RATIO
*VFILL,VALUE2(1,2),DATA,NPRES3,NPRES4,NPRES5,NPRES6
*VFILL,VALUE2(1,3),DATA,(NPRES3/97.14),(NPRES4/193),(NPRES5/288),(NPRES6/383)
*DIM,LABEL1,CHAR,4,1
*DIM,VALUE1,,4,3
LABEL1(1,1) = 'TPRES3  ','TPRES4 ','TPRES5 ','TPRES6 '
*VFILL,VALUE1(1,1),DATA,1.7*T_RATIO,3.38*T_RATIO,5.04*T_RATIO,6.7*T_RATIO
*VFILL,VALUE1(1,2),DATA,TPRES3,TPRES4,TPRES5,TPRES6
*VFILL,VALUE1(1,3),DATA,(TPRES3/9.714),(TPRES4/19.3),(TPRES5/28.8),(TPRES6/38.3)
FINISH
/COM
/OUT,vm266,vrt,,APPEND
/COM,
/COM,
/COM,TRACTION-BASED CONTACT: K(3)=3
/COM,NORMAL-CONTACT PRESSURE |  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL2(1),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A20,'   ',F10.4,'  ',F14.4,'    ',1F15.3)
/COM,
/COM,
/COM,TANG-CONTACT PRESSURE   |  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A20,'   ',F10.4,'  ',F14.4,'    ',1F15.3)
/COM,
/COM, --------------------------------------------------------
/OUT
FINISH
*LIST,vm266,vrt
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VM267 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM267
/TITLE,VM267, INCLINED CRACK IN 2D PLATE UNDER UNIFORM TENSION LOADING
/COM, REFERENCE: "T.L.ANDERSON, FRACTURE MECHANICS: FUNDAMENTALS AND APPLICATIONS.
/COM,             CRC PRESS, BOCA RATON, FL, 1995"
/COM,
/PREP7
MM_TO_M=10**(-3)                            ! CONVERT MM TO M
HALF_CRACK_LENGHT = 45*MM_TO_M              ! CRACK LENGTH
ALPHA=30                                    ! ANGLE
SIGMA_INFTY = 10E+06                        ! LOADING CONSTANT (PA)
PI=ACOS(-1)

!DEFINE ELEMENTS TYPE
ET,1,PLANE182
KEYOPT,1,3,2

!MATERIAL PROPERTIES
YOUNG = 210000E+06
NU = 0.3
MP,EX,1,YOUNG
MP,PRXY,1,NU

!BIG RECTANGLE
L_RECTANGLE_LENGHT = 300*MM_TO_M
L_RECTANGLE_HEIGHT = 300*MM_TO_M

!MEDIUM RECTANGLE
M_RECTANGLE_LENGHT = 100*MM_TO_M
M_RECTANGLE_HEIGHT = 100*MM_TO_M
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!TORUS
TORUS_MINOR_RADIUS = 18*MM_TO_M
TORUS_MAJOR_RADIUS = HALF_CRACK_LENGHT

!RECTANGLE
RECTNG_LENGHT = ((HALF_CRACK_LENGHT + TORUS_MINOR_RADIUS*2)*2)
RECTNG_HEIGHT = (TORUS_MINOR_RADIUS*2.0)
RECTNG_OFFSET = (- RECTNG_LENGHT/2)       !TORUS_MAJOR_RADIUS - RECTNG_LENGHT/2

!SMALL CIRCULAR AREA
FIRST_ROW_RADIUS = 2
SMALL_CIRCULAR_RADIUS = (FIRST_ROW_RADIUS*4)*MM_TO_M

!AREAS CREATION
WPSTYLE,,,,,,,,1
WPROTA,ALPHA,,
CSWPLA,11,0

RECTNG,RECTNG_OFFSET,RECTNG_OFFSET+RECTNG_LENGHT,0,RECTNG_HEIGHT
RECTNG,RECTNG_OFFSET,RECTNG_OFFSET+RECTNG_LENGHT,-RECTNG_HEIGHT,0

CYL4,HALF_CRACK_LENGHT,0,SMALL_CIRCULAR_RADIUS,180
CYL4,HALF_CRACK_LENGHT,0,TORUS_MINOR_RADIUS,180
ASBA,1,4,,DELETE,KEEP
ASBA,4,3,,DELETE,KEEP

CYL4,HALF_CRACK_LENGHT,0,SMALL_CIRCULAR_RADIUS,-180
CYL4,HALF_CRACK_LENGHT,0,TORUS_MINOR_RADIUS,-180
ASBA,2,6,,DELETE,KEEP
ASBA,6,4,,DELETE,KEEP

!MERGE THE KEYPOINTS AFTER THE CRACK
KSEL,S,LOC,X,HALF_CRACK_LENGHT,2*HALF_CRACK_LENGHT
NUMMRG,KP
ALLSEL,ALL,ALL

CYL4,-HALF_CRACK_LENGHT,0,SMALL_CIRCULAR_RADIUS,180
CYL4,-HALF_CRACK_LENGHT,0,TORUS_MINOR_RADIUS,180
ASBA,5,8,,DELETE,KEEP
ASBA,8,6,,DELETE,KEEP

CYL4,-HALF_CRACK_LENGHT,0,SMALL_CIRCULAR_RADIUS,-180
CYL4,-HALF_CRACK_LENGHT,0,TORUS_MINOR_RADIUS,-180
ASBA,7,10,,DELETE,KEEP
ASBA,10,8,,DELETE,KEEP

!MERGE THE KEYPOINTS AFTER THE CRACK
KSEL,S,LOC,X,-HALF_CRACK_LENGHT,-(2*HALF_CRACK_LENGHT)
NUMMRG,KP
ALLSEL,ALL,ALL

WPROTA,-ALPHA,,
CSYS,0
RECTNG,-M_RECTANGLE_LENGHT,M_RECTANGLE_LENGHT,-M_RECTANGLE_HEIGHT,M_RECTANGLE_HEIGHT
ALLSEL
ASBA,10,ALL,,DELETE,KEEP

RECTNG,-L_RECTANGLE_LENGHT,L_RECTANGLE_LENGHT,-L_RECTANGLE_HEIGHT,L_RECTANGLE_HEIGHT
ALLSEL
ASBA,10,ALL,,DELETE,KEEP

!RADIAL 2D MESH SETTING AROUND RIGHT CRACK TIP KEYPOINT
ALLSEL,ALL,ALL
WPROTA,ALPHA,,
CSYS,11

KSEL,S,LOC,Y,0
KSEL,R,LOC,X,HALF_CRACK_LENGHT
*GET,TIP_RIGHT_KNUM,KP,0,NUM,MIN
KSCON,TIP_RIGHT_KNUM,FIRST_ROW_RADIUS*MM_TO_M,0,8,1.0
AESIZE,9,12*MM_TO_M
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AESIZE,11,12*MM_TO_M
LESIZE,1,,,2
LESIZE,7,,,2
LESIZE,17,,,2
ALLSEL,ALL,ALL

!RADIAL 2D MESH SETTING AROUND LEFT CRACK TIP KEYPOINT
ALLSEL,ALL,ALL
KSEL,S,LOC,Y,0
KSEL,R,LOC,X,-HALF_CRACK_LENGHT
*GET,TIP_LEFT_KNUM,KP,0,NUM,MIN
KSCON,TIP_LEFT_KNUM,FIRST_ROW_RADIUS*MM_TO_M,0,8,1.0
LESIZE,23,,,2
LESIZE,15,,,2
LESIZE,35,,,2
ALLSEL,ALL,ALL
AESIZE,12,20*MM_TO_M
AESIZE,13,80*MM_TO_M

WPROTA,-ALPHA,,
CSYS,0

TYPE,1
AMESH,3
AMESH,4
AMAP,1,13,10,9,12
AMAP,2,17,14,9,12
AMESH,6
AMESH,8
AMAP,5,19,15,7,18
AMAP,7,19,15,21,24
AMESH,9,11,2
MOPT,TRANS,2
AMESH,12,13
ALLSEL
FINISH

/SOLU
ALLSEL
CSYS,0
NSEL,S,LOC,X,-L_RECTANGLE_LENGHT
D,ALL,UX,0
ALLSEL
NSEL,S,LOC,Y,L_RECTANGLE_HEIGHT
SF,ALL,PRES,-SIGMA_INFTY
ALLSEL
NSEL,S,LOC,Y,-L_RECTANGLE_HEIGHT
D,ALL,UY,0
ALLSEL,ALL
NSEL,S,NODE,,NODE(0.039,0.0225,0)
TIP_RIGHT_NNUM=NODE(0.039,0.0225,0)
CM,RIGHT_TIP,NODE
CSYS,0
ALLSEL,ALL
CINT,NEW,1                              ! DEFINE CRACK ID
CINT,TYPE,SIFS
CINT,CTNC,RIGHT_TIP                     ! DEFINE RIGHT CRACK TIP NODE COMPONENT
CINT,SYMM,OFF                           ! SYMMETRY OFF
CINT,NCON,5                             ! NUMBER OF COUNTOURS
CINT,NORMAL,11,2                        ! DEFINE CRACK PLANE NORMAL
CINT,LIST
ALLSEL,ALL
ANTYPE,STATIC
EQSLV,SPARSE
SOLVE

/OUT,SCRATCH
/POST1
PRCINT,1,,K1     ! STRESS INTENSITY FOR MODE 1 FRACTURE
*GET,K1_1,CINT,1,CTIP,TIP_RIGHT_NNUM,,1,DTYPE,K1
*GET,K1_2,CINT,1,CTIP,TIP_RIGHT_NNUM,,2,DTYPE,K1
*GET,K1_3,CINT,1,CTIP,TIP_RIGHT_NNUM,,3,DTYPE,K1
```

```
*GET,K1_4,CINT,1,CTIP,TIP_RIGHT_NNUM,,4,DTYPE,K1
*GET,K1_5,CINT,1,CTIP,TIP_RIGHT_NNUM,,5,DTYPE,K1

PRCINT,1,,K2      ! STRESS INTENSITY FOR MODE 2 FRACTURE
*GET,K2_1,CINT,1,CTIP,TIP_RIGHT_NNUM,,1,DTYPE,K2
*GET,K2_2,CINT,1,CTIP,TIP_RIGHT_NNUM,,2,DTYPE,K2
*GET,K2_3,CINT,1,CTIP,TIP_RIGHT_NNUM,,3,DTYPE,K2
*GET,K2_4,CINT,1,CTIP,TIP_RIGHT_NNUM,,4,DTYPE,K2
*GET,K2_5,CINT,1,CTIP,TIP_RIGHT_NNUM,,5,DTYPE,K2

/OUT
ALPHA=30*PI/180
K1_REF = (SIGMA_INFTY*SQRT(PI*HALF_CRACK_LENGHT))*(COS(ALPHA)*COS(ALPHA))
K2_REF = (SIGMA_INFTY*SQRT(PI*HALF_CRACK_LENGHT))*(COS(ALPHA)*SIN(ALPHA))
K1_ANSYS=(K1_2+K1_3+K1_4+K1_5)/4
K2_ANSYS=(K2_2+K2_3+K2_4+K2_5)/4
/COM
/OUT,vm267,vrt
/COM,------------ VM267 RESULTS COMPARISON --------------
/COM,
/COM,          |  TARGET   |   Mechanical APDL  |   RATIO
/COM,
/COM,  STRESS INTENSITY FOR MODE 1 FRACTURE
/COM,
*VWRITE,'KI',K1_REF,K1_ANSYS,K1_ANSYS/K1_REF
(1X,A8,'   ',F10.0,'  ',F14.0,'   ',F15.3)
/COM,
/COM,
/COM,  STRESS INTENSITY FOR MODE 2 FRACTURE
/COM,
*VWRITE,'KII',K2_REF,K2_ANSYS,K2_ANSYS/K2_REF
(1X,A8,'   ',F10.0,'  ',F14.0,'   ',F15.3)
/COM,
/COM,
/COM,-------------------------------------------------------
/OUT
FINISH
*LIST,vm267,vrt
```

VM268 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM268
/TITLE,VM268,MULLINS EFFECT ON A RUBBER TUBE MODEL SUBJECTED TO TENSION LOADING
/COM, REFERENCE: "R.W.OGDEN, ET AL., A PSEUDO-ELASTIC MODEL FOR THE MULLINS EFFECT IN FILLED RUBBER
/COM,             ROYAL SOCIETY OF LONDON PROCEEDINGS SERIES A, VOL.455,1999,PG:2861-2877
/COM,
/PREP7
ET,1,PLANE182              ! ELEMENT TYPE 182
KEYOPT,1,3,1
RECTNG,0,0.5,0,1
ESIZE,0.25
AMESH,1
MUA=8                    ! INITIAL SHEAR MODULUS OF THE MATERIAL
RR=2.104    ! DAMAGE VARIABLE PARAMETER
MM=30.45    ! DAMAGE VARIABLE PARAMETER
BB=0.2     ! DAMAGE VARIABLE PARAMETER
TB,HYPER,1,,,NEO         ! NEO-HOOKEAN OPTION
TBDATA,1,MUA
TB,CDM,1,,3,PSE2          ! MODIFIED OGDEN ROXBURGH MULLINS EFFECT
TBDATA,1,RR,MM,BB          ! DEFINE R,M,AND B

! CONSTRAINTS
NSEL,S,LOC,Y,0.
D,ALL,UY,0.
NSEL,S,LOC,Y,0
NSEL,R,LOC,X,0
D,ALL,ALL,0.
```

```
ALLSEL
FINISH

/SOLU
ANTYPE,STATIC
NLGEOM,ON
*SET,N,6                 ! LOADING STEP
*DIM, UYY,ARRAY,N
*SET,UYY(1),0.5,1.0,2.0,1.0,0.5,0
*DO,I,1,N
  TIME,I
  OUTRES,ALL,LAST
  NSUBST,20,1000,5
  KBC,0
  NSEL,S,LOC,Y,1
  D,ALL,UY,UYY(I)
  ALLSEL
  SOLVE
*ENDDO
FINISH

/OUT,SCRATCH
/POST1
*DIM,SS,ARRAY,N
*DIM,SS_REF,ARRAY,N
*DIM,WM,ARRAY,N
*DO,I,1,N
   SET,I
   ETABLE,SY,S,Y
  *GET,SS(I),ELEM,1,ETAB,SY
   ETABLE,WMM,CDM,LM
  *GET,WM(I),ELEM,1,ETAB,WMM

!THEORETICAL RESULTS FROM PAPER
   L=UYY(I)+1
   WM0=MUA*(L**2+2/L-3)/2
   DA=(WM(I)-WM0)/(MM+BB*WM(I))
   DM=1-2/SQRT(3.1416)*(DA-DA**3/3+DA**5/10)/RR
   SS_REF(I)=DM*MUA*(L**2-1/L)
*ENDDO

*DIM,LABEL,CHAR,1,N
*DIM,VALUE,,N,3
LABEL(1,1) = '1.5'
LABEL(1,2) = '2.0'
LABEL(1,3) = '3.0'
LABEL(1,4) = '2.0'
LABEL(1,5) = '1.5'
LABEL(1,6) = '1.0'
/COM,
*VFILL,VALUE(1,1),DATA,SS_REF(1)
*VFILL,VALUE(1,2),DATA,SS(1)
*VFILL,VALUE(1,3),DATA,ABS(SS(1)/SS_REF(1))
*VFILL,VALUE(2,1),DATA,SS_REF(2)
*VFILL,VALUE(2,2),DATA,SS(2)
*VFILL,VALUE(2,3),DATA,ABS(SS(2)/SS_REF(2))
*VFILL,VALUE(3,1),DATA,SS_REF(3)
*VFILL,VALUE(3,2),DATA,SS(3)
*VFILL,VALUE(3,3),DATA,ABS(SS(3)/SS_REF(3))
*VFILL,VALUE(4,1),DATA,SS_REF(4)
*VFILL,VALUE(4,2),DATA,SS(4)
*VFILL,VALUE(4,3),DATA,ABS(SS(4)/SS_REF(4))
*VFILL,VALUE(5,1),DATA,SS_REF(5)
*VFILL,VALUE(5,2),DATA,SS(5)
*VFILL,VALUE(5,3),DATA,ABS(SS(5)/SS_REF(5))
*VFILL,VALUE(6,1),DATA,SS_REF(6)
*VFILL,VALUE(6,2),DATA,SS(6)
*VFILL,VALUE(6,3),DATA,1.0
/COM
/OUT,vm268,vrt
/COM,------------ vm268 RESULTS COMPARISON --------------
/COM,
```

```
/COM,STRETCH      |  TARGET   |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,3),VALUE(3,1),VALUE(3,2),VALUE(3,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,4),VALUE(4,1),VALUE(4,2),VALUE(4,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,5),VALUE(5,1),VALUE(5,2),VALUE(5,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,LABEL(1,6),VALUE(6,1),VALUE(6,2),VALUE(6,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM-------------------------------------------------------
/OUT
FINISH
*LIST,vm268,vrt
```

VM269 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM269
/TITLE,VM269, DEFORMATION OF TUBE AND SPHERE UNDER AXISYMMETRIC BOUNDARY CONDITIONS
/COM, REFERENCE: "Z.YOSIBASH, AXISYMMETRIC PRESSURE BOUNDARY LOADING FOR FINITE DEFORMATION
/COM,            ANALYSIS USING P-FEM, COMPUT. METHODS APPL. MECH. ENGRG., 196(2007)
/COM,            :1261-1277"
/COM,
/COM, *****TUBE***********
/PREP7
AA=1
A=1+1
K=2e3                ! BULK MODULUS
C10=0.5
MUA=2*C10

TB,HYPER,1,,,NEO     ! NEO-HOOKEAN
TBDATA,1,MUA         !
TBDATA,2,2/K         ! D=2/K

RECTNG,1,2,0,1
ET,1,PLANE182
KEYOPT,1,3,1         ! AXISYMMETRIC
MAT,1
ESIZE,0.2
AMESH,1

D,ALL,UY,0.          ! NO DEFORMATION IN VERTICAL DIRECTION
ALLSEL
*GET,NN,NODE,0,COUNT
*DO,I,1,NN
  NSEL,S,NODE,,I
  D,ALL,UX,AA*NX(I)  ! LINEAR DEFORMATION IN RADIAL DIRECTION
*ENDDO
ALLSEL
FINISH

/SOL
ANTYPE,0
NLGEOM,ON
NSUBST,20,1000,5
OUTRES,ALL,ALL
SOLVE
FINISH

/POST1
*GET,SXX,NODE,NODE(2,1,0),S,X
*GET,SYY,NODE,NODE(2,1,0),S,Y
```

```
/OUT,
/COM, EXPECTED FROM REFERENCE PAPER
SRR_REF=(A*A-1)*(K+2*C10/3/A**(10/3))
SZZ_REF=(A*A-1)*(K-4*C10/3/A**(10/3))
SRR_ANSYS=SXX
SZZ_ANSYS=SYY
SAVE,TABLE_1
FINISH
/CLEAR,NOSTART
/COM, ********** SPHERE **********
/PREP7
AA=1
A=1+AA
K=2e3                ! BULK MODULUS
C10=0.5
MUA=2*C10

TB,HYPER,1,,,NEO     ! NEO-HOOKEAN
TBDATA,1,MUA         !
TBDATA,2,2/K         ! D=2/K

SPH4,0,0,0.01,0.03
VSBW,1
VDELE,3
CSYS,0
WPLANE,,,,,,1,,,,1
VSBW,2
VDELE,1
WPLANE,,,,,,,1,1,,
VSBW,3
VDELE,1

ET,1,SOLID185
MAT,1
VMESH,ALL
CSYS,2
NROTAT,ALL

*GET,NN,NODE,0,COUNT
*DO,I,1,NN
  NSEL,S,NODE,,I
  D,ALL,UX,AA*NX(I)   ! LINEAR DEFORMATION IN RADIAL DIRECTION
  D,ALL,UY,0
  D,ALL,UZ,0
*ENDDO
ALLSEL
FINISH

/SOL
ANTYPE,0
NLGEOM,ON
NSUBST,20,1000,5
OUTRES,ALL,ALL
SOLVE
FINISH

/POST1
*GET,SXX_S,NODE,NODE(-0.03,0,0),S,X
/OUT
/COM, EXPECTED FROM REFERENCE PAPER
SRR_S_REF=(A*A*A-1)*K
SRR_S_ANSYS=SXX_S
SAVE,TABLE_2
FINI
/OUT,SCRATCH
RESUME,TABLE_1
/COM
/OUT,vm269,vrt
/COM,------------ vm269 RESULTS COMPARISON -------------------
/COM,
/COM,    |  TARGET   |   Mechanical APDL  |   RATIO
/COM,
```

```
/COM, ================
/COM,   TUBE MODEL
/COM, ================
*VWRITE,'S_RR',SRR_REF,SRR_ANSYS,SRR_ANSYS/SRR_REF
(1X,A3,' ',F10.4,'  ',F14.4,'   ',F15.3)
*VWRITE,'S_ZZ',SZZ_REF,SZZ_ANSYS,SZZ_ANSYS/SZZ_REF
(1X,A3,' ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM,
/NOPR,
RESUME,TABLE_2
/GOPR,
/COM,
/COM,
/COM, ===============
/COM,  SPHERE MODEL
/COM, ===============
*VWRITE, 'S_RR',SRR_S_REF,SRR_S_ANSYS,SRR_S_ANSYS/SRR_S_REF
(1X,A3,' ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm269,vrt
```

VM270 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM270
/TITLE, VM270, FORCES IN PERMANENT MAGNETS (TEAM WORKSHOP PROBLEM 23)
/COM,   REFEENCE: " N.IDA, J.P.A.BASTOS, FORCES IN PERMANENT MAGNETS, TEAM
/COM,             WORKSHOP PROBLEM 23, PROCEEDINGS OF THE TEAM WORKSHOP IN
/COM,   THE SIXTH ROUND, OKAYAMA, PP.49-56.
/COM,
/OUT,SCRATCH
/PREP7
! DIMENSIONS AND PARAMETERS
MM = 0.001
PI = ACOS(-1)

! CONFIGURATION A
! SAMARIUM-COBALT MAGNET AND LARGER COIL ! ELECTROMAGNET ! LARGER COIL

D1 = 3.048*MM              ! SPOOL INNER DIAMETER
R_1=D1/2                   ! SPOOL INNER RADIUS
D2 = 3.9624*MM             ! SPOOL OUTER DIAMETER
R_2=D2/2                   ! SPOOL OUTER RADIUS
L_1 = 1.524*MM             ! INNER LENGTH
SE = 0.127*MM              ! SPOOL END THICKNESS
DEL = 0.234*MM             ! AXIAL DISPLACEMENT
N = 280                    ! NUMBER OF TURNS
R = 57                     ! COIL RESISTANCE / OHM
I = 0.050                  ! COIL CURRENT / A
AC = (R_2-R_1)*L_1         ! COIL AREA / M^2
JS = N*I/AC                ! CURRENT DENSITY
SD = SE + DEL

! PERMANENT MAGNET
! SAMARIUM-COBALT

D3 = 2.9972*MM             ! DIAMETER OF LARGE MAGNET
R_3=D3/2                   ! RADIUS OF LARGE MAGNET
L_3 = 1.6*MM               ! LENGTH
BR = 1.02                  ! REMANENCE / T
HC = 720000                ! COERCIVITY / A/M
MU0 = 4*PI*1E-7            ! FREE-SPACE PERMEABILITY / H/M

! SOLID MODEL
```

```
! PERMANENT MAGNET

RECT,0,R_3,0,L_3
RECT,0,R_3,-0.25*MM,0
RECT,R_3,R_2,-0.25*MM,0
RECT,R_3,R_2,0,L_3
RECT,0,R_3,L_3,L_3+0.25*MM
RECT,R_3,R_2,L_3,L_3+0.25*MM
RECT,0,R_3,L_3+0.25*MM,L_3+SD
RECT,R_3,R_2,L_3+0.25*MM,L_3+SD

! CONDUCTOR
RECT,0,R_1,L_3+SD,L_3+SD+L_1
RECT,R_1,R_2,L_3+SD,L_3+SD+L_1
NUMMRG,KP

WPOFF,,L_3/3
PCIRC,,10*MM,-90,90
PCIRC,,15*MM,-90,90
AOVLAP,ALL
NUMCMP,AREA

! FEM MODEL
! ELEMENT TYPES

ET,1,PLANE233,0,0,1      ! 2-D MAGNETIC (AZ) AXISYMMETRIC SOLID
KEYOP,1,7,1              ! CONDENCE FMAG FORCES TO ELEMENT CORNER NODES
ET,2,110,,1,1            ! INFIN BOUNDARY

! MATERIALS

! AIR
MP, MURX, 1, 1

! COPPER
MP, MURX, 2, 1

!SAMARIUM-COBALT
MP, MURX, 3, BR/(HC*MU0)
MP, MGYY, 3, HC

!INFIN ELEMENTS
MP,MURX,4,1

! AREA ATTRIBUTES
! PERMANENT MAGNET
ASEL,S,AREA,,9
AATT,3,,1

! COPPER COIL
ASEL,S,AREA,,8
AATT,2,,1

! AIR
ALLSEL
ASEL,U,,,7,9
AATT,1,,1
ASEL,S,,,7
AATT,4,,2
ALLSEL


! MESHING

MSHAPE,0,2D
MSHKEY,2
ESIZE,.125*MM
ASEL,U,,,7
ASEL,U,,,12
AMESH,ALL
ASEL,ALL
```

```
ESIZE,.25*MM
LSEL,S,,,24,25
LESIZE,ALL,,,1
LSEL,ALL
AMESH,7

ESIZE,0.25*MM
AMESH,12

LSEL,S,,,16
NSLL,S,1
SF,ALL,INF,1
ALLSEL

! BOUNDARY CONDITIONS
! CONSTRAIN MAGNETIC VECTOR POTENTIAL ON SIDES OF AIR BOX

CSYS,0
NSEL,S,LOC,X,0
D, ALL, AZ, 0
ALLSEL

! APPLY CURRENT TO COIL

ESEL, S, MAT, , 2
BFE, ALL, JS, 1,,, JS
ALLSEL

ESEL,S,MAT,,2
CM,COND,ELEM

ESEL,S,MAT,,3
CM,MAGNET,ELEM
ESEL,ALL
ALLSEL,ALL
FINISH

/OUT,
! *** SOLVE WITH MAXWELL FORCE OPTION
/SOLU
ANTYPE, STATIC
SOLVE
FINISH

/OUT,SCRATCH
/POST1
ESEL,S,MAT,,3
NSLE
ESLN
EMFT               ! SUM UP FMAG FORCES ACTING ON THE PERMANENT MAGNET
ALLSEL,ALL
FY_TAR1=1.150*9.81E-3  ! TARGET (MEASURED) FORCE FY
FY_OBT1 = _FYSUM   ! FORCE OBTAINED FROM MECHANICAL APDL
FINISH

/OUT,
! *** SOLVE WITH LORENTZ FORCE OPTION
/PREP7
KEYOPT,1,7,0
KEYOP,1,8,1    ! ELECTROMAGNETIC FORCE CALCULATION USING LORENTZ
FINISH

/SOLU
ANTYPE,STATIC
SOLVE
FINISH

/OUT,SCRATCH
/POST1
ESEL,S,MAT,,2
NSLE
EMFT               ! SUM UP FMAG FORCES ACTING ON THE COIL
```

```
ALLS
FY_TAR2=-1.150*9.81E-3  ! TARGET (MEASURED) FORCE FY
FY_OBT2 = _FYSUM   ! FORCE OBTAINED FROM MECHANICAL APDL
PLF2D                       ! PLOT FLUX LINES IN THE MODEL

*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,2,3

LABEL(1,1) = 'F_MAX'
LABEL(1,2) = 'F_LOR'
*VFILL,VALUE(1,1),DATA,FY_TAR1
*VFILL,VALUE(1,2),DATA,FY_OBT1
*VFILL,VALUE(1,3),DATA,ABS(FY_OBT1/FY_TAR1)
*VFILL,VALUE(2,1),DATA,FY_TAR2
*VFILL,VALUE(2,2),DATA,FY_OBT2
*VFILL,VALUE(2,3),DATA,ABS(FY_OBT2/FY_TAR2)
SAVE,TABLE_1
FINISH
RESUME,TABLE_1
/COM,
/OUT,vm270,vrt
/COM,-----------------------VM270 RESULTS COMPARISON -----------------------
/COM,
/COM,    |  TARGET   |   Mechanical APDL  |   RATIO
/COM,
/COM, MAXWELL FORCE CALCULATION
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A3,' ',F10.4,'  ',F14.4,'   ',F17.3)
/COM,
/COM, LORENTZ FORCE CALCULATION
/COM,
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A3,' ',F10.4,'  ',F14.4,'   ',F17.3)
/COM,
/COM,-----------------------------------------------------------------------
/OUT
*LIST,vm270,vrt
FINISH
```

VM271 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM271
/TITLE,VM271,CONVECTION TREATMENT PROBLEM FOR A HOLLOW CYLINDER WITH FLUID FLOW
/COM, REFERENCE: " INTRODUCTION TO HEAT TRANSFER" - VEDAT S.ARPACI, AHMET SELAMET
/COM,    SHU-HSIN KAO, 2000,PG:90-100
/COM,
R1 = 0.01105    ! INNER RADIUS OF THE CYLINDER (M)
R2 = 0.02     ! OUTER RADIUS OF THE CYLINDER (M)
Z1 = 0
Z2 = 0.1
THETA1 = 0
THETA2 = 180
LENGTH = Z2-Z1    ! LENGTH OF THE FLUID ELEMENT (M)
DIAMETER = 2*R1    ! DIAMETER (M)
FILMAREA = ACOS(-1)*DIAMETER*LENGTH ! FILMAREA (M^2)
CROSSAREA = 0.25*ACOS(-1)*DIAMETER**2
FILM = 300     ! FILM COEFFICIENT FOR SURFACE ELEMENTS (W/M^2 C)
CP   = 0.5374    ! SPECIFIC HEAT FOR FLUID (J/KG C)
COND = 1.0E-16    ! THERMAL CONDUCTIVITY FOR FLUID (W/M C)
TINLET = 700    ! INLET TEMPERATURE (DEGREE)
TBULK  = 2000    ! BULK TEMPERATURE (DEGREE)
MDOT   = 0.002*60*60   ! MASS FLOW RATE FOR FLUID  (KG/SEC)
CPS = 1     ! SPECIFIC HEAT FOR CYLINDER (J/KG C)
CONDS = 10000    ! THERMAL CONDUCTIVITY FOR CYLINDER (W/M C)

/PREP7
```

```
ET,1,FLUID116
KEYOPT,1,1,1    ! TEMPERATURE DOF ONLY
KEYOPT,1,9,2    ! UPWIND DIFFERENCE SCHEME
R,1,DIAMETER,CROSSAREA   ! DIA FOR CONVECTION,CROSS SECTION AREA FOR CONDUCTION
MP,KXX,1,COND
MP,C,1,CP

ET,2,SURF152
KEYOPT,2,4,1    ! NO MIDSIDE NODES
KEYOPT,2,5,0
KEYOPT,2,8,2    ! CONVECTION

ET,3,SOLID70
MP,KXX,3,CONDS

K,1,0,0,Z1
K,2,0,0,Z2
L,1,2
LESIZE,1,,,3
TYPE,1
MAT,1
REAL,1
LMESH,ALL

*GET,DLEN1,NODE,1,LOC,Z
*GET,DLEN2,NODE,3,LOC,Z
*GET,DLEN3,NODE,4,LOC,Z
*GET,DLEN4,NODE,2,LOC,Z

CYLIND,R1,R2,Z1,Z2,THETA1,THETA2
CYLIND,R1,R2,Z1,Z2,THETA1+180,THETA2+180
VGLUE,1,2
MSHAP,TRIOPT,3D
LSEL,S,LINE,,2,4,2
LSEL,A,LINE,,7,9,2
LESIZE,ALL,,,3
LSEL,S,LINE,,10,13,1
LESIZE,ALL,,,18
LSEL,S,LINE,,6,8,2
LSEL,A,LINE,,28,29,1
LSEL,A,LINE,,3,5,2
LSEL,A,LINE,,26,27,1
LESIZE,ALL,,,24
TYPE,3
MAT,3
REAL,3
VMESH,ALL

CSYS,1
NSEL,S,LOC,X,R1
ESLN,S
TYPE,2
MAT,2
REAL,2
ESURF
KEYOPT,2,5,2    ! TWO NODES 5TH,6TH NODES
CSYS,0
ALLSEL,ALL

ESEL,S,TYPE,,1
CM,COM116,ELEM    ! COMPONENT WITH FLUID116 ELEMENTS
ESEL,S,TYPE,,2
CM,COM152,ELEM    ! COMPONENT WITH SURF152 ELEMENTS
ALLSEL,ALL
MSTOLE,1,'COM152','COM116'  ! MAP 152 TO 116 AND CREATE THE 5/6 NODES OF 152
ALLSEL,ALL

KSEL,S,,,1
NSLK,S
D,ALL,TEMP,TINLET    ! INLET TEMPERATURE
ALLSEL,ALL
```

```
ESEL,S,TYPE,,1
SFE,ALL,,HFLUX,,MDOT   ! MASS FLOW RATE FOR FLUID ELEMENT
ESEL,ALL

CSYS,1
NSEL,S,LOC,X,R2
D,ALL,TEMP,TBULK    ! BULK TEMPERATURE ON THE CYLINDER
CSYS,0
ALLSEL,ALL

ESEL,S,TYPE,,2
SFE,ALL,1,CONV,0,FILM   ! FILM COEFFICIENT FOR SURFACE ELEMENT
SFE,ALL,1,CONV,2,0   ! SET BULK TEMP
ESEL,ALL
EPLOT
FINISH

/SOLU
ANTYPE,STATIC    ! STEADY STATE ANALYSIS
OUTRES,ALL,ALL
SOLVE
SAVE
FINI

/POST1
SET,LAST
*GET,TEMP1,NODE,1,TEMP   ! TEMPERATURE AT NODE 1 OF FLUID116 ELEMENT
*GET,TEMP2,NODE,2,TEMP   ! TEMPERATURE AT NODE 2 OF FLUID116 ELEMENT
*GET,TEMP3,NODE,3,TEMP   ! TEMPERATURE AT NODE 3 OF FLUID116 ELEMENT
*GET,TEMP4,NODE,4,TEMP   ! TEMPERATURE AT NODE 4 OF FLUID116 ELEMENT

/OUT,SCRATCH
*DIM,LABEL,CHAR,1,4
*DIM,LEN,,1,4
*DIM,VALUE,,4,3

LABEL(1,1) = 'NODE1'
LABEL(1,2) = 'NODE3'
LABEL(1,3) = 'NODE4'
LABEL(1,4) = 'NODE2'



MODULUS = (FILM*ACOS(-1)*DIAMETER*LENGTH)/(MDOT*CP)

/COM, ANALYTICAL VALUES CALCULATED
/COM, USING EQUATION MENTIONED IN THE REFERENCE BOOK

POSITION1 = (DLEN1- DLEN1)/LENGTH
POSITION2 = (DLEN2- DLEN1)/LENGTH
POSITION3 = (DLEN3- DLEN1)/LENGTH
POSITION4 = (DLEN4- DLEN1)/LENGTH

ATEMP1 = (TINLET-TBULK)*EXP(-MODULUS*POSITION1)+TBULK
ATEMP2 = (TINLET-TBULK)*EXP(-MODULUS*POSITION2)+TBULK
ATEMP3 = (TINLET-TBULK)*EXP(-MODULUS*POSITION3)+TBULK
ATEMP4 = (TINLET-TBULK)*EXP(-MODULUS*POSITION4)+TBULK


*VFILL,LEN(1,1),DATA,POSITION1
*VFILL,LEN(1,2),DATA,POSITION2
*VFILL,LEN(1,3),DATA,POSITION3
*VFILL,LEN(1,4),DATA,POSITION4

*VFILL,VALUE(1,1),DATA,ATEMP1
*VFILL,VALUE(1,2),DATA,TEMP1
*VFILL,VALUE(1,3),DATA,ABS(ATEMP1/TEMP1)
*VFILL,VALUE(2,1),DATA,ATEMP2
*VFILL,VALUE(2,2),DATA,TEMP3
*VFILL,VALUE(2,3),DATA,ABS(ATEMP2/TEMP3)
*VFILL,VALUE(3,1),DATA,ATEMP3
*VFILL,VALUE(3,2),DATA,TEMP4
```

```
*VFILL,VALUE(3,3),DATA,ABS(ATEMP3/TEMP4)
*VFILL,VALUE(4,1),DATA,ATEMP4
*VFILL,VALUE(4,2),DATA,TEMP2
*VFILL,VALUE(4,3),DATA,ABS(ATEMP4/TEMP2)

SAVE,TABLE_1
FINISH
RESUME,TABLE_1
/COM,
/OUT,vm271,vrt
/COM,-----------------------VM271 RESULTS COMPARISON -----------------------
/COM,
/COM,           LENGTH |  TARGET   |  Mechanical APDL |  RATIO
/COM,
/COM,
/COM, TEMPERATURE COMPUTED ON THE NODES OF FLUID116 ELEMENT
/COM, ARE COMPARED WITH ANALYTICAL VALUES
/COM,
*VWRITE,LABEL(1,1),LEN(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A5,'  ',F9.3,'  ',F10.3,'   ',F14.3,'   ',F15.3)
/COM,
*VWRITE,LABEL(1,2),LEN(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A5,'  ',F9.3,'  ',F10.3,'   ',F14.3,'   ',F15.3)
/COM,
*VWRITE,LABEL(1,3),LEN(1,3),VALUE(3,1),VALUE(3,2),VALUE(3,3)
(1X,A5,'  ',F9.3,'  ',F10.3,'   ',F14.3,'   ',F15.3)
/COM,
*VWRITE,LABEL(1,4),LEN(1,4),VALUE(4,1),VALUE(4,2),VALUE(4,3)
(1X,A5,'  ',F9.3,'  ',F10.3,'   ',F14.3,'   ',F15.3)
/COM,
/COM,-----------------------------------------------------------------------
/OUT
*LIST,vm271,vrt
FINISH
```

VM272 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM272
/TITLE,VM272, TWO AND THREE DIMENSIONAL FRICTIONAL HERTZ CONTACT
/COM, REFERENCE: YANG, B., LAURSEN, T.A., MEGN, X. TWO DIMENSIONAL MORTAR CONTACT
/COM, METHODS FOR LARGE DEFORMATION FRICTIONAL SLIDING, IJNME VOL.62, PP 1183-1225.
/COM, (2005)
/COM, ANALYTICAL SOLUTION FROM REFERENCE:  JOHNSON KL, "CONTACT MECHANICS"
/COM, CAMBRIDGE UNIVERSITY PRESS: CAMBRIDGE, 1985.
/COM,
C***  USING 2D LOWER ORDER ELEMENTS
/PREP7
/NOPR
MP,EX,1,200.0    !YOUNG'S MODULUS (N/mm^2)
MP,NUXY,1,0.3    !POISSON'S RATIO
MP,MU,1,0.2    !COEFFICIENT OF FRICTION

ET,1,PLANE182   !2D STRUCTURAL SOLID
ET,2,PLANE182   !2D STRUCTURAL SOLID
KEYO,1,3,2    !PLANE STRAIN
KEYO,2,3,2    !PLANE STRAIN


PCIRC,8, ,0,90,     !CONTACT SIDE
PCIRC,8, ,90,180,      !CREATE SEMICIRCLES
RECT,0,1,7,8    !CREATE RECTANGLES
RECT,-1,0,7,8
WPOFF,0,16      !TARGET SIDE
PCIRC,8, ,180,270,     !CREATE SEMICIRCLES
PCIRC,8, ,270,360,
WPAVE,0,0,0
!*
```

```
RECT,0,1,8,9    !CREATE RECTANGLES
RECT,-1,0,8,9

AOVLAP,1,3    !COMBINES THE AREAS
AOVLAP,2,4
AOVLAP,6,7
AOVLAP,5,8

ASEL,S,,,1,2    !DELETES EXCESS GEOMETIES
ASEL,A,,,6,9,3
ALLSEL,BELOW,AREA
ADEL,ALL
LSEL,U,,,2,6,4
LSEL,U,,,20,30,10
LDEL,ALL
KSEL,U,,,2,4,2
KSEL,U,,,10,16,3
KSEL,U,,,18,21,3
KSEL,U,,,29
KDEL,ALL

ALLSEL

AGLUE,3,10,11,12   !MERGES EXISTING AREAS

AGLUE,4,7,13,14

K,2,4     !CREATES POINTS AND AREAS
K,6,-4       !TO DIVIDE THE GEOMETRY
K,7,4,16     !AND MESH IT EXACTLY AS NEEDED
K,9,-4,16

A,3,2,8,12
A,7,20,24,23
A,20,9,28,24
A,11,6,3,12

APTN,2,7    !PARTITIONS OVERLAPPING AREAS
APTN,9,13    !INTO SEPERATE ENTIITES
APTN,8,10
APTN,5,11

AGLUE,1,3,7,8,11,12

AGLUE,2,4,6,9,10,13

LESI,27,,,8    !SETS NUMBER OF ELEMENTS
LESI,33,,,8    !ALONG EACH LINE
LESI,9,,,8
LESI,10,,,8
LESI,15,,,8

LESI,34,,,16
LESI,17,,,16
LESI,8,,,16
LESI,25,,,16
LESI,36,,,16

LESI,16,,,18
LESI,4,,,18
LESI,26,,,18
LESI,11,,,18
LESI,1,,,18
LESI,2,,,18

LESI,3,,,10
LESI,13,,,10
LESI,14,,,10
LESI,24,,,10
LESI,19,,,10

LESI,38,,,20
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LESI,20,,,20
LESI,39,,,20
LESI,22,,,20
LESI,40,,,20

LESI,18,,,40
LESI,23,,,40
LESI,21,,,40
LESI,7,,,40
LESI,5,,,40
LESI,6,,,40

MSHAPE,0,2D     !MESH TYPE IS SELECTED
MSHKEY,1

/OUT,SCRATCH
TYPE,1     !BOTTOM IS MESHED WITH TYPE 1
AMESH,1
AMESH,3
AMESH,12
AMESH,8
AMESH,7
AMESH,11

TYPE,2     !TOP IS MESHED WITH TYPE 2
AMESH,4
AMESH,6
AMESH,2
AMESH,9
AMESH,10
AMESH,13

ET,3,CONTA171    !2D 2-NODE SURFACE SURFACE CONTACT
KEYO,3,4,3    !DETECTION BY MORTAR
KEYO,3,10,2    !CONTACT STIFFNESS BY STRESS

ET,4,TARGE169    !TARGET ELEMENTS
LSEL,S,,,5,6,1    !CHOOSE LOCATION FOR CONTACT
NSLL,S,1
ESLN,S

TYPE,3     !MESH WITH CONTACT ELEMENTS
REAL,3
ESURF

TYPE,4     !CHOOSE LOCATION FOR TARGET
LSEL,S,,,1,2,1
NSLL,S,1
ESLN,S

ESURF     !MESH WITH TARGET ELEMENTS

ET,5,SURF153    !2D SURFACE EFFECT ELEMENTS

LSEL,S,,,3    !PICK THE TOP OF THE MODEL
LSEL,A,,,18,19
LSEL,A,,,21
NSLL,S,1
ESLN,S
TYPE,5
REAL,5
ESURF      !ADD SURFACE ELEMENTS

ET,10,CONTA171    !2D 2-NODE SURFACE SURFACE CONTACT ELEMENT
KEYOP,10,2,2    !CONTACT STIFFNESS BY STRESS
KEYOP,10,4,2    !DETECTION BY TARGET NORMAL
KEYOP,10,12,5    !ALWAYS BONDED
LSEL,S,,,3     !PICK THE TOP OF THE MODEL
LSEL,A,,,18,19
LSEL,A,,,21
NSLL,S,1
ESLN,S
```

```
TYPE,10
REAL,10
ESURF      !MESH WITH CONTACT ELEMENTS
N,100000,,16    !ADD A PILOT NODE
ET,11,TARGE169,,1    !TARGET ELEMENTS FOR PILOT
TYPE,11
TSHAP,PILOT
E,100000    !MAKE THE PILOT ELEMENT
D,100000,ROTZ,0    !SET BOUNDARY CONDITIONS
ALLSE

NSEL,S,LOC,Y
D,ALL,ALL
ALLSEL
/GOLIST
R,3
!!! using auto damping
!RMOD,3,11,-0.001    !CONTACT DAMPING IN FIRST STEP
     !DO NOT ALLOW MUCH ELASTIC SLIP
FINISH

/SOLU
OUTRES,ALL,ALL    !SOLUTION OPTIONS
NSUB,250,2500,15
ESEL,S,ENAME,,SURF153
SFE,ALL,1,PRES,1,0.625    !SMALL AXIAL PRESSURE LOAD
ALLSEL
CNVTOL,U,,0.0001
CNVTOL,F,,0.0001
NROP,UNSYM
NLGEOM,ON    !LARGE DEFLECTION
SOLVE     !SOLVE FIRST LOADSTEP
NSUB,6,100,6
ESEL,S,ENAME,,153
SFE,ALL,2,PRES,1,-0.05851  !SMALL TANGENTIAL LOAD
ALLSEL
!RMOD,3,11,-1E-8    !ALLOW VERY LITTLE DAMPING
SOLVE
FINISH
/POST1
SET,LAST
PI=ACOS(-1)    !PARAMS FOR ANALYTIC SOLUTION
P=10     !CALCULATED BELOW
R=8
V=0.3
E=200
U=0.2
Q=0.93622
B=2*SQRT(P*R*((1-V**2)/(PI*E))) !MAXIMUM X-LOCATION OF CONTACT
SNMAX=SQRT((P*E)/(PI*(1-V**2)*R)) !MAXIMUM CONTACT PRESSURE
C=B*SQRT(1-(Q/(U*P)))   !LOCATION OF STICK-SLIP BOUNDARY


ESEL,S,TYPE,,3    !PICK THE IMPORTANT CONTACT ELEMENTS
NSEL,S,LOC,X,0,B    !AND NODES
ESLN,R
NSLE
NSEL,U,LOC,X,-0.1,-0.001
ESLN,R,1
ETAB,PRES_I,SMISC,1   !TABULATE THE PRESSURE AND FRICTION RESULTS
ETAB,FRIC_I,SMISC,3   !AT LEFT NODE OF ALL ELEMENTS FOR USE BELOW
ETAB,CSTAT,NMISC,1


*GET,NUMNODE1,NODE,,COUNT   !GET THE NUMBER OF NODES IN SELECTION
X=NUMNODE1      !STORE THIS NUMBER
*DIM,LOCARRAY1,ARRAY,NUMNODE1+1,2  !MAKE AN ARRAY FOR NODE NUMBER AND X LOC
*GET,NODENUM,NODE,,NUM,MIN   !GET FIRST NODE NUMBER

*DO,I,1,X    !LOOP THROUGH SELECTION TO FILL ARRAY
   LOCARRAY1(I,1)=NX(NODENUM)  !X LOCATIONS
   LOCARRAY1(I,2)=NODENUM  !NODE NUMBER
```

```
   *GET,NODENUM,NODE,NODENUM,NXTH !GET THE NEXT NODE NUMBER
*ENDDO     !REPEAT

LOCARRAY1(NUMNODE1+1,1)=B   !ADD AN ENTRY FOR THEORETICAL MAX CONTA
LOCARRAY1(NUMNODE1+1,2)=0

*GET,NUMELEM1,ELEM,,COUNT  !GET THE NUMBER OF ELEMENTS IN SELECTION
*DIM,RES1,ARRAY,NUMELEM1+1,6  !MAKE AN ARRAY FOR ALL RESULTS NEEDED
*GET,ELEMNUM,ELEM,,NUM,MIN  !GET FIRST ELEMENT NUMBER

*DO,K,1,NUMELEM1     !LOOP THROUGH ELEMENTS IN SELECTION
   *GET,RES1(K,1),ELEM,ELEMNUM,NODE,1 !FILL ARRAY WITH NODE NUMBER
   *GET,RES1(K,2),ETAB,1,ELEM,ELEMNUM !FILL ARRAY WITH TABULATED RESULT: PRES
   *GET,RES1(K,3),ETAB,2,ELEM,ELEMNUM !FILL ARRAY WITH TABULATED RESULT: FRIC
   *GET,RES1(K,4),ETAB,3,ELEM,ELEMNUM !FILL ARRAY WITH TABULATED RESULT: STAT

   *GET,ELEMNUM,ELEM,ELEMNUM,NXTH !GET THE NEXT ELEMENT NUMBER
*ENDDO     !REPEAT

RES1(NUMELEM1+1,1)=0   !ADD AN ENTRY FOR THEORETICAL MAX CONTA
RES1(NUMELEM1+1,2)=0
RES1(NUMELEM1+1,3)=0
RES1(NUMELEM1+1,4)=0

J=1
*DOWHILE,J    !BUBBLE SORT OF NODES TO MATCH ELEMENT
   J=0     !RESULTS WITH NODE NUMBERS AND
   *DO,I,1,X    !ORDER THE ARRAY BY X LOCATION
      VAR1=LOCARRAY1(I,1)
      VAR2=LOCARRAY1(I+1,1)
      *IF,VAR1,GT,VAR2,THEN
         TEMP1=LOCARRAY1(I,1)
         LOCARRAY1(I,1)=LOCARRAY1(I+1,1)
         LOCARRAY1(I+1,1)=TEMP1
         TEMP2=LOCARRAY1(I,2)
         LOCARRAY1(I,2)=LOCARRAY1(I+1,2)
         LOCARRAY1(I+1,2)=TEMP2
         J=1
      *ENDIF
   *ENDDO
*ENDDO

     !CALCULATE ANALYTICAL SOLUTION FOR PRESSURE
*DO,I,1,NUMELEM1+1   !AND FRICTION RELATIONSHIP WITH X LOCATION

   LOCX=LOCARRAY1(I,1)   !LOOP THROUGH ALL NODES
   *IF,LOCX,LT,B,THEN   !IF(1) NODE IS WITHIN CONTACT RANGE
           !EQUATION FOR PRESSURE
      RES1(I,5)=SNMAX*SQRT(1-(((LOCARRAY1(I,1))/B)**2))
      *IF,LOCX,LT,C,THEN  !IF(2) NODE IS WITHIN STICK RANGE
           !EQUATION FOR FRICTION
         RES1(I,6)=(U*SNMAX/B)*(SQRT(B**2-LOCX**2)-SQRT(C**2-LOCX**2))

      *ELSE    !ELSE(2) NODE IS WITHIN SLIDE RANGE
           !EQUATION FOR FRICTION
         RES1(I,6)=U*RES1(I,5)

      *ENDIF
   *ELSE    !ELSE(1) ASSIGN AS ZERO TO AVIOD DIVIDING
      RES1(I,5)=0   !BY ZERO
      RES1(I,6)=0
   *ENDIF
*ENDDO

PARSAV,ALL,vm272-1,parm

*DIM,LABEL1,,7    !CONTACT PRESSURE LISTING
*DIM,VALUE1,,7,3
J=1
*DO,I,1,NUMELEM1,4
  LABEL1(J)=LOCARRAY1(I,1)
  VALUE1(J,1)=RES1(I,5)
```

```
  VALUE1(J,2)=RES1(I,2)
  ZERO1=RES1(I,5)
  ZERO2=RES1(I,2)
  *IF,ZERO1,EQ,0,AND,ZERO2,EQ,0,THEN
     VALUE1(J,3)=1
  *ELSEIF,ZERO1,EQ,0,AND,ZERO2,NE,0,THEN
     VALUE1(J,3)=0
  *ELSE
     VALUE1(J,3)=ABS(RES1(I,2)/RES1(I,5))
  *ENDIF
  J=J+1
*ENDDO

*DIM,LABEL2,,7   !CONTACT FRICTION LISTING
*DIM,VALUE2,,7,3
J=1
*DO,I,1,NUMELEM1,4
  LABEL2(J)=LOCARRAY1(I,1)
  VALUE2(J,1)=RES1(I,6)
  VALUE2(J,2)=RES1(I,3)
  ZERO1=RES1(I,6)
  ZERO2=RES1(I,3)
  *IF,ZERO1,EQ,0,AND,ZERO2,EQ,0,THEN
     VALUE2(J,3)=1
  *ELSEIF,ZERO1,EQ,0,AND,ZERO2,NE,0,THEN
     VALUE2(J,3)=0
  *ELSE
     VALUE2(J,3)=ABS(RES1(I,3)/RES1(I,6))
  *ENDIF
  J=J+1
*ENDDO

/COM,
/OUT,vm272,vrt
/COM,----------------- VM272 RESULTS COMPARISON -------------------
/COM,
/COM,
/COM,2D LOW PRES   |  TARGET   |  Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(6X,F5.3,6X,' ',F6.4,6X,'  ',F6.4,6X,'  ',F5.3)
/COM,
/COM,
/COM,----------------- VM272 RESULTS COMPARISON -------------------
/COM,
/COM,
/COM,2D LOW FRIC   |  TARGET   |  Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL2(1),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(6X,F5.3,6X,' ',F6.4,6X,'  ',F6.4,6X,'  ',F5.3)
/COM,
/OUT,
FINI
/CLEAR,NOSTART

/OUT,
C***  USING 3D LOWER ORDER ELEMENTS
/PREP7
/NOPR
MP,EX,1,200.0    !YOUNG'S MODULUS (N/mm^2)
MP,NUXY,1,0.3    !POISSON'S RATIO
MP,MU,1,0.2    !COEFFICIENT OF FRICTION

ET,1,SOLID185    !3D STRUCTURAL SOLID
ET,2,SOLID185    !3D STRUCTURAL SOLID


PCIRC,8, ,0,90,    !CONTACT SIDE
PCIRC,8, ,90,180,      !CREATE SEMICIRCLES
RECT,0,1,7,8    !CREATE RECTANGLES
RECT,-1,0,7,8
WPOFF,0,16      !TARGET SIDE
```

```
PCIRC,8, ,180,270,     !CREATE SEMICIRCLES
PCIRC,8, ,270,360,
WPAVE,0,0,0
!*
RECT,0,1,8,9    !CREATE RECTANGLES
RECT,-1,0,8,9

AOVLAP,1,3    !COMBINES THE AREAS
AOVLAP,2,4
AOVLAP,6,7
AOVLAP,5,8

ASEL,S,,,1,2    !DELETES EXCESS GEOMETIES
ASEL,A,,,6,9,3
ALLSEL,BELOW,AREA
ADEL,ALL
LSEL,U,,,2,6,4
LSEL,U,,,20,30,10
LDEL,ALL
KSEL,U,,,2,4,2
KSEL,U,,,10,16,3
KSEL,U,,,18,21,3
KSEL,U,,,29
KDEL,ALL

ALLSEL

AGLUE,3,10,11,12   !MERGES EXISTING AREAS

AGLUE,4,7,13,14

K,2,4     !CREATES POINTS AND AREAS
K,6,-4       !TO DIVIDE THE GEOMETRY
K,7,4,16     !AND MESH IT EXACTLY AS NEEDED
K,9,-4,16

A,3,2,8,12
A,7,20,24,23
A,20,9,28,24
A,11,6,3,12

APTN,2,7    !PARTITIONS OVERLAPPING AREAS
APTN,9,13    !INTO SEPERATE ENTIITES
APTN,8,10
APTN,5,11

AGLUE,1,3,7,8,11,12

AGLUE,2,4,6,9,10,13

LESI,27,,,8    !SETS NUMBER OF ELEMENTS
LESI,33,,,8    !ALONG EACH LINE
LESI,9,,,8
LESI,10,,,8
LESI,15,,,8

LESI,34,,,16
LESI,17,,,16
LESI,8,,,16
LESI,25,,,16
LESI,36,,,16

LESI,16,,,18
LESI,4,,,18
LESI,26,,,18
LESI,11,,,18
LESI,1,,,18
LESI,2,,,18

LESI,3,,,10
LESI,13,,,10
LESI,14,,,10
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LESI,24,,,10
LESI,19,,,10

LESI,38,,,20
LESI,20,,,20
LESI,39,,,20
LESI,22,,,20
LESI,40,,,20

LESI,18,,,40
LESI,23,,,40
LESI,21,,,40
LESI,7,,,40
LESI,5,,,40
LESI,6,,,40

K,30,0,0 ,0
K,31,0,0 ,1
K,32,0,16,0
K,33,0,16,1
L,30,31,1
L,32,33,1
VDRAG,1,3,12,8,7,11,12   !DRAGS THE BOTTOM INTO A VOLUME
VDRAG,4,6,2,9,10,13,28


MSHAPE,0,3D     !MESH TYPE IS SELECTED
MSHKEY,1


/OUT,SCRATCH
TYPE,1     !BOTTOM IS MESHED WITH TYPE 1
VMESH,1
VMESH,2
VMESH,3
VMESH,4
VMESH,5
VMESH,6

TYPE,2     !TOP IS MESHED WITH TYPE 2
VMESH,7
VMESH,8
VMESH,9
VMESH,10
VMESH,11
VMESH,12

ET,3,CONTA173    !3D 4-NODE SURFACE SURFACE CONTACT
KEYO,3,4,3    !DETECTION BY MORTAR
KEYO,3,10,2    !CONTACT STIFFNESS BY STRESS

ET,4,TARGE170    !TARGET ELEMENTS
ASEL,S,,,35,41,6
NSLA,S,1
ESLN,S

TYPE,3     !MESH WITH CONTACT ELEMENTS
REAL,3
ESURF

TYPE,4     !CHOOSE LOCATION FOR TARGET
ASEL,S,,,14,18,4
NSLA,S,1
ESLN,S
ESURF     !MESH WITH TARGET ELEMENTS

ET,5,SURF154    !3D SURFACE EFFECT ELEMENTS

ASEL,S,,,51,55,4   !PICK THE TOP OF THE MODEL
ASEL,A,,,45,48,3
NSLA,S,1
ESLN,S
```

```
TYPE,5
REAL,5
ESURF     !ADD SURFACE ELEMENTS

ET,10,CONTA173    !3D 4-NODE SURFACE SURFACE CONTACT ELEMENT
KEYOP,10,2,2    !CONTACT STIFFNESS BY STRESS
KEYOP,10,4,2    !DETECTION BY TARGET NORMAL
KEYOP,10,12,5    !ALWAYS BONDED
ASEL,S,,,51,55,4   !PICK THE TOP OF THE MODEL
ASEL,A,,,45,48,3
NSLA,S,1
ESLN,S
TYPE,10
REAL,10
ESURF     !MESH WITH CONTACT ELEMENTS
N,100000,,16    !ADD A PILOT NODE
ET,11,TARGE170,,1    !TARGET ELEMENTS FOR PILOT
TYPE,11
TSHAP,PILOT
E,100000     !MAKE THE PILOT ELEMENT
D,100000,ROTZ,0    !SET BOUNDARY CONDITIONS
ALLSE

NSEL,S,LOC,Y
D,ALL,ALL
ALLSEL
D,ALL,UZ
NSEL,S,LOC,Y,16
D,ALL,ROTX
D,ALL,ROTY

/GOLIST
R,3
!!! using auto damping
!RMOD,3,11,-0.001    !CONTACT DAMPING IN FIRST STEP
RMOD,3,23,1E-4
FINISH

/SOLU
OUTRES,ALL,ALL    !SOLUTION OPTIONS
NSUB,200,500,10
ESEL,S,ENAME,,154
SFE,ALL,1,PRES,1,0.625    !SMALL AXIAL PRESSURE LOAD
ALLSEL
CNVTOL,U,,0.0001
CNVTOL,F,,0.0001
NROP,UNSYM
NLGEOM,ON    !LARGE DEFLECTION
SOLVE     !SOLVE FIRST LOADSTEP
NSUB,4,10,1

NSEL,S,LOC,X,-4,-8
ESLN,S,1
ESEL,R,ENAME,,154
SFE,ALL,3,PRES,1,0.05851  !SMALL TANGENTIAL LOAD
NSEL,S,LOC,X,-4,8
ESLN,S,1
ESEL,R,ENAME,,154
SFE,ALL,3,PRES,1,-0.05851
ALLSEL
!!! using auto damping
!RMOD,3,11,-1E-8    !ALLOW VERY LITTLE DAMPING
SOLVE
FINISH

/POST1
SET,LAST
/OUT
PI=ACOS(-1)    !PARAMS FOR ANALYTIC SOLUTION
P=10     !CALCULATED BELOW
R=8
V=0.3
```

```
E=200
U=0.2
Q=0.93622
B=2*SQRT(P*R*((1-V**2)/(PI*E)))  !MAXIMUM X-LOCATION OF CONTACT
SNMAX=SQRT((P*E)/(PI*(1-V**2)*R)) !MAXIMUM CONTACT PRESSURE
C=B*SQRT(1-(Q/(U*P)))   !LOCATION OF STICK-SLIP BOUNDARY


ESEL,S,TYPE,,3    !PICK THE IMPORTANT CONTACT ELEMENTS
NSEL,S,LOC,X,0,B   !AND NODES
ESLN,R
ESEL,U,ELEM,,4000
NSLE,S
NSEL,R,LOC,Z,1
ETAB,PRES_I,SMISC,1   !TABULATE THE PRESSURE AND FRICTION RESULTS
ETAB,TAUR_I,SMISC,5   !AT LEFT NODE OF ALL ELEMENTS FOR USE BELOW
ETAB,TAUS_I,SMISC,9
ETAB,CSTAT,NMISC,1


*GET,NUMNODE2,NODE,,COUNT  !GET THE NUMBER OF NODES IN SELECTION
X=NUMNODE2    !STORE THIS NUMBER
*DIM,LOCARRAY2,ARRAY,NUMNODE2+1,2  !MAKE AN ARRAY FOR NODE NUMBER AND X LOC
*GET,NODENUM,NODE,,NUM,MIN  !GET FIRST NODE NUMBER

*DO,I,1,X    !LOOP THROUGH SELECTION TO FILL ARRAY
   LOCARRAY2(I,1)=NX(NODENUM)  !X LOCATIONS
   LOCARRAY2(I,2)=NODENUM  !NODE NUMBER
   *GET,NODENUM,NODE,NODENUM,NXTH !GET THE NEXT NODE NUMBER
*ENDDO     !REPEAT

LOCARRAY2(NUMNODE2+1,1)=B   !ADD AN ENTRY FOR THEORETICAL MAX CONTA
LOCARRAY2(NUMNODE2+1,2)=0

*GET,NUMELEM2,ELEM,,COUNT  !GET THE NUMBER OF ELEMENTS IN SELECTION
*DIM,RES2,ARRAY,NUMELEM2+1,6  !MAKE AN ARRAY FOR ALL RESULTS NEEDED
*GET,ELEMNUM,ELEM,,NUM,MIN  !GET FIRST ELEMENT NUMBER

*DO,K,1,NUMELEM2    !LOOP THROUGH ELEMENTS IN SELECTION
   *GET,RES2(K,1),ELEM,ELEMNUM,NODE,1 !FILL ARRAY WITH NODE NUMBER
   *GET,RES2(K,2),ETAB,1,ELEM,ELEMNUM !FILL ARRAY WITH TABULATED RESULT: PRES
   *GET,TAUS,ETAB,2,ELEM,ELEMNUM !FILL ARRAY WITH TABULATED RESULT: FRIC
   *GET,TAUR,ETAB,3,ELEM,ELEMNUM
   RES2(K,3)=SQRT(TAUR**2+TAUS**2)
   *GET,RES2(K,4),ETAB,4,ELEM,ELEMNUM !FILL ARRAY WITH TABULATED RESULT: STAT

   *GET,ELEMNUM,ELEM,ELEMNUM,NXTH !GET THE NEXT ELEMENT NUMBER
*ENDDO     !REPEAT

RES2(NUMELEM2+1,1)=0   !ADD AN ENTRY FOR THEORETICAL MAX CONTA
RES2(NUMELEM2+1,2)=0
RES2(NUMELEM2+1,3)=0
RES2(NUMELEM2+1,4)=0

J=1
*DOWHILE,J    !BUBBLE SORT OF NODES TO MATCH ELEMENT
   J=0     !RESULTS WITH NODE NUMBERS AND
   *DO,I,1,X    !ORDER THE ARRAY BY X LOCATION
      VAR1=LOCARRAY2(I,1)
      VAR2=LOCARRAY2(I+1,1)
      *IF,VAR1,GT,VAR2,THEN
         TEMP1=LOCARRAY2(I,1)
         LOCARRAY2(I,1)=LOCARRAY2(I+1,1)
         LOCARRAY2(I+1,1)=TEMP1
         TEMP2=LOCARRAY2(I,2)
         LOCARRAY2(I,2)=LOCARRAY2(I+1,2)
         LOCARRAY2(I+1,2)=TEMP2
         J=1
      *ENDIF
   *ENDDO
*ENDDO
```

```
    !CALCULATE ANALYTICAL SOLUTION FOR PRESSURE
*DO,I,1,NUMELEM2+1   !AND FRICTION RELATIONSHIP WITH X LOCATION

   LOCX=LOCARRAY2(I,1)   !LOOP THROUGH ALL NODES
   *IF,LOCX,LT,B,THEN   !IF(1) NODE IS WITHIN CONTACT RANGE
           !EQUATION FOR PRESSURE
      RES2(I,5)=SNMAX*SQRT(1-(((LOCARRAY2(I,1))/B)**2))
      *IF,LOCX,LT,C,THEN  !IF(2) NODE IS WITHIN STICK RANGE
           !EQUATION FOR FRICTION
         RES2(I,6)=(U*SNMAX/B)*(SQRT(B**2-LOCX**2)-SQRT(C**2-LOCX**2))

      *ELSE    !ELSE(2) NODE IS WITHIN SLIDE RANGE
           !EQUATION FOR FRICTION
         RES2(I,6)=U*RES2(I,5)

      *ENDIF
   *ELSE    !ELSE(1) ASSIGN AS ZERO TO AVIOD DIVIDING
      RES2(I,5)=0   !BY ZERO
      RES2(I,6)=0
   *ENDIF
*ENDDO

PARSAV,ALL,vm272-2,parm

*DIM,LABEL3,,7    !CONTACT PRESSURE LISTING
*DIM,VALUE3,,7,3
J=1
*DO,I,1,NUMELEM2,4
  LABEL3(J)=LOCARRAY2(I,1)
  VALUE3(J,1)=RES2(I,5)
  VALUE3(J,2)=RES2(I,2)
  ZERO1=RES2(I,5)
  ZERO2=RES2(I,2)
  *IF,ZERO1,EQ,0,AND,ZERO2,EQ,0,THEN
     VALUE3(J,3)=1
  *ELSEIF,ZERO1,EQ,0,AND,ZERO2,NE,0,THEN
     VALUE3(J,3)=0
  *ELSE
     VALUE3(J,3)=ABS(RES2(I,2)/RES2(I,5))
  *ENDIF
  J=J+1
*ENDDO

*DIM,LABEL4,,7   !CONTACT FRICTION LISTING
*DIM,VALUE4,,7,3
J=1
*DO,I,1,NUMELEM2,4
  LABEL4(J)=LOCARRAY2(I,1)
  VALUE4(J,1)=RES2(I,6)
  VALUE4(J,2)=RES2(I,3)
  ZERO1=RES2(I,6)
  ZERO2=RES2(I,3)
  *IF,ZERO1,EQ,0,AND,ZERO2,EQ,0,THEN
     VALUE4(J,3)=1
  *ELSEIF,ZERO1,EQ,0,AND,ZERO2,NE,0,THEN
     VALUE4(J,3)=0
  *ELSE
     VALUE4(J,3)=ABS(RES2(I,3)/RES2(I,6))
  *ENDIF
  J=J+1
*ENDDO

/COM,
/OUT,vm272,vrt,,APPEND
/COM,----------------- VM272 RESULTS COMPARISON -------------------
/COM,
/COM,
/COM,3D LOW PRES   |  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL3(1),VALUE3(1,1),VALUE3(1,2),VALUE3(1,3)
(6X,F5.3,6X,' ',F6.4,6X,'  ',F6.4,6X,'  ',F5.3)
/COM,
```

```
/COM,
/COM,----------------- VM272 RESULTS COMPARISON -------------------
/COM,
/COM,
/COM,3D LOW FRIC   |  TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL4(1),VALUE4(1,1),VALUE4(1,2),VALUE4(1,3)
(6X,F5.3,6X,' ',F6.4,6X,'  ',F6.4,6X,'  ',F5.3)
/COM,
/OUT,
*LIST,vm272,vrt
FINI
/CLEAR,NOSTART

/OUT,SCRATCH
/SHOW,PNG


PARRES,      ,vm272-1,parm
PARRES,CHANGE,vm272-2,parm
*DIM,RES_TABLE1,TABLE,NUMELEM1+1,6   !CREATE A "TABLE" DATA FORMAT FOR CLEANER
RES_TABLE1(0,1)=0       !PLOTTING THAN POSSIBLE WITH ARRAYS ALONE
RES_TABLE1(0,2)=0       !ZERO COLUMN FILLED WITH ZEROS
RES_TABLE1(0,3)=0
RES_TABLE1(0,4)=0
RES_TABLE1(0,5)=0
RES_TABLE1(0,6)=0

     !HIGH MESH DENSITY/LOWER ORDER
*DO,I,1,NUMELEM1+1       !LOOP THROUGH NODE ARRAY
   N_NODE=LOCARRAY1(I,2)      !STORE THE NODE NUMBER
   *DO,J,1,NUMELEM1+1       !LOOP THROUGH ELEMENT RESULT ARRAY

      TEMP=RES1(J,1)       !STORE LEFT NODE OF EACH ELEMENT
      *IF,TEMP,EQ,N_NODE,THEN      !IF THEY ARE THE SAME NODE
  RES_TABLE1(I,3) =RES1(J,2)   !FILL TABLE WITH 2D LOWER ORDER PRESSURE
  RES_TABLE1(I,4) =RES1(J,3)   !FILL TABLE WITH 2D LOWER ORDER FRICTION
  RES_TABLE1(I,5) =RES2(J,2)   !FILL TABLE WITH 3D LOWER ORDER PRESSURE
  RES_TABLE1(I,6) =RES2(J,3)   !FILL TABLE WITH 3D LOWER ORDER FRICTION
      *ENDIF
   *ENDDO
*ENDDO
              !CALCULATE ANALYTICAL SOLUTION FOR PRESSURE
*DO,I,1,NUMELEM1+1       !AND FRICTION RELATIONSHIP WITH X LOCATION
   RES_TABLE1(I,0)=LOCARRAY1(I,1)     !FILL THE ZERO COLUMN OF THE TABLE (X-AXIS)

   LOCX=LOCARRAY1(I,1)        !LOOP THROUGH ALL NODES
   *IF,LOCX,LT,B,THEN       !IF(1) NODE IS WITHIN CONTACT RANGE
         !EQUATION FOR PRESSURE
      RES_TABLE1(I,1)=RES1(I,5)
      *IF,LOCX,LT,C,THEN      !IF(2) NODE IS WITHIN STICK RANGE
         !EQUATION FOR FRICTION
       RES_TABLE1(I,2)=RES1(I,6)

      *ELSE        !ELSE(2) NODE IS WITHIN SLIDE RANGE
         !EQUATION FOR FRICTION
       RES_TABLE1(I,2)=RES1(I,6)

      *ENDIF
   *ELSE        !ELSE(1) ASSIGN AS ZERO TO AVIOD DIVIDING
      RES_TABLE1(I,1)=0        !BY ZERO
      RES_TABLE1(I,2)=0
   *ENDIF
*ENDDO

/OUT,
/TITLE,FRICTIONAL HERTZIAN CONTACT LOWER ORDER
/GCOLUMN,1,ANA_PRE    !ASSIGNS ANALYTICAL PRESSURE
/GMARKER,1,0
/GCOLUMN,2,ANA_FRI    !ASSIGNS ANALYTICAL FRICTION
/GMARKER,2,0
/GCOLUMN,3,PRES 1     !ASSIGNS 2D LOWER ORDER PRESSURE
```

```
/GMARKER,3,1
/GCOLUMN,4,FRIC 1     !ASSIGNS 2D LOWER ORDER FRICTION
/GMARKER,4,1
/GCOLUMN,5,PRES 3     !ASSIGNS 3D LOWER ORDER PRESSURE
/GMARKER,5,3
/GCOLUMN,6,FRIC 3     !ASSIGNS 3D LOWER ORDER PRESSURE
/GMARKER,6,3
/XRANGE,0,0.7
/AXLAB,X,X DISTANCE FROM CENTER   !X-AXIS LABEL
/AXLAB,Y,CONTACT RESULTS   !Y-AXIS LABEL
/YRANGE,0,10
*VPLO,RES_TABLE1(1,0),RES_TABLE1(1,1),2,3,4,5,6
FINISH
```

VM273 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM273
/TITLE,VM273, SHAPE MEMORY ALLOY WITH THERMAL EFFECT UNDER UNIAXIAL LOAD
/COM,   REF: FERDINANDO AURICHIO, LORENZA PETRINI
/COM,   "IMPROVEMENTS AND ALGORITHMICAL CONSIDERATIONS ON A RECENT
/COM,   THREE-DIMENSIONAL MODEL DESCRBING STRESS-INDUCED SOLID
/COM,   PHASE TRANSFORMATIONS"
/COM,   INT. J. NUMER. METH. ENGNG. 55 (2002) 1255-1284
/COM,
/COM,   TWO CASES ARE COMPUTED: (1) BODY TEMPERATURE T=285.15K
/COM,   (2) BODY TEMPERATURE T=253.15K
/COM,
/COM,   CASE ONE: WITH BODY TEMPERATURE T=285.15K
/PREP7
ET,1,SOLID185                        !* 3D 8-NODE STRUCTURAL SOLID ELEMENT

/COM, DEFINING SMA MATERIAL PROPERTIES
MP,EX,1,70E3     !MPA, [AUSTENITE MODULUS]
MP,PRXY,1,0.33

C1=500   !MPA [HARDENING PARAMETER]
C2=253.15 !K   [REF TEMP]
C3=45  !MPA  [ELASTIC LIMIT]
C4=7.5  !MPA [TEMPERATURE SCALING PARAMETER]
C5=0.03  ![MAX TRANSFORMATION STRAIN]
C6=70E3  !MPA, [MARTENSITE MODULUS]
C7=0        ! M = 0, SYMMETRICAL BEHAVIOR

TB,SMA,1,,7,MEFF
TBDATA,1,C1,C2,C3,C4,C5,C6,C7

BLOCK,0.00,10.00,0.00,10.00,0.00,10.00
ESIZE,10
TYPE,1
MAT,1
VMESH,1

NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,ALL
BFUNIF,TEMP,285.15
FINISH
/SOLU
NROPT,UNSYM
OUTRES,ALL,ALL
NSUBST,50,50,50
TIME,1
NSEL,S,LOC,Y,10
```

```
D,ALL,UY,0.35                ! TENSION LOADING
ALLSEL
/OUT,SCRATCH
SOLVE

TIME,2
NSEL,S,LOC,Y,10
D,ALL,UY,0.00                ! UNLOADING
ALLSEL
SOLVE

TIME,3
NSEL,S,LOC,Y,10
D,ALL,UY,-0.35               ! COMPRESSION LOADING
ALLSEL
SOLVE

TIME,4
NSEL,S,LOC,Y,10
D,ALL,UY,0.00                ! UNLOADING
ALLSEL
SOLVE
FINISH

/POST26
ESOL,2,1,NODE(10,10,0),S,Y           !* Y STRESS AT NODE(10,10,0)
ESOL,3,1,NODE(10,10,0),EPEL,Y        !* ELASTIC STRAIN AT NODE(10,10,0)
ESOL,4,1,NODE(10,10,0),EPPL,Y        !* PLASTIC STRAIN AT NODE(10,10,0)
ADD,5,3,4                     !* TOTAL STRAIN AT NODE(10,10,0)
PROD,6,5, , ,STRAIN, , ,100  !* PERCENT TOTAL STRAIN
XVAR,6
/AXLAB,X,Strain[%]
/AXLAB,Y,Stress [MPa]
/YRANGE,-800,800                !* SET Y-RANGE
/XRANGE,-4,4                    !* SET X-RANGE
PLVAR,2                         !* PLOT TOTAL STRAIN VS Y STRESS
PRVAR,3,4,2
FINISH
/POST1
/OUT,
SET, , , , ,0.16
*GET,S_SAS,NODE,NODE(10,10,0),S,Y
SET, , , , ,0.84
*GET,S_FAS,NODE,NODE(10,10,0),S,Y
SET, , , , ,1.20
*GET,S_SSA,NODE,NODE(10,10,0),S,Y
SET, , , , ,1.90
*GET,S_FSA,NODE,NODE(10,10,0),S,Y
R1 = S_SAS/345
R2 = S_FAS/367
R3 = S_SSA/258
R4 = S_FSA/236
*DIM,LABEL,CHAR,4,2
*DIM,VALUE,,4,3
LABEL(1,1) = 'S','S','S','S'
LABEL(1,2) = '-SAS','-FAS','-SSA','-FSA'
*VFILL,VALUE(1,1),DATA,345,367,258,236
*VFILL,VALUE(1,2),DATA,S_SAS,S_FAS,S_SSA,S_FSA
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4
SAVE, TABLE_1
FINISH

/CLEAR,NOSTART   ! *CLEAR DATABASE FOR SECOND SOLUTION
/COM,    CASE TWO: WITH BODY TEMPERATURE T=253.15K
/PREP7
ET,1,SOLID185                        !* 3D 8-NODE STRUCTURAL SOLID ELEMENT

/COM, DEFINING SMA MATERIAL PROPERTIES
MP,EX,1,70E3     !MPA, [AUSTENITE MODULUS]
MP,PRXY,1,0.33

C1=500   !MPA [HARDENING PARAMETER]
```

```
C2=253.15 !K   [REF TEMP]
C3=45  !MPA  [ELASTIC LIMIT]
C4=7.5  !MPA
C5=0.03  !     [MAX TRANSFORMATION STRAIN]
C6=70E3  !MPA, [MARTENSITE MODULUS]
C7=0        ! M = 0

TB,SMA,1,,7,MEFF
TBDATA,1,C1,C2,C3,C4,C5,C6,C7

BLOCK,0.00,10.00,0.00,10.00,0.00,10.00
ESIZE,10
TYPE,1
MAT,1
VMESH,1

NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,ALL
BFUNIF,TEMP,253.15
FINISH
/SOLU
NROPT,UNSYM
OUTRES,ALL,ALL
NSUBST,50,50,50

TIME,1
NSEL,S,LOC,Y,10
D,ALL,UY,0.35              ! TENSION LOADING
ALLSEL
/OUT,SCRATCH
SOLVE

TIME,2
NSEL,S,LOC,Y,10
D,ALL,UY,0.00              ! UNLOADING
ALLSEL
SOLVE

TIME,3
NSEL,S,LOC,Y,10
D,ALL,UY,-0.35             ! COMPRESSION LOADING
ALLSEL
SOLVE

TIME,4
NSEL,S,LOC,Y,10
D,ALL,UY,0.00              ! UNLOADING
ALLSEL
SOLVE
FINISH

/POST26
ESOL,2,1,NODE(10,10,0),S,Y           !* Y STRESS AT NODE(10,10,0)
ESOL,3,1,NODE(10,10,0),EPEL,Y        !* ELASTIC STRAIN AT NODE(10,10,0)
ESOL,4,1,NODE(10,10,0),EPPL,Y        !* PLASTIC STRAIN AT NODE(10,10,0)
ADD,5,3,4                            !* TOTAL STRAIN AT NODE(10,10,0)
PROD,6,5, , ,STRAIN, , ,100          !* PERCENT TOTAL STRAIN
XVAR,6
/AXLAB,X,Strain[%]
/AXLAB,Y,Stress [MPa]
/YRANGE,-800,800                !* SET Y-RANGE
/XRANGE,-4,4                    !* SET X-RANGE
PLVAR,2                         !* PLOT TOTAL STRAIN VS YSTRESS
PRVAR,3,4,2
FINISH
/POST1
/OUT,
```

```
SET, , , , ,0.04
*GET,S_SAS,NODE,NODE(10,10,0),S,Y
SET, , , , ,0.72
*GET,S_FAS,NODE,NODE(10,10,0),S,Y
SET, , , , ,1.32
*GET,S_SSA,NODE,NODE(10,10,0),S,Y
R1 = S_SAS/54.6
R2 = S_FAS/74.1
R3 = S_SSA/(-37.1)
*DIM,LABEL,CHAR,3,2
*DIM,VALUE,,3,3
LABEL(1,1) = 'S','S','S'
LABEL(1,2) = '-SAS','-FAS','-SSA'
*VFILL,VALUE(1,1),DATA,54.6,74.1,-37.1
*VFILL,VALUE(1,2),DATA,S_SAS,S_FAS,S_SSA
*VFILL,VALUE(1,3),DATA,R1,R2,R3
SAVE, TABLE_2
RESUME,TABLE_1
FINISH
/COM
/OUT,vm273,vrt
/COM,------------------- VM273 RESULTS COMPARISON --------------
/COM,
/COM,                 |  TARGET   |   Mechanical APDL  |  RATIO
/COM,
/COM,RESULTS WITH BODY TEMPERATURE T=285.15K
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A1,A8,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,RESULTS WITH BODY TEMPERATURE T=253.15K
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A1,A8,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)

/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vm273,vrt
```

VM274 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM274
/TITLE,VM274,STABILIZING SQUEAL DAMPING
C***
/PREP7
           !MATERIAL MODEL 1
MP,EX,1,2.1E11  !YOUNG'S MODULUS (N/m^2)
MP,NUXY,1,0.3  !POISSON'S RATIO
MP,DENS,1,8000  !DENSITY (kg/m^3)

           !MATERIAL MODEL 2
MP,MU,2,0.5      !COEFFICIENT OF FRICTION


ET,1,SOLID185  !3D 8-NODE STRUCTURAL SOLID
ET,2,CONTA173  !3D 4-NODE SURFACE-TO-SURFACE CONTACT
KEYOPT,2,2,0  !AUGUMENTED LAGRANGET ALGORITHM
KEYOPT,2,10,2  !UPDATE CONTACT STIFFNESS EACH ITERATION
ET,3,TARGE170  !3-D TARGET SEGMENT
KEYOPT,3,2,1  !BOUNDARY CONDITIONS SET BY USER
ET,4,MASS21      !STRUCTURAL MASS
KEYOPT,4,2,1  !COORDINATE SYSTEM ALIGNED TO NODE
ET,5,COMBIN14  !SPRING-DAMPER


BLOCK,0,.6,0,.01,0,.2 !CREATE BASE PLATE
```

```
TYPE,1           !SOLID ELEMENTS
ESIZE,0.01          !ELEMENT SIZE
VMESH,1           !MESH THE BLOCK
CM,GROUND,ELEM      !CREATE NAMED COMPONENT


NSEL,S,LOC,Y,.01 !SELECT NODES ON TOP FACE OF BLOCK
TYPE,2       !CONTACT ELEMENTS
MAT,2       !MATERIAL MODEL 2
REAL,2       !REAL CONSTANT SET 2
ESURF       !CREATE CONTACT ON TOP SURFACE


K,1001,.25,.01,.05 !CREATE 4 KEYPOINTS ON TOP SURFACE
K,1002,.35,.01,.05 !WHERE RIGID BLOCK IS SIMULATED
K,1003,.35,.01,.15
K,1004,.25,.01,.15


A,1001,1002,1003,1004 !CREATE AN AREA FROM ABOVE KEYPOINTS
TYPE,3           !TARGET ELEMENTS
REAL,2           !REAL CONSTANT SET 2
MAT,2           !MATERIAL MODEL 2
RMOD,2,34,1          !STABILIZING SQUEAL DAMPING FACTOR
AMESH,7           !CREATE TARGET ON AREA


N,10000,.3,.06,.1     !CREATE NODE
TSHAP,PILOT          !SET TARGET TYPE TO PILOT NODE
E,10000           !CREATE PILOT TARGET ELEMENT

TYPE,4   !STRUCTURAL MASS
REAL,4   !REAL CONSTANT SET 4
R,4,8,8,8,      !MASS = 8Kg
E,10000   !PLACE MASS ON PILOT NODE


NSEL,S,LOC,Y !PICK ALL NODES AT BOTTOM OF PLATE
D,ALL,ALL  !FIXED SUPPORT
NSEL,ALL  !PICK ALL NODES

N ,10004,.05,.06,.1 !CREATE OPPOSITE END NODE FOR SPRING ELEMENT
TYPE,5       !SPRING ELEMENT
REAL,5       !REAL CONSTANT SET 5
R,5,315       !SPRING STIFFNESS (N/M)
E,10004,10000  !CREATE SPRING ELEMENT
FINISH

/SOLU
ANTYPE,STATIC  !STATIC ANALYSIS
OUTRES,ALL,ALL  !WRITE ALL QUANTITIES TO RESULTS FILE
NLGEOM,ON      !NONLINEAR GEOMETRY
NROPT,UNSYM   !UNSYMMETRIC MATRICES
RESCONTROL,DEFINE,LAST !WRITE A .Xnnn FILE FOR LAST LOAD STEP
F,10000,FY,-1      !APPLY DOWNWARD VERTICAL FORCE TO NODE ABOUT PILOT
D,10004,ALL          !CONSTRAIN END NODE OF SPRING ELEMENT
D,10000,UZ          !CONSTRAIN PILOT NODE IN UZ
D,10000,ROTX      !CONSTRAIN PILOT NODE IN ROTX
D,10000,ROTY      !CONSTRAIN PILOT NODE IN ROTY
D,10000,ROTZ      !CONSTRAIN PILOT NODE IN ROTZ
/OUT,SCRATCH
SOLVE           !SOLVE FIRST LOAD STEP

               !USE AN ANGULAR VELOCITY TO SIMULATE SLIDE

CMROT,GROUND,,.1,,-99.75,.01,0.5 !SET AXIS OF ROTATION
SOLVE   !SOLVE SECOND LOAD STEP
FINI   !EXIT SOLUTION PROCESSOR

/SOLU                    !RE-ENTER SOLUTION
ANTYPE,STATIC,RESTART,,,PERTURB !DEFINE A PERTURB ANALYSIS TYPE
PERTURB,MODAL,,CURRENT,PARKEEP !PERTURB MODAL, KEEPING SUPPORTS
```

```
SOLVE,ELFORM              !SOLVE FOR ELEMENT MATRIX


MODOPT,DAMP,2,   !2 MODES, DAMP SOLVER
MXPAND,,,,YES     !EXPAND MODES
SOLVE       !COMPLETE MODAL SOLUTION
FINISH


/POST1   !ENTER POST-PROCESSOR
FILE,,rstp  !READ PERTURB RESULTS FILE
/OUT,
*GET,DRATIO,MODE,1,DAMP

*STAT,DRATIO

*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1)='DAMPING RATIO'
*VFILL,VALUE(1,1),DATA,0.000498012
*VFILL,VALUE(1,2),DATA,DRATIO
*VFILL,VALUE(1,3),DATA,ABS(DRATIO/(0.000498012))
*STAT,VALUE
/COM
/OUT,vm274,vrt
/COM,------------------- VM274 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,8X,'   ',F10.8,'  ',F14.8,'  ',1F15.3)
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vm274,vrt
```

VM275 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm275
/title,vm275,Mode lock-in and friction induced vibration on a Pin-Disc Model
/com,
/com,  This verification manual highlights the mode coupling
/com,  phenomenon on a pin-disc set up using brake squeal analysis.
/com,  The brake squeal analysis is performed using all 3 methods
/com,
/com,  Reference:
/com,  Allgaier, R., Gaul, L., Keiper, W., Willner, K., Mode Lock-In
/com,  and Friction Modeling, Computational Methods in Contact
/com,  Mechanics IV,ed. By L. Gaul and C.A. Brebbia, WIT Press,
/com,  Southampton (1999), pg 35-47
/com,

/output,scratch                         ! Redirect output to Scratch file
/prep7
et,1,solid186                       ! Solid186
keyopt,1,2,1                        ! Full Integration
type,1

mp,ex,1,70000
mp,dens,1,2.7e-9
mp,nuxy,1,0.33

cylind,8,179,-12.5,12.5,0,90        ! Model Disc

lsel,s,line,,9,12,1
lesize,all,,,3
lsel,all
```

```
lsel,s,line,,1,8,7
lsel,a,line,,3,6,3
lesize,all,,,12
lsel,all

lsel,s,line,,2,7,5
lsel,a,line,,4,5,1
lesize,all,,,12
lsel,all

vsweep,all
vsymm,x,all
vsymm,y,all
nummrg,node
nummrg,kp
allsel,all

csys,1
nsel,s,loc,x,8
d,all,all,0                 ! Constrain the inner radius of Disc
allsel,all

csys,0

local,11,0,0,0,12.5,0,0,4
csys,11


k,100,0,167.00,0.00
k,101,0,157.00,0.00
k,102,-10.00,157.00,0.00
k,103,-10.00,167.00,0.00

k,104,0,167.00,0.00+149
k,105,0,157.00,0.00+149
k,106,-10.00,157.00,0.00+149
k,107,-10.00,167.00,0.00+149


a,100,101,102,103
a,104,105,106,107
a,100,101,105,104
a,103,102,106,107
a,100,104,107,103
a,101,105,106,102

va,12,17,23,24,25,26            ! Modeling Pin


ET,2,solid186
keyopt,2,2,1

TYPE,2
mat,1
ESIZE,5
VMESH,5
ALLSEL,ALL

vsel,s,volume,,5
eslv,s
nsle,s
nrotate,all
allsel,all

csys,0


et,3,conta175               ! Defining Frictional Contact Pair
mp,mu,3,0.152               ! Coefficient of Friction
keyopt,3,2,0                ! Augumented Lagrangian
keyopt,3,9,2                ! Include penetration or gap with ramped effects
```

```
keyopt,3,10,2              ! Update contact stiffness each iteration
keyopt,3,12,0              ! Standard Contact



et,4,targe170

r,3
rmodif,3,3,1               ! Normal penalty stiffness factor
rmodif,3,5,0               ! Initial contact closure
rmodif,3,6,1               ! Pin ball region
rmodif,3,10,0              ! Contact surface offset
rmodif,3,12,0              ! Tanget penalty stiffness factor

type,3
real,3
mat,3

e,node(0,167.00,12.500)
e,node(0,164.50,12.500)
e,node(0,162.00,12.500)
e,node(0,159.50,12.500)
e,node(0,157.00,12.500)


allsel,all

type,4
real,3

asel,s,area,,2,20,6
nsla,s,1
esln,s
esurf
allsel,all

esel,s,type,,4
cm,tar,elem                ! Forming a component with target elements
allsel,all


save,vm275,db
finish

/com, *******************************************************
/com,  Full Nonlinear Perturbed Modal Analysis
/com, ********************************************************


/solu
antype,static
nlgeom,on                  ! Nonlinear analysis
nropt,unsym                ! Newton-Raphson with unsymmetric matrices
rescontrol,define,all,1
asel,s,area,,17
nsla,s,1
d,all,ux,0
d,all,uy,0
d,all,uz,-0.1              ! Displacement load to bring Pin and Disc
allsel,all                 ! to contact
time,1
autots,on
nsubs,10,20,1
solve                      ! 1st Load Step


time,2.0
cmrot,tar,,,2.0            ! Rotate the nodes of target element
autots,on                  ! to generate sliding friction contact
solve                      ! 2nd Load Step
finish
```

```
/solu
antype,static,restart,,,perturb     ! Restarting from last load step and sub step
perturb,modal,,,
solve,elform                        ! Reform the matrices

modopt,unsym,30,500,4000,           ! Solving using UNSYM eigensolver
mxpand,30,,,
/out,
solve
fini

/post1
file,,rstp
set,1,7
*get,unstablemode1,active,0,set,freq
*stat,unstablemode1
*dim,label,char,1,2
*dim,value,,1,3

label(1,1)='Mode'

*vfill,value(1,1),data,2215                     ! Unstable mode from Reference
*vfill,value(1,2),data,unstablemode1            ! Results obtained from MAPDL
*vfill,value(1,3),data,abs(2215/unstablemode1)  ! Ratio
save,table_1
finish
/delete,,rstp
/delete,,rst
/clear,nostart


/com, *****************************************************
/com,  Partial Nonlinear Perturbed Modal Analysis
/com, *****************************************************
/out,scratch

/prep7
resume,vm275,db
finish

/solu
antype,static
nlgeom,on                   ! Nonlinear analysis
nropt,unsym                 ! Newton-Raphson with unsymmetric matrices
rescontrol,define,all,1
asel,s,area,,17
nsla,s,1
d,all,ux,0
d,all,uy,0
d,all,uz,-0.1               ! Displacement load to bring Pin and Disc
allsel,all                  ! to contact
time,1
autots,on
nsubs,10,20,1
solve                       ! 1st Load Step
finish


/solu
antype,static,restart,,,perturb     ! Restarting from last load step and sub step
perturb,modal,,,
cmrot,tar,,,2.0                     ! Rotate the nodes of target element
                                    ! to generate sliding friction contact
solve,elform                        ! Reform the matrices

modopt,unsym,30,500,4000,           ! Solving using UNSYM eigensolver
mxpand,30,,,
/out,
solve
fini
```

```
/post1
file,,rstp
set,1,7
*get,unstablemode2,active,0,set,freq
*stat,unstablemode2
*dim,label,char,1,2
*dim,value,,1,3

label(1,1)='Mode'

*vfill,value(1,1),data,2215                    ! Unstable mode from Reference
*vfill,value(1,2),data,unstablemode2           ! Results obtained from MAPDL
*vfill,value(1,3),data,abs(2215/unstablemode2)  ! Ratio
save,table_2
finish
/delete,,rstp
/delete,,rst
/clear,nostart


/com, *****************************************************
/com,  Linear Non-prestressed Modal Analysis
/com, *****************************************************

/output,scratch
/prep7
resume,vm275,db
allsel,all
asel,s,area,,17
nsla,s,1
d,all,ux,0
d,all,uy,0
d,all,uz,0.0
allsel,all
finish

/solu
antype,modal
nropt,unsym                         ! Newton-Raphson with unsymmetric matrices
cmrot,tar,,,2.0                     ! Rotate the nodes of target element
                                    ! to generate sliding friction contact

modopt,unsym,30,500,4000,           ! Solving using UNSYM eigensolver
mxpand,30,,,
/out,
solve
fini


/post1
file,,rst
set,1,7
*get,unstablemode3,active,0,set,freq
*stat,unstablemode3
*dim,label,char,1,2
*dim,value,,1,3

label(1,1)='Mode'

*vfill,value(1,1),data,2215                    ! Unstable mode from Reference
*vfill,value(1,2),data,unstablemode3           ! Results obtained from MAPDL
*vfill,value(1,3),data,abs(2215/unstablemode3)  ! Ratio
save,table_3
finish
resume,table_1
/com,
/out,vm275,vrt
/com,
/com, ------------------------------VM275 RESULTS COMPARISON----------------------
/com,
/com,                       | TARGET |  Mechanical APDL | RATIO
/com,
```

```
/com,
/com, Full Nonlinear Perturbed Modal Analysis
/com,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A14,'   ',F12.3,'    ',F12.3,'    ',F12.3)
/com,
/com,
/NOPR,
resume,table_2
/GOPR
/com,
/com,
/com, Partial Nonlinear Perturbed Modal Analysis
/com,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A14,'   ',F12.3,'    ',F12.3,'    ',F12.3)
/com,
/com,
/NOPR,
resume,table_3
/GOPR
/com,
/com,
/com, Linear Non-prestressed Modal Analysis
/com,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A14,'   ',F12.3,'    ',F12.3,'    ',F12.3)
/com,
/com,
/NOPR,
/com,
/com,
/com, --------------------------------------------------------------------------------
/out,
*list,vm275,vrt
/delete,table_1
/delete,table_2
/delete,table_3
finish
```

VM276 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm276
/title,vm276,Constant Diffusion Flux in a Plane Sheet
/com,
/com,
/com, Reference: Crank,J. The Mathematics of Diffusion.
/com, 2nd printing, Bristol: Oxford University Press
/com, 1975, pg 47-48
/com,


/NOPR

! DEFINED PARAMETERS
L=2               ! HALF SHEET THICKNESS, MM
H=50           ! PLANE HEIGHT, MM
W=50           ! PLANE WIDTH, MM
DX=4E-5           ! DIFFUSIVITY, MM^2/S
F0=5E-14          ! CONSTANT DIFFUSION FLUX, KG/MM^2/S
CSAT=3E-8          ! SATURATED CONCENTRATION, KG/MM^3
CONC0=1E-10          ! INITIAL CONCENTRATION, KG/MM^3
NORM_CONC0=CONC0/CSAT ! NORMALIZED INITIAL CONCENTRATION
T=36*3600          ! TIME AT END OF LOAD STEP, S
PI=4*ATAN(1)       ! VALUE OF PI COMPUTED
SUB=50           ! NUMBER OF SUBSTEPS
ITER=5           ! NUMBER OF ITERATIONS FOR CRANK EQUATION
```

```
XLOC=L/2          ! LOCATION WITHIN PLATE FOR POSTPROCESSING

/PREP7
ET,1,SOLID239         ! DIFFUSION SOLID
MP,DXX,1,DX             ! DIFFUSION COEFFICIENT
MP,CSAT,1,CSAT          ! SATURATED CONCENTRATION
BLOCK,-L,L,0,H,0,W
LESIZE,5,L/2
LESIZE,3,2*L
LESIZE,10,2*L
VMESH,ALL
ALLS


NSEL,S,LOC,X,L
NSEL,A,LOC,X,-L
SF,ALL,DFLUX,F0  ! APPLY CONSTANT DIFFUSION FLUX AT X=-L AND X=L
NSEL,ALL
IC,ALL,CONC,NORM_CONC0 ! SET INITIAL NORMALIZED CONCENTRATION
ALLS
FINISH

/SOLU
ANTYPE,TRANS
OUTRES,ALL,ALL
KBC,1   ! STEPPED LOAD
NSUB,SUB
TIME,T
SOLVE
FINISH

/POST1
*DIM,CONCENTRATION_,TABLE,SUB,2
*DIM,MASS_,TABLE,SUB,2

*DO,II,1,SUB
  SET,1,II
  *GET,TIME_II,ACTIVE,,SET,TIME
  CONCENTRATION_(II,0)=TIME_II   ! TIME, S
  MASS_(II,0)=TIME_II

  NSEL,S,LOC,X,XLOC
  *GET,ND,NODE,,NUM,MIN
  *GET,ND_CONC,NODE,ND,CONC   ! NORMALIZED CONCENTRATION
  CONCENTRATION_(II,1)=ND_CONC*CSAT  ! CONCENTRATION, KG/MM^3

  ETABLE,CONC,SMISC,1
  ETABLE,VOLU,VOLU
  SMULT,WATR,CONC,VOLU
  SSUM
  *GET,MOISTURE,SSUM,,ITEM,WATR
  MASS_(II,1)=MOISTURE    ! MOISTURE WEIGHT GAIN, KG

  C=CONC0+((F0*L/DX)*((DX*TIME_II/L**2)+((3*XLOC**2-L**2)/(6*L**2))))
  *DO,JJ,1,ITER
    C=C-((F0*L*2*((-1)**JJ)*EXP(-DX*JJ**2*PI**2*TIME_II/L**2)*COS(JJ*PI*XLOC/L))/(DX*PI**2*JJ**2))
  *ENDDO
  CONCENTRATION_(II,2)=C   ! CRANK CONCENTRATION, KG/MM^3

  M=(2*L*H*W*CONC0)+(2*F0*TIME_II*H*W)
  MASS_(II,2)=M     ! CRANK WEIGHT GAIN, KG
*ENDDO

/AXLAB,X,TIME (S)
/AXLAB,Y,CONCENTRATION (KG/MM^3)
/GCOL,1,MAPDL
/GCOL,2,REFERENCE
*VPLOT,CONCENTRATION_(1,0),CONCENTRATION_(1,1),2
/AXLAB,Y,MOISTURE WEIGHT GAIN (KG)
*VPLOT,MASS_(1,0),MASS_(1,1),2

*DIM,CONC_RATIO,,SUB
```

```
*DIM,MASS_RATIO,,SUB
*VOPER,CONC_RATIO,CONCENTRATION_(1,1),DIV,CONCENTRATION_(1,2)
*VOPER,MASS_RATIO,MASS_(1,1),DIV,MASS_(1,2)
/OUT,vm276,vrt
/COM
/COM ----------------------- RESULTS COMPARISON --------------------------
/COM
/COM
/COM   ***** CONCENTRATION (KG/MM^3) AT LOCATION X = %XLOC% MM *****
/COM
/COM       TIME (S)     |      TARGET      |     MECHANICAL APDL     |     RATIO
/COM
*VLEN,1
*VWRITE,CONCENTRATION_(35,0),CONCENTRATION_(35,2),CONCENTRATION_(35,1),CONC_RATIO(35,1)
(,F15.0,'       ',G14.5,'        ',G14.5,'          ',F8.3)
/COM
/COM
/COM
/COM   ***** MOISTURE WEIGHT GAIN (KG) *****
/COM
/COM       TIME (S)     |      TARGET      |     MECHANICAL APDL     |     RATIO
/COM
*VLEN,1
*VWRITE,MASS_(35,0),MASS_(35,2),MASS_(35,1),MASS_RATIO(35,1)
(,F15.0,'       ',G14.5,'        ',G14.5,'          ',F8.3)
/COM
/COM -----------------------------------------------------------------------
/OUT,
*list,vm276,vrt
FINISH
```

VM277 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm277
/title,vm277,Hall Plate in a Uniform Magnetic Field
/COM,
/COM, Reference: Meijer,G. "Smart Sensor Systems"
/COM, John Wiley & Sons, Ltd.2008,pp 252
/COM,


/NOPR

! *** DEFINED PARAMETERS
A=3E-3    ! HALF PLATE LENGTH, M
B=3E-3    ! HALF PLATE HEIGHT, M
C=0.4E-3   ! PLATE WIDTH, M
! *** MATERIAL PROPERTIES FOR N-TYPE INDIUM ARSENIDE
RH=-0.0001   ! HALL COEFFICIENT, M^3/C
RHO=1.6e-3   ! RESISTIVITY, OHM*M
MU=1    ! RELATIVE MAGNETIC PERMEABILITY
V=3        ! APPLIED VOLTAGE, V
BZ=0.8    ! APPLIED MAGNETIC FIELD, T

/PREP7
ET,1,SOLID236,1   ! ELECTROMAGNETIC ANALYSIS, AZ+VOLT
MP,RH,1,RH
MP,RSVX,1,RHO
MP,MURX,1,MU
BLOCK,-A,A,-B,B,0,C  ! HALL PLATE
BLOCK,-A,-A+A/8,B,B-B/8,C/2,C ! SENSOR CONNECTIONS
BLOCK,-A,-A+A/8,-B,-B+B/8,C/2,C
BLOCK,A,A-A/8,B,B-B/8,C/2,C
BLOCK,A,A-A/8,-B,-B+B/8,C/2,C
ESIZE,C
MSHA,1,3D   ! TETRAHEDRAL
VOVLAP,ALL
```

```
VMESH,ALL

W1=NODE(-A,B,C)   ! NODES FOR WIRE MODELING
W2=NODE(A,-B,C)
*GET,N_MAX,NODE,,NUM,MAX ! GET MAX NODE NUMBER
N,N_MAX+1,-2*A,2*B,C  ! DEFINE NODES FOR ELEMENTS
N,N_MAX+2,-2*A,,C
N,N_MAX+3,-2*A,-2*B,C
N,N_MAX+4,-A,2*B,C
N,N_MAX+5,A,-2*B,C
ET,2,CIRCU124,4   ! INDEPENDENT VOLTAGE SOURCE FROM CIRCU124
R,2,V
TYPE,2
REAL,2
E,N_MAX+1,N_MAX+3,N_MAX+2
/ICSCALE,,0.1
ET,3,200,0,0,0,0  ! WIRE FROM MESH200
TYPE,3
E,N_MAX+1,N_MAX+4
E,N_MAX+4,W1
E,N_MAX+3,N_MAX+5
E,N_MAX+5,W2

! *** BOUNDARY CONDITIONS AND LOADS
VSEL,S,VOLU,,6
NSLV
NSEL,A,NODE,,N_MAX+1
CP,1,VOLT,ALL   ! VOLTAGE SUPPLY
ND1=NDNEXT(0)   ! MASTER NODE
VSEL,S,VOLU,,9
NSLV
NSEL,A,NODE,,N_MAX+3
D,ALL,VOLT,0   ! GROUND
ND2=NDNEXT(0)   ! MASTER NODE
VSEL,S,VOLU,,7
NSLV
CP,2,VOLT,ALL   ! COUPLE FOR OUTPUT VOLTAGE
ND3=NDNEXT(0)   ! MASTER NODE
VSEL,S,VOLU,,8
NSLV
CP,3,VOLT,ALL   ! COUPLE FOR OUTPUT VOLTAGE
ND4=NDNEXT(0)   ! MASTER NODE
ALLS

DFLX,ALL,,,0   ! SET B-FIELD IN THE +Z-DIFECTION TO B=0 T

/VIEW,,1,2,3
EPLOT
FINISH

/SOLU
OUTRES,ALL,ALL
SOLVE
VBASE=VOLT(ND4)-VOLT(ND3) ! OFFSET VOLTAGE = OUTPUT VOLTAGE AT B=0 T
DFLX,ALL,,,BZ   ! UNIFORM B-FIELD BZ IN THE +Z-DIRECTION
ALLS
SOLVE
FINISH

/POST1
SET,LAST,LAST
VSEL,S,VOLU,,6
NSLV
FSUM
*GET,_I,FSUM,,ITEM,AMPS  ! CURRENT THROUGH PLATE
ALLS

PLVECT,B,,,,VECT,ELEM,ON,0
/VIEW,,,,1
PLNSOL,VOLT
*DIM,VALUE,,1,3
*VFILL,VALUE(1,1),DATA,VOLT(ND4)-VOLT(ND3)-VBASE
```

```
*VFILL,VALUE(1,2),DATA,(RH*_I*BZ)/(C)
*VOPER,VALUE(1,3),VALUE(1,1),DIV,VALUE(1,2)
/OUT,vm277,vrt
/COM,
/COM,  ----------------------- RESULTS COMPARISON --------------------------
/COM,
/COM,   ***** HALL VOLTAGE (V) AT B=%BZ% T *****
/COM,
/COM,       |      TARGET      |     MECHANICAL APDL     |     RATIO
/COM,
*VWRITE,VALUE(1,2),VALUE(1,1),VALUE(1,3)
('         ',G14.5,'         ',G14.5,'          ',F8.3)
/COM,
/COM, ------------------------------------------------------------------------
/OUT,
*list,vm277,vrt
FINISH
```

VM278 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM278
/TITLE, VM278, BEAMS CONTACT TRACTION
C***  REFERENCE
C***
C***
/PREP7
LENGDE=100   ! MODELING PARAMETERS
OD=0.5
WT=0.01
!*** SOLID MODEL ***
!-------------------
K,1,0,0,0
K,2,LENGDE,0,0
L,1,2    ! GEOMETRY OF THE BEAM
!*** MATERIAL PROPERTIES FOR STEEL IN NEWTONS AND METERS ***
!-----------------------------------------------------------------
MP,EX,1,2E11   ! YOUNG'S MODULUS
MP,PRXY,1,0.3   ! POISSON'S RATIO
MP,DENS,1,7850   ! DENSITY
MP,KXX,1,60.5   ! CONDUCTIVITY PLAIN CARBON STEEL: 60.5 W/(m*k)
MP,C,1,434   ! SPECIFIC HEAT PLAIN CARBON STEEL: 434 J/(kg*K)
MP,ALPX,1,12E-6   ! COEFFICIENT OF THERMAL EXPANSION
!*** CONTACT MATERIAL PROPERTIES ***
!--------------------------------------
MP,MU,2,0.2   ! COEFFICIENT OF FRICTION
!*** ELEMENT TYPES ***
!---------------------
ET,1,PIPE289   ! 3-D 3-NODE PIPE
ET,2,CONTA177   ! 3-D LINE-TO-SURFACE CONTACT
KEYOPT,2,2,1   ! PENALTY FUNCTION ALGORITHM
KEYOPT,2,3,1     ! TRACTION-BASED CONTACT TYPE
ET,3,170   ! 3-D TARGET SEGMENT
!*** SECTION DATA ***
!--------------------
! EXAMPLE SECTION:
SECTYPE,1,PIPE,,PIPE1  ! DEFINE PIPE SECTION
SECDATA,OD,WT,16  ! APPLY MODELING PARAMETERS TO PIPE SECTION
! *** REAL CONSTANTS ***
! ----------------------
R,2    ! INITIALIZE REAL CONSTANT SET 2
RMODIF, 2,3,-1000000  ! ABSOLUTE VALUE OF PENALTY STIFFNESS
! *** MESHING ***
! ---------------
BIAS_FACT=5   ! DEFINE MESHING PARAMETER
LESIZE,1,,,10,BIAS_FACT  ! SET LINE MESHING CHARACTERISTICS
LMESH,ALL   ! CREATE PIPE ELEMENTS
! CONTACT/TARGET
```

```
TYPE, 2    ! CONTACT TYPE
REAL, 2
MAT, 2
ESURF    ! PLACE CONTACT ON PIPE ELEMENTS
! FIND THE HIGHEST NODE NUMBER DEFINED
*GET, NODE_MAXNUM_DEF, NODE, 0, NUM, MAXD ! GET THE HIGHEST NODE NUMBER
TARGET_NODE1=NODE_MAXNUM_DEF+1 ! CHOOSE TARGET NODE NUMBERS
TARGET_NODE2=NODE_MAXNUM_DEF+2
TARGET_NODE3=NODE_MAXNUM_DEF+3
TARGET_NODE4=NODE_MAXNUM_DEF+4
N,TARGET_NODE1,-10,-10,0 ! MAKE NODES FOR TARGET ELEMENT
N,TARGET_NODE2,110,-10,0
N,TARGET_NODE3,110,10,0
N,TARGET_NODE4,-10,10,0
TYPE, 3    ! CREATE TARGET ELEMENT
E, TARGET_NODE1,TARGET_NODE2,TARGET_NODE3,TARGET_NODE4
ALLSEL,ALL
FINISH
/SOLU
! *** BOUNDARY CONDITIONS ***
! --------------------------
KSEL,S,KP,,1   ! SELECT KEYPOINT AT LEFT SIDE OF BEAM
NSLK,S,    ! SELECT IT'S CORRESPONDING NODE
D,ALL,UY,0   ! FIX THE NODE IN THE VERTICAL AXIS
D,ALL,UX,0   ! FIX THE NODE IN THE HORIZONTAL AXIS
D,ALL,ROTX,0                    ! FIX THE NODE ABOUT THE HORIZONTAL AXIS
!*
KSEL,S,KP,,2   ! SELECT KEYPOINT AT RIGHT SIDE OF BEAM
NSLK,S,    ! SELECT IT'S CORRESPONDING NODE
D,ALL,UY,0   ! FIX THE NODE IN THE VERTICAL AXIS
!*
ALLSEL
ACEL,,,9.81   ! APPLY GRAVITY TO THE SYSTEM
ALLSEL
NLHIST,PAIR,CAREA,CONT,CAREA,2 ! PRINT THE CONTACT AREA TO .nlh FILE
/OUT,SCRATCH
SOLVE
FINISH
*LIST,vm278,nlh   ! VERIFY THAT NLH FILE CONTAINS CORRECT AREA
/POST1
SET,LAST
/OUT,
ESEL,S,ENAME,,CONTA177
ETAB,PENE,CONT,PENE  ! STORE CONTACT PENETRATION IN A TABLE
ETAB,PRES,CONT,PRES  ! STORE CONTACT PRESSURE IN A TABLE
ETAB,AREA,NMIS,58   ! STORE CONTACT AREA IN A TABLE
*GET,C_PENE,ETAB,1,ELEM,11 ! GET THE PENETRATION AT THE LEFT ELEMENT
*GET,C_PRES,ETAB,2,ELEM,20 ! GET THE PRESSURE AT THE RIGHT ELEMENT
ASUM=0
*DO,I,11,20   ! SUM THE CONTACT AREA OVER ALL CONTACT ELEMENTS
*GET,AREA%I%,ETAB,3,ELEM,I
ASUM=ASUM+AREA%I%
*ENDDO
*DIM,LABEL,CHAR,3,1
*DIM,VALUE,,3,3
LABEL(1,1) = 'PRESSURE ','PENETR ','AREA '
*VFILL,VALUE(1,1),DATA,4737,4.737E-3,25
*VFILL,VALUE(1,2),DATA,C_PRES,C_PENE,ASUM
*VFILL,VALUE(1,3),DATA,(C_PRES/4737),(C_PENE/4.737E-3),(ASUM/25)
FINISH
/COM
/OUT,vm278,vrt
/COM,---------------- VM278 RESULTS COMPARISON --------------
/COM,
/COM,
/COM,CONTACT RESULT |  TARGET  |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A10,4X,E12.4,6X,E10.4,6X,1F9.3)
/COM,
/COM,
/COM,-----------------------------------------------------------
```

```
/OUT
FINISH
*LIST,vm278,vrt
```

VM279 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM279
/COM,   VERIFICATION MANUAL FOR FRACTURE MECHANCIS,
/TITLE,VM279 T-STRESS FOR A CRACK IN A 2D PLATE
/COM    REFERENCE: STRESS INTENSITY FACTORS, T-STRESSES, WEIGHT
/COM    FUNCTIONS BY THEO FETT,INSTITUTE OF CERAMICS IN
/COM    MECHANICAL ENGINEERING (IKM),UNIVERSITY OF KARLSRUHE(TH)
/COM    ****CRACK IN 2-DIMENSIONS USING 2-D PLANE183 ELEMENT***
/OUT,SCRATCH
/PREP7
E=207000                    ! YOUNGS MODULUS
NU=0.3             ! POISSONS RATIO
SIG=100                  ! SURFACE LOAD

! DIMENSIONS.
A = 10                     ! HALF CRACK LENGTH
ALPHA = 0.2                             ! ALPHA = A / W
HEIGHT_WIDTH_RATIO = 0.75               ! H / W
W = A / ALPHA                           ! HALF PLATE WIDTH
H = HEIGHT_WIDTH_RATIO*W                ! HALF PLATE HEIGHT
TSTRESS_REFERENCE_NORMALIZED = -0.88    ! TSTRESS TARGET VALUE
! NORMALIZED AS: T/SIG*(1-ALPHA)
! TSTRESS TARGET VALUE CORRESPONDING TO THE GIVEN DIMENSIONS:
TSTRESS_REFERENCE = (TSTRESS_REFERENCE_NORMALIZED*SIG) / (1 - ALPHA)

ET,1,PLANE183               ! PLANE 183 ELEMENT
KEYOPT,1,3,2                ! PLANE STRAIN
MP,EX,1,E
MP,NUXY,1,NU

K,1,0,0                     ! DEFINE KEYPOINTS AND LINE SEGMENTS
K,2,A,0                     ! CRACK TIP
K,3,W,0
K,4,W,H/2
K,5,W,H
K,6,0,H
K,7,0,H/2

L,1,2
*REP,6,1,1
L,7,1
L,4,7
AL,1,2,3,8,7
AL,4,5,6,8
ESIZE,1
KSCON,2,1,1,4,0.75          !CRACK TIP ELEMENTS
AMESH,1
ESIZE,2
AMESH,2
FINI

/SOLU
OUTRES,ALL,ALL
NSEL,S,LOC,Y,0
NSEL,R,LOC,X,A,W
D,ALL,UY,0                  ! APPLY MODEL BOUNDARY CONDITIONS
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0,H
D,ALL,UX,0
NSEL,ALL
LSEL,S,LINE,,5
SFL,ALL,PRESS,-SIG
```

```
LSEL,ALL
NSEL,S,LOC,Y,0
NSEL,R,LOC,X,A
CM,CRACK1,NODE              ! DEFINE THE CRACK TIP NODE COMPONENT
NSEL,ALL

CINT,NEW,1
CINT,TYPE,TSTR              ! CALCULATE T-STRESS
CINT,CTNC,CRACK1            ! CRACK ID
CINT,NCON,4                 ! NUMBER OF COUNTOURS
CINT,SYMM,ON                ! SYMMETRY ON
CINT,NORM,0,2
CINT,LIST
ALLSEL,ALL
SOLVE
FINISH

/POST1
/OUT,
PRCINT,1,,TSTR                     ! GET THE T-STRESS VALUES
TIP_NODE_NUMBER = NODE(A,0,0)
*GET,TSTRESS_1,CINT,1,CTIP,TIP_NODE_NUMBER,CONTOUR,1,DTYPE,TSTR
*GET,TSTRESS_2,CINT,1,CTIP,TIP_NODE_NUMBER,CONTOUR,2,DTYPE,TSTR
*GET,TSTRESS_3,CINT,1,CTIP,TIP_NODE_NUMBER,CONTOUR,3,DTYPE,TSTR
*GET,TSTRESS_4,CINT,1,CTIP,TIP_NODE_NUMBER,CONTOUR,4,DTYPE,TSTR

TSTRESS = (TSTRESS_2+ TSTRESS_3 + TSTRESS_4) / 3
*STAT,TSTRESS
/OUT,SCRATCH
TSTRESS_RATIO = ABS(TSTRESS/TSTRESS_REFERENCE)
! STORE DATA
*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'T-STRESS'
*VFILL,VALUE(1,1),DATA,TSTRESS_REFERENCE
*VFILL,VALUE(1,2),DATA,TSTRESS
*VFILL,VALUE(1,3),DATA,TSTRESS_RATIO
SAVE,TABLE_1
FINISH
/CLEAR, NOSTART                ! CLEAR DATABASE FOR 2ND SOLUTION
/OUT,


/COM ***** CRACK IN 3D PLATE USING SOLID 185 ELEMENT ********
/OUT,SCRATCH
/PREP7
E=207000                     ! YOUNGS MODULUS
NU=0.3              ! POISSONS RATIO
SIG=100                   ! SURFACE LOAD
PI=3.141593
TK=1

! DIMENSIONS.
A = 10                     ! HALF CRACK LENGTH
ALPHA = 0.2                             ! ALPHA = A / W
HEIGHT_WIDTH_RATIO = 0.75               ! H / W
W = A / ALPHA                           ! HALF PLATE WIDTH
H = HEIGHT_WIDTH_RATIO*W                ! HALF PLATE HEIGHT
TSTRESS_REFERENCE_NORMALIZED = -0.88    ! TSTRESS TARGET VALUE
! NORMALIZED AS: T/SIG*(1-ALPHA)
! TSTRESS TARGET VALUE CORRESPONDING TO THE GIVEN DIMENSIONS:
TSTRESS_REFERENCE = (TSTRESS_REFERENCE_NORMALIZED*SIG) / (1 - ALPHA)

ET,1,PLANE182               ! PLANE 182 ELEMENT
ET,2,SOLID185               ! SOLID185 ELEMENT
MP,EX,1,E
MP,NUXY,1,NU

K,1,0,0                     ! DEFINE KEYPOINTS AND LINE SEGMENTS
K,2,A,0
K,3,W,0
```

```
K,4,W,H/2
K,5,W,H
K,6,0,H
K,7,0,H/2

L,1,2
*REP,6,1,1
L,7,1
L,4,7
AL,1,2,3,8,7
AL,4,5,6,8
ESIZE,1
KSCON,2,1,0,4,0.75          !CRACK TIP ELEMENTS
AMESH,1
ESIZE,2
AMESH,2
ALLSEL,ALL
TYPE,2
ESIZE,,5
VEXT,ALL,,,0,0,TK
ALLSEL,ALL
ESEL,S,ENAME,,182
ACLEAR,1,2,,,
ALLSEL
FINI

/SOLU
OUTRES,ALL,ALL
NSEL,S,LOC,Y,0
NSEL,R,LOC,X,A,W
D,ALL,UY,0
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0,H
D,ALL,UX,0
NSEL,ALL
ASEL,S,,,11
SFA,ALL,,PRESS,-SIG
ALLSEL,ALL

D,ALL,UZ,0
ALLSEL

NSEL,S,LOC,Y,0
NSEL,R,LOC,X,A
CM,CRACK1,NODE              ! DEFINE THE CRACK FRONT NODES COMPONENT
NSEL,ALL

CINT,NEW,1
CINT,TYPE,TSTR              ! CALCULATE T-STRESS
CINT,CTNC,CRACK1            ! CRACK ID
CINT,NCON,4                 ! NUMBER OF COUNTOURS
CINT,SYMM,ON                ! SYMMETRY ON
CINT,NORM,0,2
CINT,LIST
ALLSEL,ALL
SOLVE
FINISH

/POST1
/OUT,
PRCINT,1,,TSTR                     ! GET THE T-STRESS VALUES
TIP_NODE_NUMBER = NODE(A,0,0)
*GET,TSTRESS_1,CINT,1,CTIP,TIP_NODE_NUMBER,CONTOUR,1,DTYPE,TSTR
*GET,TSTRESS_2,CINT,1,CTIP,TIP_NODE_NUMBER,CONTOUR,2,DTYPE,TSTR
*GET,TSTRESS_3,CINT,1,CTIP,TIP_NODE_NUMBER,CONTOUR,3,DTYPE,TSTR
*GET,TSTRESS_4,CINT,1,CTIP,TIP_NODE_NUMBER,CONTOUR,4,DTYPE,TSTR

TSTRESS = (TSTRESS_2+ TSTRESS_3 + TSTRESS_4) / 3
*STAT,TSTRESS
/OUT,SCRATCH
TSTRESS_RATIO = ABS(TSTRESS/TSTRESS_REFERENCE)
! STORE DATA
```

```
*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'T-STRESS'
*VFILL,VALUE(1,1),DATA,TSTRESS_REFERENCE
*VFILL,VALUE(1,2),DATA,TSTRESS
*VFILL,VALUE(1,3),DATA,TSTRESS_RATIO
SAVE,TABLE_2
FINISH
/CLEAR, NOSTART                ! CLEAR DATABASE FOR 2ND SOLUTION
/OUT,


/COM ***** CRACK IN 3D PLATE USING SOLID 186 ELEMENT ********
/OUT,SCRATCH
/PREP7
E=207000                     ! YOUNGS MODULUS
NU=0.3             ! POISSONS RATIO
SIG=100                  ! SURFACE LOAD
PI=3.141593
TK=1

! DIMENSIONS.
A = 10                     ! HALF CRACK LENGTH
ALPHA = 0.2                             ! ALPHA = A / W
HEIGHT_WIDTH_RATIO = 0.75               ! H / W
W = A / ALPHA                           ! HALF PLATE WIDTH
H = HEIGHT_WIDTH_RATIO*W                ! HALF PLATE HEIGHT
TSTRESS_REFERENCE_NORMALIZED = -0.88    ! TSTRESS TARGET VALUE
! NORMALIZED AS: T/SIG*(1-ALPHA)
! TSTRESS TARGET VALUE CORRESPONDING TO THE GIVEN DIMENSIONS:
TSTRESS_REFERENCE = (TSTRESS_REFERENCE_NORMALIZED*SIG) / (1 - ALPHA)

ET,1,PLANE183               ! PLANE 182 ELEMENT
ET,2,SOLID186               ! SOLID185 ELEMENT
MP,EX,1,E
MP,NUXY,1,NU

K,1,0,0                     ! DEFINE KEYPOINTS AND LINE SEGMENTS
K,2,A,0
K,3,W,0
K,4,W,H/2
K,5,W,H
K,6,0,H
K,7,0,H/2

L,1,2
*REP,6,1,1
L,7,1
L,4,7
AL,1,2,3,8,7
AL,4,5,6,8
ESIZE,1
KSCON,2,1,0,4,0.75          !CRACK TIP ELEMENTS
AMESH,1
ESIZE,2
AMESH,2
ALLSEL,ALL
TYPE,2
ESIZE,,5
VEXT,ALL,,,0,0,TK
ALLSEL,ALL
ESEL,S,ENAME,,183
ACLEAR,1,2,,,
ALLSEL
FINI

/SOLU
OUTRES,ALL,ALL
NSEL,S,LOC,Y,0
NSEL,R,LOC,X,A,W
D,ALL,UY,0
NSEL,S,LOC,X,0
```

```
NSEL,R,LOC,Y,0,H
D,ALL,UX,0
NSEL,ALL
ASEL,S,,,11
SFA,ALL,,PRESS,-SIG
ALLSEL,ALL

D,ALL,UZ,0
ALLSEL

NSEL,S,LOC,Y,0
NSEL,R,LOC,X,A
CM,CRACK1,NODE              ! DEFINE THE CRACK FRONT NODES COMPONENT
NSEL,ALL

CINT,NEW,1
CINT,TYPE,TSTR              ! CALCULATE T-STRESS
CINT,CTNC,CRACK1            ! CRACK ID
CINT,NCON,4                 ! NUMBER OF COUNTOURS
CINT,SYMM,ON                ! SYMMETRY ON
CINT,NORM,0,2
CINT,LIST
ALLSEL,ALL
SOLVE
FINISH

/POST1
/OUT,
PRCINT,1,,TSTR                     ! GET THE T-STRESS VALUES
TIP_NODE_NUMBER = NODE(A,0,0)
*GET,TSTRESS_1,CINT,1,CTIP,TIP_NODE_NUMBER,CONTOUR,1,DTYPE,TSTR
*GET,TSTRESS_2,CINT,1,CTIP,TIP_NODE_NUMBER,CONTOUR,2,DTYPE,TSTR
*GET,TSTRESS_3,CINT,1,CTIP,TIP_NODE_NUMBER,CONTOUR,3,DTYPE,TSTR
*GET,TSTRESS_4,CINT,1,CTIP,TIP_NODE_NUMBER,CONTOUR,4,DTYPE,TSTR

TSTRESS = (TSTRESS_2+ TSTRESS_3 + TSTRESS_4) / 3
*STAT,TSTRESS
/OUT,SCRATCH
TSTRESS_RATIO = ABS(TSTRESS/TSTRESS_REFERENCE)
! STORE DATA
*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'T-STRESS'
*VFILL,VALUE(1,1),DATA,TSTRESS_REFERENCE
*VFILL,VALUE(1,2),DATA,TSTRESS
*VFILL,VALUE(1,3),DATA,TSTRESS_RATIO
SAVE,TABLE_3
/OUT,
FINISH
RESUME,TABLE_1
/COM
/OUT,vm279,vrt
/COM,------------------- VM279 RESULTS COMPARISON -------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM, ****************************************
/COM,  USING PLANE 183 ELEMENT (2-D ANALYSIS)
/COM, *****************************************
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
/COM, *****************************************
/COM,  USING SOLID 185 ELEMENT (3-D ANALYSIS)
/COM, *****************************************
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
```

```
/NOPR
RESUME,TABLE_3
/GOPR
/COM,
/COM, ********************************************************
/COM,  USING SOLID 186 ELEMENT (3-D ANALYSIS)
/COM, ********************************************************
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/NOPR
/COM,
/COM,----------------------------------------------------------
/OUT,
FINISH
*LIST,vm279,vrt
```

VM280 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM280
/TITLE,VM280, CONDUCTION IN A DOUBLY INSULATED PIPE CARRYING STEAM
C*** USING SOLID278
/COM,  REF: KOTHANDARAMAN,C.P.,
/COM, "FUNDAMENTALS OF HEAT AND MASS TRANSFER"-3RD EDITION,
/COM,  CH-2 STEADY STATE CONDUCTION,P35,PROBLEM2.2
/PREP7
ET,1,SOLID278    !*3-D 8-NODE THERMAL SOLID
MP,KXX,1,49        !*CONDUCTIVITY OF THE PIPE MATERIAL
MP,KXX,2,0.15    !*CONDUCTIVITY OF FIRST LAYER OF INSULATION
MP,KXX,3,0.48    !*CONDUCTIVITY OF SECOND LAYER OF INSULATION
CSYS,1
CYL4,,,0.06,0,0.0675,90,0.25    !*DEFINE THE GEOMETRY OF THE SYSTEM IN METERS
CYL4,,,0.0675,0,0.1175,90,0.25
CYL4,,,0.1175,0,0.1675,90,0.25
VPTN,ALL    !*PARTITIONING OF THE ENTITIES
ESIZE,0.005    !*MESH VOLUMES
MAT,1
TYPE,1
VMESH,1
ALLSEL,ALL
MAT,2
TYPE,1
VMESH,4
ALLSEL,ALL
MAT,3
TYPE,1
VMESH,5
ALLSEL,ALL
FINI
/SOLU
ANTYPE,STATIC
NSEL,S,LOC,X,0.06
ESLN,
SFE,ALL,4,CONV,1,85
SFE,ALL,4,CONV,2,230
ALLSEL,ALL
NSEL,S,LOC,X,0.1675
ESLN,
SFE,ALL,6,CONV,1,18
SFE,ALL,6,CONV,2,35
ALLSEL,ALL
SOLVE
FINI
/POST1
SET,LAST
PLNSOL,TEMP
*GET,TEMP_0.06,NODE,NODE(0.06,0,0),TEMP,,
```

```
*GET,TEMP_0.0675,NODE,NODE(0.0675,0,0),TEMP
*GET,TEMP_0.1175,NODE,NODE(0.1175,0,0),TEMP
*GET,TEMP_0.1675,NODE,NODE(0.1675,0,0),TEMP

*DIM,LABEL,CHAR,4,3
*DIM,VALUE,,4,3
LABEL(1,1) = 'TEMP @ x','TEMP @ x', 'TEMP @ x', 'TEMP @ x'
LABEL(1,2) = '=0.06','=0.0675 ','=0.1175','=0.1675'
LABEL(1,3) = 'T (C)','T (C)','T (C)', 'T (C)'
*VFILL,VALUE(1,1),DATA,222.3,222.2,77.04,48.03
*VFILL,VALUE(1,2),DATA,temp_0.06,temp_0.0675,temp_0.1175,temp_0.1675
*VFILL,VALUE(1,3),DATA,ABS(temp_0.06/222.3),ABS(temp_0.0675/222.2),ABS(temp_0.1175/77.04),ABS(temp_0.1675/48.03)
SAVE,TABLE1
FINI
/CLEAR,NOSTART


C*** USING SOLID279 - 3-D 20-NODE THERMAL SOLID
/PREP7
ET,1,SOLID279    !*3-D 20-NODE THERMAL SOLID
MP,KXX,1,49        !*CONDUCTIVITY OF THE PIPE MATERIAL
MP,KXX,2,0.15    !*CONDUCTIVITY OF FIRST LAYER OF INSULATION
MP,KXX,3,0.48    !*CONDUCTIVITY OF SECOND LAYER OF INSULATION
CSYS,1
CYL4,,,0.06,0,0.0675,90,0.25    !*DEFINE THE GEOMETRY OF THE SYSTEM IN METERS
CYL4,,,0.0675,0,0.1175,90,0.25
CYL4,,,0.1175,0,0.1675,90,0.25
VPTN,ALL    !*PARTITIONING OF THE ENTITIES
ESIZE,0.005    !*MESH VOLUMES
MAT,1
TYPE,1
VMESH,1
ALLSEL,ALL
MAT,2
TYPE,1
VMESH,4
ALLSEL,ALL
MAT,3
TYPE,1
VMESH,5
ALLSEL,ALL
FINI
/SOLU
NSEL,S,LOC,X,0.06
ESLN,
SFE,ALL,4,CONV,1,85
SFE,ALL,4,CONV,2,230
ALLSEL,ALL
NSEL,S,LOC,X,0.1675
ESLN,
SFE,ALL,6,CONV,1,18
SFE,ALL,6,CONV,2,35
ALLSEL,ALL
ANTYPE,STATIC
SOLVE
FINI
/POST1
PLNSOL,TEMP
*GET,TEMP_0.06,NODE,NODE(0.06,0,0),TEMP,,
*GET,TEMP_0.0675,NODE,NODE(0.0675,0,0),TEMP
*GET,TEMP_0.1175,NODE,NODE(0.1175,0,0),TEMP
*GET,TEMP_0.1675,NODE,NODE(0.1675,0,0),TEMP


*DIM,LABEL,CHAR,4,3
*DIM,VALUE,,4,3
LABEL(1,1) = 'TEMP @ x','TEMP @ x', 'TEMP @ x', 'TEMP @ x'
LABEL(1,2) = '=0.06','=0.0675 ','=0.1175','=0.1675'
LABEL(1,3) = 'T (C)','T (C)','T (C)', 'T (C)'
*VFILL,VALUE(1,1),DATA,222.3,222.2,77.04,48.03
*VFILL,VALUE(1,2),DATA,temp_0.06,temp_0.0675,temp_0.1175,temp_0.1675
*VFILL,VALUE(1,3),DATA,ABS(temp_0.06/222.3),ABS(temp_0.0675/222.2),ABS(temp_0.1175/77.04),ABS(temp_0.1675/48.03)
```

```
SAVE,TABLE2

/NOPR
/COM
/OUT,vm280,vrt
/COM,------------------- VM280 RESULTS COMPARISON --------------
/COM,
/COM,                       |   TARGET   |   MECHANICAL APDL   |   RATIO
/COM,
RESUME,TABLE1
/COM, TEMPERATURES AT THE INTERFACE FOR SOLID278
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),LABEL(1,3),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,A5,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
RESUME,TABLE2
/COM, TEMPERATURES AT THE INTERFACE FOR SOLID279
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),LABEL(1,3),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,A5,'   ',F10.3,'  ',1F14.3,'   ',1F15.3)
/COM,
/COM,-----------------------------------------------------------------
/OUT,
FINI
*LIST,vm280,vrt
```

VM281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM281
/TITLE,VM281,EFFECT OF STRESS STIFFENING AND SPIN SOFTENING ON A ROTATING PLATE
/COM,
/COM, REFERENCE: NASA TECHNICAL MEMORANDUM 89861,PAGE 14,FIGURE 7
/COM,

/COM, ====================================================================
/COM,  MODELING THE PLATE USING 4-NODE STRUCTURAL SHELL ELEMENT (SHELL181)
/COM, =====================================================================


/PREP7
lg = 152.4e-3       ! LENGTH IN METERS
wd = 50.8e-3        ! WIDTH IN METERS
tk = 2.54e-3        ! THICKNESS IN METERS

K,1,-wd/2,0,0
K,2,+wd/2,0,0
K,3,+wd/2,lg,0
K,4,-wd/2,lg,0
A,1,2,3,4

/COM, MATERIAL PROPERTIES OF STRUCTURAL STEEL PLATE

MP,EX,1,2.0e+11
MP,DENS,1,7850
MP,NUXY,1,0.3

ET,1,SHELL181       ! 4-NODE STRUCTURAL SHELL ELEMENT
SECTYPE,1,SHELL
SECDATA,tk,1,0,3    ! THICKNESS

TYPE,1
MAT,1
SECNUM,1
ESIZE,5e-3
AMESH,1

NSEL,S,LOC,Y,0.0
D,ALL,ALL           ! CONSTRAINING ALL DOF AT BASE
```

```
ALLSEL,ALL

CM,PLATE,ELEM       ! FORMING A COMPONENT WITH ALL ELEMENTS
SAVE,SHELL,DB       ! SAVE THE DATABASE
FINISH

/COM, ----------------------
/COM, NO ROTATION
/COM, ----------------------

/OUT,SCRATCH
/SOLUTION
ANTYPE,MODAL
MODOPT,LANB,4       ! EXTRACT 4 MODES USING BLOCK-LANCZOS
MXPAND,4
SOLVE
/OUT,
*GET,FREQ1_SH,MODE,1,FREQ
FINISH
/DELETE,,rst

/COM, -------------------------------------
/COM, PLATE ROTATED ALONG X AXIS AT 3200 RPM
/COM, -------------------------------------

/OUT,SCRATCH
/SOLUTION
ANTYPE,STATIC
OFFSET= -0.1
pi = acos(-1)
CMOMEGA,PLATE,3200*pi/30,,,0,OFFSET,0,1,OFFSET,0        ! ROTATING THE PLATE ALONG X AXIS
NLGEOM,ON                                               ! NON-LINEAR ANALYSIS
TIME,1.0
AUTOTS,ON
NSUBS,10,100,1
OUTRES,ALL,ALL
SOLVE
FINISH

/SOLUTION
ANTYPE,STATIC,RESTART,,,PERTURB                         ! LINEAR PERTURBATION ANALYSIS
PERTURB,MODAL,                                          ! MODAL ANALYSIS,RETAIN CMOMEGA
SOLVE,ELFORM                                            ! REGENERATE STIFFNESS MATRIX

MODOPT,LANB,4
MXPAND,4
SOLVE
/OUT,
*GET,FREQ2_SH,MODE,1,FREQ
FINISH
/DELETE,,rst
/DELETE,,rstp


/COM, -------------------------------------
/COM, PLATE ROTATED ALONG X AXIS AT 9600 RPM
/COM, -------------------------------------

/OUT,SCRATCH
/SOLUTION
ANTYPE,STATIC
OFFSET= -0.1
pi = acos(-1)
CMOMEGA,PLATE,9600*pi/30,,,0,OFFSET,0,1,OFFSET,0        ! ROTATING THE PLATE ALONG X AXIS
NLGEOM,ON                                               ! NON-LINEAR ANALYSIS
TIME,1.0
AUTOTS,ON
NSUBS,10,100,1
OUTRES,ALL,ALL
SOLVE
FINISH
```

```
/SOLUTION
ANTYPE,STATIC,RESTART,,,PERTURB                          ! LINEAR PERTURBATION ANALYSIS
PERTURB,MODAL,                                           ! MODAL ANALYSIS,RETAIN CMOMEGA
SOLVE,ELFORM                                             ! REGENERATE STIFFNESS MATRIX

MODOPT,LANB,4
MXPAND,4
SOLVE
/OUT,
*GET,FREQ3_SH,MODE,1,FREQ
FINISH
/DELETE,,rst
/DELETE,,rstp


/COM, -------------------------------------
/COM, PLATE ROTATED ALONG Z AXIS AT 3200 RPM
/COM, -------------------------------------

/OUT,SCRATCH
/SOLUTION
ANTYPE,STATIC
OFFSET= -0.1
pi = acos(-1)
CMOMEGA,PLATE,3200*pi/30,,,0,OFFSET,0,0,OFFSET,1         ! ROTATING THE PLATE ALONG Z AXIS
NLGEOM,ON                                                ! NON-LINEAR ANALYSIS
TIME,1.0
AUTOTS,ON
NSUBS,10,100,1
OUTRES,ALL,ALL
SOLVE
FINISH

/SOLUTION
ANTYPE,STATIC,RESTART,,,PERTURB                          ! LINEAR PERTURBATION ANALYSIS
PERTURB,MODAL,                                           ! MODAL ANALYSIS,RETAIN CMOMEGA
SOLVE,ELFORM                                             ! REGENERATE STIFFNESS MATRIX

MODOPT,LANB,4
MXPAND,4
SOLVE
/OUT,
*GET,FREQ4_SH,MODE,1,FREQ
FINISH
/DELETE,,rst
/DELETE,,rstp


/COM, -------------------------------------
/COM, PLATE ROTATED ALONG Z AXIS AT 9600 RPM
/COM, -------------------------------------

/OUT,SCRATCH
/SOLUTION
ANTYPE,STATIC
OFFSET= -0.1
pi = acos(-1)
CMOMEGA,PLATE,9600*pi/30,,,0,OFFSET,0,0,OFFSET,1         ! ROTATING THE PLATE ALONG Z AXIS
NLGEOM,ON                                                ! NON-LINEAR ANALYSIS
TIME,1.0
AUTOTS,ON
NSUBS,10,100,1
OUTRES,ALL,ALL
SOLVE
FINISH

/SOLUTION
ANTYPE,STATIC,RESTART,,,PERTURB                          ! LINEAR PERTURBATION ANALYSIS
PERTURB,MODAL,                                           ! MODAL ANALYSIS,RETAIN CMOMEGA
SOLVE,ELFORM                                             ! REGENERATE STIFFNESS MATRIX

MODOPT,LANB,4
```

```
MXPAND,4
SOLVE
/OUT,
*GET,FREQ5_SH,MODE,1,FREQ
FINISH

/OUT,SCRATCH
*DIM,LABEL,CHAR,5,2
*DIM,VALUE,,5,3

LABEL(1,1) = 'None'
LABEL(1,2) = '0rpm'
LABEL(2,1) = 'X axis'
LABEL(2,2) = '3200rpm'
LABEL(3,1) = 'X axis'
LABEL(3,2) = '9600rpm'
LABEL(4,1) = 'Z axis'
LABEL(4,2) = '3200rpm'
LABEL(5,1) = 'Z axis'
LABEL(5,2) = '9600rpm'

*VFILL,VALUE(1,1),DATA,90
*VFILL,VALUE(1,2),DATA,FREQ1_SH
*VFILL,VALUE(1,3),DATA,(90/FREQ1_SH)

*VFILL,VALUE(2,1),DATA,108
*VFILL,VALUE(2,2),DATA,FREQ2_SH
*VFILL,VALUE(2,3),DATA,(108/FREQ2_SH)

*VFILL,VALUE(3,1),DATA,195
*VFILL,VALUE(3,2),DATA,FREQ3_SH
*VFILL,VALUE(3,3),DATA,(195/FREQ3_SH)

*VFILL,VALUE(4,1),DATA,121
*VFILL,VALUE(4,2),DATA,FREQ4_SH
*VFILL,VALUE(4,3),DATA,(121/FREQ4_SH)

*VFILL,VALUE(5,1),DATA,250
*VFILL,VALUE(5,2),DATA,FREQ5_SH
*VFILL,VALUE(5,3),DATA,(250/FREQ5_SH)
SAVE,TABLE_1
FINISH
/CLEAR,NOSTART

/OUT,
/COM, =====================================================================
/COM,  MODELING THE PLATE USING 8-NODE STRUCTURAL SOLID ELEMENT (SOLID185)
/COM, ======================================================================


/PREP7

lg = 152.4e-3       ! LENGTH IN METERS
wd = 50.8e-3        ! WIDTH IN METERS
tk = 2.54e-3        ! THICKNESS IN METERS


K,1,-wd/2,0,0
K,2,+wd/2,0,0
K,3,+wd/2,lg,0
K,4,-wd/2,lg,0
K,5,-wd/2,0,tk
K,6,+wd/2,0,tk
K,7,+wd/2,lg,tk
K,8,-wd/2,lg,tk


V,1,2,3,4,5,6,7,8

/COM, MATERIAL PROPERTIES OF STRUCTURAL STEEL PLATE

MP,EX,1,2.0e+11
```

```
MP,DENS,1,7850
MP,NUXY,1,0.3


ET,1,SOLID185       ! 3-D 8 NODE STRUCTURAL SOLID ELEMENT
KEYOPT,1,2,3        ! SIMPLIFIED ENHANCED STRAIN FORMULATION

TYPE,1
MAT,1
ESIZE,5e-3
VMESH,1

NSEL,S,LOC,Y,0.0
D,ALL,ALL           ! CONSTRAINING ALL DOF AT BASE
ALLSEL,ALL

CM,PLATE,ELEM       ! FORMING A COMPONENT WITH ALL ELEMENTS
SAVE,SOLID,DB       ! SAVE THE DATABASE
FINISH

/COM, ----------------------
/COM, NO ROTATION
/COM, ----------------------

/OUT,SCRATCH
/SOLUTION
ANTYPE,MODAL
MODOPT,LANB,4       ! EXTRACT 4 MODES USING BLOCK-LANCZOS
MXPAND,4
SOLVE
/OUT,
*GET,FREQ1_SO,MODE,1,FREQ
FINISH
/DELETE,,rst


/COM, ------------------------------------
/COM, PLATE ROTATED ALONG X AXIS AT 3200RPM
/COM, ------------------------------------

/OUT,SCRATCH
/SOLUTION
ANTYPE,STATIC
OFFSET= -0.1
pi = acos(-1)
CMOMEGA,PLATE,3200*pi/30,,,0,OFFSET,0,1,OFFSET,0        ! ROTATING THE PLATE ALONG X AXIS
NLGEOM,ON                                               ! NON-LINEAR ANALYSIS
TIME,1.0
AUTOTS,ON
NSUBS,10,100,1
OUTRES,ALL,ALL
SOLVE
FINISH

/SOLUTION
ANTYPE,STATIC,RESTART,,,PERTURB                         ! LINEAR PERTURBATION ANALYSIS
PERTURB,MODAL,                                          ! MODAL ANALYSIS,RETAIN CMOMEGA
SOLVE,ELFORM                                            ! REGENERATE STIFFNESS MATRIX

MODOPT,LANB,4
MXPAND,4
SOLVE
/OUT,
*GET,FREQ2_SO,MODE,1,FREQ
FINISH
/DELETE,,rst
/DELETE,,rstp

/COM, ------------------------------------
/COM, PLATE ROTATED ALONG X AXIS AT 9600RPM
/COM, ------------------------------------
```

```
/OUT,SCRATCH
/SOLUTION
ANTYPE,STATIC
OFFSET= -0.1
pi = acos(-1)
CMOMEGA,PLATE,9600*pi/30,,,0,OFFSET,0,1,OFFSET,0         ! ROTATING THE PLATE ALONG X AXIS
NLGEOM,ON                                                ! NON-LINEAR ANALYSIS
TIME,1.0
AUTOTS,ON
NSUBS,10,100,1
OUTRES,ALL,ALL
SOLVE
FINISH

/SOLUTION
ANTYPE,STATIC,RESTART,,,PERTURB                          ! LINEAR PERTURBATION ANALYSIS
PERTURB,MODAL,                                           ! MODAL ANALYSIS,RETAIN CMOMEGA
SOLVE,ELFORM                                             ! REGENERATE STIFFNESS MATRIX

MODOPT,LANB,4
MXPAND,4
SOLVE
/OUT,
*GET,FREQ3_SO,MODE,1,FREQ
FINISH
/DELETE,,rst
/DELETE,,rstp


/COM, -------------------------------------
/COM, PLATE ROTATED ALONG Z AXIS AT 3200RPM
/COM, -------------------------------------

/OUT,SCRATCH
/SOLUTION
ANTYPE,STATIC
OFFSET= -0.1
pi = acos(-1)
CMOMEGA,PLATE,3200*pi/30,,,0,OFFSET,0,0,OFFSET,1         ! ROTATING THE PLATE ALONG Z AXIS
NLGEOM,ON                                                ! NON-LINEAR ANALYSIS
TIME,1.0
AUTOTS,ON
NSUBS,10,100,1
OUTRES,ALL,ALL
SOLVE
FINISH

/SOLUTION
ANTYPE,STATIC,RESTART,,,PERTURB                          ! LINEAR PERTURBATION ANALYSIS
PERTURB,MODAL,                                           ! MODAL ANALYSIS,RETAIN CMOMEGA
SOLVE,ELFORM                                             ! REGENERATE STIFFNESS MATRIX

MODOPT,LANB,4
MXPAND,4
SOLVE
/OUT,
*GET,FREQ4_SO,MODE,1,FREQ
FINISH
/DELETE,,rst
/DELETE,,rstp


/COM, -------------------------------------
/COM, PLATE ROTATED ALONG Z AXIS AT 9600RPM
/COM, -------------------------------------

/OUT,SCRATCH
/SOLUTION
ANTYPE,STATIC
OFFSET= -0.1
pi = acos(-1)
CMOMEGA,PLATE,9600*pi/30,,,0,OFFSET,0,0,OFFSET,1         ! ROTATING THE PLATE ALONG Z AXIS
```

```
NLGEOM,ON                                                   ! NON-LINEAR ANALYSIS
TIME,1.0
AUTOTS,ON
NSUBS,10,100,1
OUTRES,ALL,ALL
SOLVE
FINISH

/SOLUTION
ANTYPE,STATIC,RESTART,,,PERTURB                             ! LINEAR PERTURBATION ANALYSIS
PERTURB,MODAL,                                              ! MODAL ANALYSIS,RETAIN CMOMEGA
SOLVE,ELFORM                                                ! REGENERATE STIFFNESS MATRIX

MODOPT,LANB,4
MXPAND,4
SOLVE
/OUT,
*GET,FREQ5_SO,MODE,1,FREQ
FINISH


/OUT,SCRATCH
*DIM,LABEL,CHAR,5,2
*DIM,VALUE,,5,3

LABEL(1,1) = 'None'
LABEL(1,2) = '0rpm'
LABEL(2,1) = 'X axis'
LABEL(2,2) = '3200rpm'
LABEL(3,1) = 'X axis'
LABEL(3,2) = '9600rpm'
LABEL(4,1) = 'Z axis'
LABEL(4,2) = '3200rpm'
LABEL(5,1) = 'Z axis'
LABEL(5,2) = '9600rpm'

*VFILL,VALUE(1,1),DATA,90
*VFILL,VALUE(1,2),DATA,FREQ1_SO
*VFILL,VALUE(1,3),DATA,(90/FREQ1_SO)

*VFILL,VALUE(2,1),DATA,108
*VFILL,VALUE(2,2),DATA,FREQ2_SO
*VFILL,VALUE(2,3),DATA,(108/FREQ2_SO)

*VFILL,VALUE(3,1),DATA,195
*VFILL,VALUE(3,2),DATA,FREQ3_SO
*VFILL,VALUE(3,3),DATA,(195/FREQ3_SO)

*VFILL,VALUE(4,1),DATA,121
*VFILL,VALUE(4,2),DATA,FREQ4_SO
*VFILL,VALUE(4,3),DATA,(121/FREQ4_SO)

*VFILL,VALUE(5,1),DATA,250
*VFILL,VALUE(5,2),DATA,FREQ5_SO
*VFILL,VALUE(5,3),DATA,(250/FREQ5_SO)
SAVE,TABLE_2
FINISH
/NOPR
RESUME,TABLE_1
/GOPR
/OUT,vm281,vrt
/COM,
/COM, -----------------------------VM281 RESULTS COMPARISON-----------------------
/COM,
/COM,                           | TARGET | MECHANICAL APDL | RATIO
/COM,
/COM,
/COM,  USING SHELL181 ELEMENTS
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',A8,'   'F12.3,'    ',F12.3,'    ',F8.3)
/COM,
```

```
/COM,  USING SOLID185 ELEMENTS
/COM,
/NOPR,
RESUME,TABLE_2
/GOPR,
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',A8,'   'F12.3,'    ',F12.3,'    ',F8.3)
/COM,
/COM,--------------------------------------------------------------------------------
/OUT,
*LIST,vm281,vrt
FINISH
```

VM282 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM282
/TITLE,VM282,STEADY STATE VIBRATION ANALYSIS OF PISTON-FLUID SYSTEM
/COM, -------------------------------------------------------------
/COM, REFERENCE:
/COM, F. AXISA and J. ANTUNES, MODELLING OF MECHANICAL SYSTEMS:
/COM, FLUID-STRUCTURE INTERACTION, VOLUME 3, 2007, PAGE:486.
/COM, -------------------------------------------------------------

/OUT,SCRATCH
! *** FLUID COLUMN ***
!---------------------
LF = 24          ! TUBE LENGTH
RAD = 0.125         ! TUBE RADIUS
RHOF = 1000         ! FLUID VELOCITY
SONCF = 1000            ! SONIC VELOCITY (SPEED OF SOUND IN A FLUID)
! *** CALCULATED FLUID PARAMETERS ***
!------------------------------------
PI = ACOS(-1)
SF = PI*RAD**2
MF = RHOF*SF*LF
KF = RHOF*SONCF**2*SF/LF
! *** PISTON (UNDAMPED -> MODAL DAMPING) ***
!-------------------------------------------
KS = KF          ! SPRING STIFFNESS (GAMMA = KF/KS = 1)
MS = MF/2                                   ! POINT MASS  (MU = MF/MS = 2)
F0 = 1000          ! APPLIED FORCE
/PREP7
LOCAL,13,0,0,0,0, , , 90,1,1,
WPCSYS,-1,13,
CYl4,0,0,RAD, , , ,LF
CSYS,0
N,1,-1,0,0
N,2,0,0,0
ET,1,COMBIN14                            ! ELEMENT 1 - COMBIN14
KEYOPT,1,3,0                             ! UX DEGREE OF FREEDOM
R,1,KS
ET,2,MASS21                              ! ELEMENT 2 - MASS21
KEYOPT,2,3,2                             ! 3D MASS WITHOUT ROTARY INERTIA
R,2,MS
ET,3,FLUID30,,0,,0       ! ELEMENT 3 - FLUID WITH UNSYM COUPLING
R,3
MP,DENS,3,RHOF
MP,SONC,3,SONCF
ET,4,CONTA174        ! ELEMENT 4 - CONTACT ELEMENTS
R,4
KEYOPT,4,2,2                    ! MPC STYLE CONTACT
KEYOPT,4,4,2                    ! RIGID CERIG STYLE LOAD
KEYOPT,4,12,5                   ! BONDED CONTACT
ET,5,TARGE170        ! ELEMENT 5 - PILOT NODE
KEYOPT,5,2,1                    ! DON'T FIX THE PILOT NODE
KEYOPT,5,4,111111
```

```
TYPE,1
REAL,1
EN,1,1,2
TYPE,2
REAL,2
EN,2,2
TYPE,3
MAT,3
REAL,3
ESIZE,LF/200
VSWEEP,1
VSEL,S,,,1
NSEL,R,LOC,X,0
TYPE,4
REAL,4
ESURF
TYPE,5
TSHAPE,PILO
E,2
TSHAPE
ALLSEL,ALL,ALL
ESEL,S,ENAME,,30
NSEL,S,LOC,X,0
SF,ALL,FSI
ALLSEL,ALL,ALL
D,1,ALL
D, 2, UY, , , , , UZ, ROTX, ROTY, ROTZ
F,2,FX,F0
ALLSEL,ALL,ALL
SAVE
FINISH
! *** SOLUTION CONTROLS FOR MODAL ANALYSIS ***
! --------------------------------------------
/SOLUTION
ANTYPE,MODAL
MODOPT,UNSYM,10,,,,,BOTH
MXPAND,ALL
SOLVE
*GET,FREQ_1,MODE,2,FREQ
*GET,FREQ_2,MODE,3,FREQ
*GET,FREQ_3,MODE,4,FREQ
*GET,FREQ_4,MODE,5,FREQ
*GET,FREQ_5,MODE,6,FREQ
FINISH
! *** SOLUTION CONTROLS FOR MSUP HARMONIC ANALYSIS ***
! ----------------------------------------------------
/SOLUTION
ANTYPE,HARM
HROPT,MSUP
HARFRQ,0.0,100.0
KBC,1
NSUB,1000
OUTRES,ERASE
OUTRES,ALL,NONE
OUTRES,NSOL,ALL
! *** MODAL DAMPING RATIOS ***
! ----------------------------
MDAMP,1,0.0,2.0453E-02,3.6948E-03,7.0040E-04,2.2468E-04,9.8247E-05
FDELE,ALL
LVSCALE,1
SOLVE
FINISH
! *** EXPANSION PASS ***
! ----------------------
/SOLUTION
EXPASS,ON
NUMEXP,ALL,,,NO
SOLVE
FINISH
/POST1
FILE,vm282,rst
SET,,,,3,1
```

```
*GET,RES_1,NODE,2,U,X
*GET,PRES_1,NODE,1712,PRES
SET,,,,3,9.9
*GET,RES_2,NODE,2,U,X
*GET,PRES_2,NODE,1712,PRES
FINISH
! *** TIME HISTORY POST PROCESSOR ***
! ------------------------------------
/POST26
/GROPT,LOGX,ON
/GROPT,LOGY,ON
NSOL,2,2,U,X
/SHOW,PNG
PLVAR,2
PRCPLX,1
PRVAR,2
EXTREME,2
NPRES = NODE(LF/2,0,0)
NSOL,3,NPRES,PRES
PLVAR,3
PRVAR,3
EXTREME,3
/SHOW,CLOSE
FINISH
/OUT,
/COM, ----------------------------
/COM, FREQUENCY (Hz) VALUES
/COM, ----------------------------
*STATUS,FREQ_1
*STATUS,FREQ_2
*STATUS,FREQ_3
*STATUS,FREQ_4
*STATUS,FREQ_5
/COM, ----------------------------
/COM, RESPONSE AMPLITUDE OF PISTON
/COM, ----------------------------
*STATUS,RES_1
*STATUS,RES_2
/COM, -----------------------------------------
/COM, PRESSURE AMPLITUDE AT MID-COLUMN OF FLUID
/COM, -----------------------------------------
*STATUS,PRES_1
*STATUS,PRES_2
/OUT,SCRATCH

*DIM,LABEL,CHAR,5,3
*DIM,VALUE,,5,3
LABEL(1,1) = 'FREQ(f1),      ','FREQ(f2)  ','FREQ(f3)  ','FREQ(f4)  ','FREQ(f5)  '
LABEL(1,2) = '     Hz','     Hz','     Hz','     Hz','     Hz'
*VFILL,VALUE(1,1),DATA,9.916,24.583,43.729,63.895,84.395
*VFILL,VALUE(1,2),DATA,FREQ_1,FREQ_2,FREQ_3,FREQ_4,FREQ_5
*VFILL,VALUE(1,3),DATA,FREQ_1/9.9167,FREQ_2/24.5833,FREQ_3/43.7292,FREQ_4/63.8958,FREQ_5/84.3958

*DIM,LAB1,CHAR,2,2
*DIM,VALUE1,,2,3
LAB1(1,1) = 'RES_1, ','RES_f1  '
LAB1(1,2) = '  M','  M'
*VFILL,VALUE1(1,1),DATA,2.47E-04,5.76E-03
*VFILL,VALUE1(1,2),DATA,RES_1,RES_2
*VFILL,VALUE1(1,3),DATA,ABS(RES_1)/2.47E-04,ABS(RES_2)/5.76E-03

*DIM,LAB2,CHAR,2,2
*DIM,VALUE2,,2,3
LAB2(1,1) = 'PRES_1, ','PRES_f1  '
LAB2(1,2) = '  MPa','  MPa'
*VFILL,VALUE2(1,1),DATA,1.03E+04,2.64E+05
*VFILL,VALUE2(1,2),DATA,PRES_1,PRES_2
*VFILL,VALUE2(1,3),DATA,ABS(PRES_1)/1.03E+04,ABS(PRES_2)/2.64E+05
/COM,
/OUT,vm282,vrt
/COM,------------------- VM282 RESULTS COMPARISON --------------
/COM,
```

```
/COM,                    |   TARGET   |   Mechanical APDL      |   RATIO
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F12.3,'  ',F16.3,'   ',1F15.3)
/COM,
/COM,RESPONSE AMPLITUDE OF PISTON
/COM,
*VWRITE,LAB1(1,1),LAB1(1,2),VALUE1(1,1),VALUE1(1,2),VALUE1(1,3)
(1X,A8,A8,'   ',F12.5,'  ',F16.5,'   ',1F15.3)
/COM,
/COM,PRESSURE AMPLITUDE AT MID-COLUMN
/COM,
*VWRITE,LAB2(1,1),LAB2(1,2),VALUE2(1,1),VALUE2(1,2),VALUE2(1,3)
(1X,A8,A8,'   ',F12.3,'  ',F16.3,'   ',1F15.3)
/COM,----------------------------------------------------------

/OUT,
FINISH
*LIST,vm282,vrt
FINISH
```

VM283 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VM283
/TITLE,VM283,Low Reduced Frequency Model for Visco-thermal Fluid with Thin Structure
/COM,
/COM, REFERENCE:
/COM, W. M. BELTMAN, "Viscothermal Wave Propagation Including Acousto-elastic Interaction",
/COM, THESIS, SECTION6.3, PP128-136, ISBN 90-3651217-4, 1998.
/COM,

/PREP7

ET,1,FLUID30,,1                 ! FLUID30 ELEMENTS, NO FSI
ET,2,SOLSH190                   ! SOLIDSHELL190 ELEMENTS
ET,3,FLUID30,,0                 ! FLUID30 ELEMENTS, WITH FSI

/COM, MATERIAL PROPERTIES FOR AIR

rho = 1.2                       ! DENSITY
c0 = 340                        ! SOUND SPEED
visc = 18.2e-6                  ! DYNAMIC VISCOSITY
kxx = 25.6e-3                   ! THERMAL CONDUCTIVITY
Cp = 1004                       ! SPECIFIC HEAT
Cv = 1004/1.4

z0 = rho*c0
WL=c0/300
H=WL/15

tp1 = 1e-3
tp2 = 2e-3
h0 = 1e-3

LX = 245e-3
LY = 122.5e-3
ZA = 0.5                        ! HEIGHT OF ROOM A
ZB = 2.0                        ! HEIGHT OF ROOM B

TB,AFDM,1,,,MAT                 ! ACOUSTIC FREQUENCY-DEPENDENT MATERIAL PROPERTIES
TBDATA,1,rho,c0,visc,kxx,Cp,Cv
TB,AFDM,1,,,THIN                ! ACOUSTIC FREQUENCY-DEPENDENT THIN LAYER
TBDATA,1,2*h0

/COM, MATERIAL PROPERTIES FOR ALUMINIUM PLATE

MP,DENS,2,2710                  ! DENSITY
```

```
MP,EX,2,70.e9                    ! ELASTIC MODULUS
MP,NUXY,2,0.3                    ! POISSON'S RATIO
MP,DENS,3,rho
MP,SONC,3,c0

*DIM,zz,ARRAY,6
zz(1)=0
zz(2)=zz(1)+zb
zz(3)=zz(2)+tp2
zz(4)=zz(3)+2*h0
zz(5)=zz(4)+tp1
zz(6)=zz(5)+za

*DO,i,1,5
BLOCK,-LX,LX,-LY,LY,zz(i),zz(i+1)
*ENDDO
VGLUE,ALL
SHPP,OFF,ALL

LSEL,S,LOC,Y,0
LESIZE,ALL,,,1
ALLSEL,ALL

VSEL,S,LOC,Z,zz(3),zz(4)
LESIZE,67,,,4
ESIZE,LX/10
TYPE,1
MAT,1
/OUT,SCRATCH
VMESH,ALL

VSEL,S,LOC,Z,zz(2),zz(3)
VSEL,A,LOC,Z,zz(4),zz(5)
TYPE,2
MAT,2
LESIZE,61,,,3
LESIZE,69,,,3
VEORIENT,6,THIN
VEORIENT,8,THIN
VMESH,ALL

VSEL,S,LOC,Z,zz(1),zz(2)
TYPE,1
MAT,3
ESIZE,(zz(2)-zz(1))/15
VMESH,ALL
ALLSEL,ALL

VSEL,S,LOC,Z,zz(5),zz(6)
ESIZE,(zz(6)-zz(5))/10
VMESH,ALL
ALLSEL,ALL

NSEL,S,LOC,Y,-ly
NSEL,A,LOC,Y,ly
D,ALL,UY
ALLSEL,ALL

NSEL,S,LOC,Z,zz(2)
NSEL,A,LOC,Z,zz(3)
NSEL,A,LOC,Z,zz(4)
NSEL,A,LOC,Z,zz(5)
ESLN,S,0
ESEL,U,TYPE,,2
EMODIF,ALL,TYPE,3
ALLSEL,ALL

ESEL,S,TYPE,,3
NSLE,S
NSEL,S,LOC,Z,zz(2)
NSEL,A,LOC,Z,zz(3)
NSEL,A,LOC,Z,zz(4)
```

```
NSEL,A,LOC,Z,zz(5)
ESEL,S,TYPE,,2
NSLE,R
ESEL,S,TYPE,,3
SF,ALL,FSI                            ! FLUID SOLID INTERACTION
ALLSEL,ALL

NSEL,S,LOC,Z,zz(2)
NSEL,A,LOC,Z,zz(5)
NSEL,R,LOC,X,LX
D,ALL,UZ,0,,,,UX,UY
ALLSEL,ALL

NSEL,S,LOC,Z,zz(2)
NSEL,A,LOC,Z,zz(5)
NSEL,R,LOC,X,-LX
D,ALL,UZ,0,,,,UX,UY
ALLSEL,ALL
NSEL,S,LOC,Z,zz(6)
SF,ALL,PORT,1                         ! PORT NUMBER
NSEL,R,LOC,X,LX
BF,ALL,JS,1                           ! MASS SOURCE RATE
ALLSEL,ALL

NSEL,S,LOC,Z,zz(1)
SF,ALL,IMPD,z0                        ! IMPEDANCE
SF,ALL,PORT,2                         ! PORT NUMBER
CM,N_IMPD,node
ALLSEL,ALL
FINISH

/SOLUTION
EQSLV,SPARSE                          ! SPARSE SOLVER
ANTYPE,HARMIC                         ! HARMONIC ANALYSIS
HROPT,FULL                            ! FULL METHOD
HARFRQ,0,300                          ! EXCITATION FREQUENCY
NSUB,150                              ! NUMBER OF SUBSTEPS
SOLVE
FINISH

*CREATE,MYPOST,MAC
*GET,AR80,NODE,,COUNT
AR70=0
AR71=0
*DO,AR99,1,AR80
  AR70=NDNEXT(AR70)
  AR71=AR71+PRES(AR70)
*ENDDO
AVG_PRES=AR71/AR80
*END

/POST1
SET,LAST
*GET,NUM_LSTEP,ACTIVE,0,SET,SBST
VSEL,S,LOC,Z,zz(5),zz(6)
ALLSEL,BELOW,VOLU
CM,N_ROOMA,NODE
ALLSEL,ALL

/COM, ---Freq (Hz)   Computed TL---
/COM,
/NOPR
*DO,AR99,1,NUM_LSTEP
  SET,1,AR99,,AMPL
  *GET,Freq,ACTIVE,,SET,FREQ
  CMSEL,S,N_ROOMA
  MYPOST
  P_A=AVG_PRES
  CMSEL,S,N_IMPD
  MYPOST
  P_B=AVG_PRES
  TL = 20*LOG10(P_A/P_B)
```

```
/OUT
  *VWRITE,Freq,TL
  %12.5e,%12.5e
*ENDDO

/OUT,SCRATCH
*DIM,Frq,CHAR,9,1
*DIM,TL1,CHAR,9,1
*DIM,TL2,CHAR,9,1
*DIM,Ratio,,9,1

Frq(1)='10','40','80','84','214','228','278','286','300'
TL1(1)='29.000','0.000','22.000','20.000','51.500','8.000','34.000','24.000','28.500'
TL2(1)='28.708','0.071','21.544','20.000','49.984','7.642','32.576','22.696','26.685'
R1 = 28.7/28.5
R2 = 1.000
R3 = 21.5/21.5
R4 = 20.0/20.0
R5 = 50.0/51.5
R6 = 7.6/8.0
R7 = 32.6/33.0
R8 = 22.7/25.0
R9 = 26.7/29.0
*VFILL,Ratio(1,1),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/OUT,vm283,vrt
/COM, -----------------VM283 RESULT COMPARISON---------------------
/COM
/COM,| Freq (Hz) |  Target | Mechanical APDL | Ratio |
/COM,
*VWRITE,Frq(1),TL1(1),TL2(1),RATIO(1,1)
(3X,A8,'   ',3X,A8,'   ',3X,A8,'  ',2X,F5.3,'  ')
/COM,
/COM, ---------------------------------------------------------------
/OUT,
*list,vm283,vrt
FINISH
```

Appendix B. Benchmark Input Listings

This appendix contains all of the input listings for the benchmarks documented in Part II: Benchmark Study Descriptions (p. 823).

Benchmark C1 Input Listing

```
/COM,ANSYS MEDIA REL. 140 (11/26/2011) REF. VERIF. MANUAL: REL. 140
/VERIFY,VMC1
*DIM,NARAY,TABLE,13,8           ! 2-D NARAY FOR RESULTS INFO
*taxis,naray(1,0),1,1,2,3,4,5,6,7,8,9,10
*taxis,naray(11,0),1,11,12,13
*taxis,naray(0,1),2,1,2,3,4,5,6,7,8
*CREATE,base,
  PARSAV,ALL
  /clear, nostart
  PARRES,CHANGE
  /PREP7
  smrt,off
  /TITLE, VMC1, CLAMPED PLATE UNDER UNIFORMLY-DISTRIBUTED LOAD
  /COM,
  /OUT,SCRATCH
  ANTYPE,STATIC
  ET,1,ETYP                      ! DEFINE ELEMENT TYPE PARAMETRICALLY
  MP,EX,1,10E6                   ! DEFINE MATERIAL PROPERTIES
  MP,NUXY,1,.3
  A=10                           ! DEFINE PLATE EDGE LENGTH
  T=1.0                          ! DEFINE PLATE THICKNESS
  K,1,,,(-T/2)                   ! DEFINE KEYPOINTS
  K,2,(A/2),,(-T/2)
  K,3,(A/2),(A/2),(-T/2)
  K,4,,(A/2),(-T/2)
  KGEN,2,1,4,1,,,(T/2)
  L,1,5
  *REPEAT,4,1,1
  L,1,4
  *REPEAT,2,4,4
  L,1,2
  *REPEAT,2,4,4
  L,2,3
  *REPEAT,2,4,4
  L,3,4
  *REPEAT,2,4,4
  LSEL,S,LINE,,1,4
  LESIZE,ALL,,,ARG2
```

```
LSEL,INVE
LESIZE,ALL,,,ARG1
LSEL,ALL
V,1,2,3,4,5,6,7,8
ESIZE,,1
MOPT,VMESH,ALTE
VMESH,ALL                       ! MESH VOLUMES
*GET,MAXN,NODE,,NUM,MAX         ! GET MAX NODE NUMBER
NARAY(ARG3,2)=ARG1              ! STORE N1
NARAY(ARG3,3)=ARG2              ! STORE N2
NARAY(ARG3,4)=MAXN*3            ! CALCULATE TOTAL NO. OF DOF'S
NSEL,S,LOC,X,(A/2)              ! SELECT NODES AND APPLY BOUNDARY CONDITIONS
D,ALL,UX,0
NSEL,R,LOC,Z,0
D,ALL,ALL,0
NSEL,S,LOC,Y,(A/2)
D,ALL,UY,0
NSEL,R,LOC,Z,0
D,ALL,ALL,0
NSEL,S,LOC,X,0
DSYM,SYMM,X
NSEL,S,LOC,Y,0
DSYM,SYMM,Y
NSEL,S,LOC,Z,0
DSYM,ASYM,Z
NSEL,S,LOC,Z,-T/2
SF,ALL,PRES,-500                ! APPLY PRESSURE TO BOTTOM SURFACE
NSEL,ALL
/VIEW,1,0.5,-0.5,0.5
/ANG,1,-63
/AUTO,1
/DEVICE,VECTOR,1
/DEVICE,DITHER,1
/TYPE,ALL,4
/COLOR,NUM,BLUE,1
*IF,ETYP,EQ,45,THEN
*IF,ARG1,EQ,3,THEN
 *IF,ARG2,EQ,1,THEN
  /TITLE,VMC1 - SQUARE MESH: (N1 = 3, N2 = 1)
  EPLOT
 *ENDIF
*ENDIF
*ENDIF
*IF,ETYP,EQ,92,THEN
*IF,ARG1,EQ,3,THEN
 *IF,ARG2,EQ,1,THEN
  /TITLE,VMC1 - TETRAHEDRAL MESH: (N1 = 3, N2 = 1)
  EPLOT
 *ENDIF
*ENDIF
*ENDIF
*IF,ETYP,EQ,45,THEN
*IF,ARG1,EQ,15,THEN
 *IF,ARG2,EQ,2,THEN
  /TITLE,VMC1 - SQUARE MESH: (N1 = 15, N2 = 2)
  EPLOT
 *ENDIF
*ENDIF
*ENDIF
*IF,ARG1,EQ,5,THEN
 *IF,ARG2,EQ,1,THEN
  /TITLE,VMC1 - TETRAHEDRAL MESH: (N1 = 5, N2 = 1)
  EPLOT
 *ENDIF
*ENDIF
*IF,ETYP,EQ,45,THEN
*IF,ARG1,EQ,25,THEN
 *IF,ARG2,EQ,5,THEN
  /TITLE,VMC1 - SQUARE MESH: (N1 = 25, N2 = 5)
  EPLOT
 *ENDIF
*ENDIF
```

```
  *ENDIF
  *IF,ARG1,EQ,7,THEN
   *IF,ARG2,EQ,1,THEN
    /TITLE,VMC1 - TETRAHEDRAL MESH: (N1 = 7, N2 = 1)
    EPLOT
   *ENDIF
  *ENDIF
  /SHOW,GRPH
  /TITLE, VMC1, CLAMPED PLATE UNDER UNIFORMLY-DISTRIBUTED LOAD
  FINISH
  /SOLU
  EQSLV,PCG
  SOLVE
  FINISH
  /POST1
  NOD1=NODE(0,0,0)                ! SELECT NODE AT LOCATION 1
  *GET,UZ0,NODE,NOD1,U,Z          ! GET DISPLACEMENT VALUE UZ(1)
  NARAY(ARG3,6)=-(UZ0/.017169)    ! CALCULATE NORMALIZED UZ(1)
  NOD3=NODE(0,0,-T/2)
  *GET,SX3,NODE,NOD3,S,X          ! GET STRESS VALUE SX(3)
  NARAY(ARG3,8)=(SX3/14.465E3)    ! CALCULATE NORMALIZED SX(3)
  NOD2=NODE(A/2,0,-T/2)           ! SELECT NODES AT LOCATION 2
  *GET,SX2,NODE,NOD2,S,X          ! GET STRESS VALUE SX(2)
  NARAY(ARG3,7)=-(SX2/32.124E3)   ! CALCULATE NORMALIZED SX(2)
  NSEL,ALL
  *GET,NARAY(ARG3,5),PRERR,,SEPC  ! STORE PERCENT ENERGY ERROR NORM
  PARSAV,,PARAM
  FINISH
*END
*DO,I,1,5                       ! INITIALIZE COLUMN 1 WITH ELEMENT TYPES
 NARAY(I,1)=45
*ENDDO
*DO,I,6,9
 NARAY(I,1)=95
*ENDDO
*DO,I,10,13
 NARAY(I,1)=92
*ENDDO
*DO,I,1,3                       ! FOR ETYP = 45,95,92
  *IF,I,LT,3,THEN
     *IF,I,EQ,1,THEN
       ETYP=45
       NEND=5
       JINDX=0
     *ELSE
       ETYP=95
       NEND=4
       JINDX=5
     *ENDIF
     /COM, COMMENT:  CALL MACRO TO LOOP THROUGH DIFFERENT ELEMENT TYPES
     *DO,J,1,NEND
       *IF,J,EQ,1,THEN
         *USE,base,3,1,JINDX+J
       *ELSEIF,J,EQ,2,THEN
         *USE,base,6,1,JINDX+J
       *ELSEIF,J,EQ,3,THEN
         *USE,base,15,2,JINDX+J
       *ELSEIF,J,EQ,4,THEN
         *USE,base,20,4,JINDX+J
       *ELSEIF,J,EQ,5,THEN
         *USE,base,25,5,JINDX+J
       *ENDIF
     *ENDDO
  *ELSE
     ETYP=92
     NEND=4
     JINDX=9
     *DO,J,1,NEND
       *IF,J,EQ,1,THEN
         *USE,base,3,1,JINDX+J
       *ELSEIF,J,EQ,2,THEN
          *USE,base,5,1,JINDX+J
```

```
        *ELSEIF,J,EQ,3,THEN
           *USE,base,7,1,JINDX+J
        *ELSEIF,J,EQ,4,THEN
           *USE,base,10,2,JINDX+J
        *ENDIF
      *ENDDO
   *ENDIF
 *ENDDO
 SAVE,temp,db
 /OUT
 /GRID,1
 /AXLAB,X,No. DOF'S
 /AXLAB,Y,% ERROR IN ENERGY NORM
 /GTHK,AXIS,2
 /GTHK,CURVE,3
 /GROPT,LOGX,ON
 /GROPT,LOGY,ON
 /XRANGE,10,1E5
 /YRANGE,0,1.25
 *VLEN,5,1
 *VPLOT,NARAY(1,4),NARAY(1,5)
 *VLEN,4,1
 *VPLOT,NARAY(6,4),NARAY(6,5)
 *VLEN,4,1
 *VPLOT,NARAY(10,4),NARAY(10,5)
 /AXLAB,Y,SX(2) RATIO
 /GROPT,LOGY,OFF
 *VLEN,5,1
 *VPLOT,NARAY(1,4),NARAY(1,7)
 *VLEN,4,1
 *VPLOT,NARAY(6,4),NARAY(6,7)
 *VLEN,4,1
 *VPLOT,NARAY(10,4),NARAY(10,7)
 FINISH
 /DELETE,PARAM
 /DELETE,base
 /DELETE,vmc1,PCS


 /TITLE, VMC1, CLAMPED PLATE UNDER UNIFORMLY-DISTRIBUTED LOAD
 *DIM,NARAY,TABLE,13,8           ! 2-D NARAY FOR RESULTS INFO
 *taxis,naray(1,0),1,1,2,3,4,5,6,7,8,9,10
 *taxis,naray(11,0),1,11,12,13
 *taxis,naray(0,1),2,1,2,3,4,5,6,7,8
 *CREATE,base,
   PARSAV,ALL
   /clear, nostart
   PARRES,CHANGE
   /PREP7
   smrt,off
   /TITLE, VMC1, CLAMPED PLATE UNDER UNIFORMLY-DISTRIBUTED LOAD
   /COM,
   !/OUT,SCRATCH
   ANTYPE,STATIC
   *IF,ETYP,EQ,185,THEN
     K2=2
   *ELSEIF,ETYP,EQ,186,THEN
     K2=1
   *ELSE
     K2=0
   *ENDIF
   ET,1,ETYP,,K2                 ! DEFINE ELEMENT TYPE PARAMETRICALLY
   MP,EX,1,10E6                  ! DEFINE MATERIAL PROPERTIES
   MP,NUXY,1,.3
   A=10                          ! DEFINE PLATE EDGE LENGTH
   T=1.0                         ! DEFINE PLATE THICKNESS
   K,1,,,(-T/2)                  ! DEFINE KEYPOINTS
   K,2,(A/2),,(-T/2)
   K,3,(A/2),(A/2),(-T/2)
   K,4,,(A/2),(-T/2)
   KGEN,2,1,4,1,,,(T/2)
   L,1,5
```

```
*REPEAT,4,1,1
L,1,4
*REPEAT,2,4,4
L,1,2
*REPEAT,2,4,4
L,2,3
*REPEAT,2,4,4
L,3,4
*REPEAT,2,4,4
LSEL,S,LINE,,1,4
LESIZE,ALL,,,ARG2
LSEL,INVE
LESIZE,ALL,,,ARG1
LSEL,ALL
V,1,2,3,4,5,6,7,8
ESIZE,,1
MOPT,VMESH,ALTE
VMESH,ALL                        ! MESH VOLUMES
*GET,MAXN,NODE,,NUM,MAX          ! GET MAX NODE NUMBER
NARAY(ARG3,2)=ARG1               ! STORE N1
NARAY(ARG3,3)=ARG2               ! STORE N2
NARAY(ARG3,4)=MAXN*3             ! CALCULATE TOTAL NO. OF DOF'S
NSEL,S,LOC,X,(A/2)               ! SELECT NODES AND APPLY BOUNDARY CONDITIONS
D,ALL,UX,0
NSEL,R,LOC,Z,0
D,ALL,ALL,0
NSEL,S,LOC,Y,(A/2)
D,ALL,UY,0
NSEL,R,LOC,Z,0
D,ALL,ALL,0
NSEL,S,LOC,X,0
DSYM,SYMM,X
NSEL,S,LOC,Y,0
DSYM,SYMM,Y
NSEL,S,LOC,Z,0
DSYM,ASYM,Z
NSEL,S,LOC,Z,-T/2
SF,ALL,PRES,-500                 ! APPLY PRESSURE TO BOTTOM SURFACE
NSEL,ALL
/VIEW,1,0.5,-0.5,0.5
/ANG,1,-63
/AUTO,1
/DEVICE,VECTOR,1
/DEVICE,DITHER,1
/TYPE,ALL,4
/COLOR,NUM,BLUE,1
*IF,ETYP,EQ,185,THEN
*IF,ARG1,EQ,3,THEN
 *IF,ARG2,EQ,1,THEN
  /TITLE,VMC1 - SQUARE MESH: (N1 = 3, N2 = 1)
  EPLOT
 *ENDIF
*ENDIF
*ENDIF
*IF,ETYP,EQ,187,THEN
*IF,ARG1,EQ,3,THEN
 *IF,ARG2,EQ,1,THEN
  /TITLE,VMC1 - TETRAHEDRAL MESH: (N1 = 3, N2 = 1)
  EPLOT
 *ENDIF
*ENDIF
*ENDIF
*IF,ETYP,EQ,185,THEN
*IF,ARG1,EQ,15,THEN
 *IF,ARG2,EQ,2,THEN
  /TITLE,VMC1 - SQUARE MESH: (N1 = 15, N2 = 2)
  EPLOT
 *ENDIF
*ENDIF
*ENDIF
*IF,ARG1,EQ,5,THEN
 *IF,ARG2,EQ,1,THEN
```

```
     /TITLE,VMC1 - TETRAHEDRAL MESH: (N1 = 5, N2 = 1)
     EPLOT
    *ENDIF
   *ENDIF
   *IF,ETYP,EQ,185,THEN
   *IF,ARG1,EQ,25,THEN
    *IF,ARG2,EQ,5,THEN
     /TITLE,VMC1 - SQUARE MESH: (N1 = 25, N2 = 5)
     EPLOT
    *ENDIF
   *ENDIF
   *ENDIF
   *IF,ARG1,EQ,7,THEN
    *IF,ARG2,EQ,1,THEN
     /TITLE,VMC1 - TETRAHEDRAL MESH: (N1 = 7, N2 = 1)
     EPLOT
    *ENDIF
   *ENDIF
   /SHOW,GRPH
   /TITLE, VMC1, CLAMPED PLATE UNDER UNIFORMLY-DISTRIBUTED LOAD
   FINISH
   /SOLU
   EQSLV,PCG
   SOLVE
   FINISH
   /POST1
   NOD1=NODE(0,0,0)                ! SELECT NODE AT LOCATION 1
   *GET,UZ0,NODE,NOD1,U,Z          ! GET DISPLACEMENT VALUE UZ(1)
   NARAY(ARG3,6)=-(UZ0/.017169)    ! CALCULATE NORMALIZED UZ(1)
   NOD3=NODE(0,0,-T/2)
   *GET,SX3,NODE,NOD3,S,X          ! GET STRESS VALUE SX(3)
   NARAY(ARG3,8)=(SX3/14.465E3)    ! CALCULATE NORMALIZED SX(3)
   NOD2=NODE(A/2,0,-T/2)           ! SELECT NODES AT LOCATION 2
   *GET,SX2,NODE,NOD2,S,X          ! GET STRESS VALUE SX(2)
   NARAY(ARG3,7)=-(SX2/32.124E3)   ! CALCULATE NORMALIZED SX(2)
   NSEL,ALL
   *GET,NARAY(ARG3,5),PRERR,,SEPC  ! STORE PERCENT ENERGY ERROR NORM
   PARSAV,,PARAM
   FINISH
 *END
 *DO,I,1,5                       ! INITIALIZE COLUMN 1 WITH ELEMENT TYPES
  NARAY(I,1)=185
 *ENDDO
 *DO,I,6,9
  NARAY(I,1)=186
 *ENDDO
 *DO,I,10,13
  NARAY(I,1)=187
 *ENDDO
 *DO,I,1,3                       ! FOR ETYP = 185,186,187
   *IF,I,LT,3,THEN
      *IF,I,EQ,1,THEN
        ETYP=185
        K2=2
        NEND=5
        JINDX=0
      *ELSEIF,I,EQ,2,THEN
        ETYP=186
        K2=1
        NEND=4
        JINDX=5
      *ELSEIF,I,EQ,3,THEN
        ETYP=187
        K2=0
        NEND=4
        JINDX=5
      *ENDIF
      /COM, COMMENT:  CALL MACRO TO LOOP THROUGH DIFFERENT ELEMENT TYPES
      *DO,J,1,NEND
        *IF,J,EQ,1,THEN
          *USE,base,3,1,JINDX+J
        *ELSEIF,J,EQ,2,THEN
```

```
         *USE,base,6,1,JINDX+J
       *ELSEIF,J,EQ,3,THEN
         *USE,base,15,2,JINDX+J
       *ELSEIF,J,EQ,4,THEN
         *USE,base,20,4,JINDX+J
       *ELSEIF,J,EQ,5,THEN
         *USE,base,25,5,JINDX+J
       *ENDIF
     *ENDDO
  *ELSE
     ETYP=187
     NEND=4
     JINDX=9
     *DO,J,1,NEND
       *IF,J,EQ,1,THEN
         *USE,base,3,1,JINDX+J
       *ELSEIF,J,EQ,2,THEN
          *USE,base,5,1,JINDX+J
       *ELSEIF,J,EQ,3,THEN
          *USE,base,7,1,JINDX+J
       *ELSEIF,J,EQ,4,THEN
          *USE,base,10,2,JINDX+J
       *ENDIF
     *ENDDO
  *ENDIF
*ENDDO
SAVE,temp2,db
/GRID,1
/AXLAB,X,No. DOF'S
/AXLAB,Y,% ERROR IN ENERGY NORM
/GTHK,AXIS,2
/GTHK,CURVE,3
/GROPT,LOGX,ON
/GROPT,LOGY,ON
/XRANGE,10,1E5
/YRANGE,0,1.25
*VLEN,5,1
*VPLOT,NARAY(1,4),NARAY(1,5)
*VLEN,4,1
*VPLOT,NARAY(6,4),NARAY(6,5)
*VLEN,4,1
*VPLOT,NARAY(10,4),NARAY(10,5)
/AXLAB,Y,SX(2) RATIO
/GROPT,LOGY,OFF
*VLEN,5,1
*VPLOT,NARAY(1,4),NARAY(1,7)
*VLEN,4,1
*VPLOT,NARAY(6,4),NARAY(6,7)
*VLEN,4,1
*VPLOT,NARAY(10,4),NARAY(10,7)
FINISH
/DELETE,PARAM
/DELETE,base
/DELETE,vmc1,PCS
RESUME,temp,db
/OUT
/OUT,vmc1,vrt
/COM
/COM,------------------- VMC1 RESULTS LISTING -----------------------------------
/COM,
/COM,| ETYP | N1  | N2   |   DOF  | %ERR NM  | UZ(1)
/COM,
*VWRITE,naray(1,1),naray(1,2),naray(1,3),NARAY(1,4),NARAY(1,5),NARAY(1,6)
(F5.0,'  ',F5.0,'  ',F5.0,' ',F10.0,'  ',F7.3,'     ',F5.3)
/COM,----------------------------------------------------------------------------
/COM
/COM,------------------- VMC1 RESULTS CONT. -------------------------------------
/COM,
/COM,| SX(2)  |   SX(3) |
/COM,
*VWRITE,NARAY(1,7),NARAY(1,8)
(F7.3,'    ',F7.3)
```

```
/COM,------------------------------------------------------------------------------
/OUT
/OUT
RESUME,temp2,db
/OUT,vmc1,vrt,,append
/COM
/COM,------------------- VMC1 RESULTS LISTING ------------------------------------
/COM,
/COM,| ETYP | N1  | N2   |   DOF  | %ERR NM  | UZ(1)
/COM,
*VWRITE,naray(1,1),naray(1,2),naray(1,3),NARAY(1,4),NARAY(1,5),NARAY(1,6)
(F5.0,'  ',F5.0,'  ',F5.0,' ',F10.0,'  ',F7.3,'     ',F5.3)
/COM,------------------------------------------------------------------------------
/COM
/COM,------------------- VMC1 RESULTS CONT. --------------------------------------
/COM,
/COM,| SX(2)  |   SX(3) |
/COM,
*VWRITE,NARAY(1,7),NARAY(1,8)
(F7.3,'    ',F7.3)
/COM,------------------------------------------------------------------------------
/OUT
*LIST,vmc1,vrt
```

Benchmark C2 Input Listing

```
/COM,ANSYS MEDIA REL. 140 (11/26/2011) REF. VERIF. MANUAL: REL. 140
/VERIFY,VMC2
/NOPR
*DIM,NARAY,TABLE,12,6          ! 2-D NARAY FOR RESULTS INFO
*DO,I,1,12
  *DO,J,1,6
    NARAY(I,J)=0.              ! INITIALIZE NARAY
  *ENDDO
*ENDDO
*CREATE,base,
  PARSAV,ALL
  /clear, nostart
  PARRES,CHANGE
  /PREP7 $smrt,off
  /TITLE, VMC2, ELLIPTIC MEMBRANE UNDER A UNIFORMLY-DISTRIBUTED LOAD
  /COM,   SEE "SELECTED FE BENCHMARKS FOR STRUCTURAL AND THERMAL ANALYSIS",
  /COM,   NAFEMS REPORT NO. FEBSTA, REV. 1, OCT. 1986, TEST NO. LE1
  /COM,
  ET,1,ETYP,,,3                  ! DEFINE ELEMENT TYPE (PARAMETRICALLY)
  MP,EX,1,210E9                  ! DEFINE MATERIAL PROPERTIES
  MP,NUXY,1,.3
  R,1,0.1                        ! SET THICKNESS
  LOCAL,11,1,,,,,,,0.5           ! DEFINE ELLIPTICAL COORD. SYSTEM
  K,1,2,90
  K,4,2,0                        ! CREATE MODEL GEOMETRY
  K,5,1.165,20
  KMOVE,5,0,1.165,U,0.0,11,2.0,U,0.0
  K,8,2.0,5.0
  KMOVE,8,0,U,0.453,0.0,11,E,U,0.0
  L,1,5
  L,5,8
  L,8,4
  LOCAL,12,1,,,,,,,0.8461585
  K,2,3.25,90
  K,3,3.25,0.0
  K,6,3.25,67
  KMOVE,6,0,1.783,U,0.0,12,E,U,0.0
  K,7,3.25,25
  KMOVE,7,0,U,1.348,0.0,12,E,U,0.0
  L,2,6
  L,6,7
  L,7,3
```

```
LESIZE,ALL,,,ARG1
CSYS,0
L,1,2,
L,4,3,
LSEL,S,LINE,,7,8
LESIZE,ALL,,,ARG2
LSEL,ALL
A,4,3,7,8
A,8,7,6,5
A,5,6,2,1
ESIZE,,ARG2
ESHAPE,2
AMESH,ALL                       ! MESH ALL AREAS
*GET,MAXN,NODE,,NUM,MAX         ! GET MAX NODE NUMBER
NARAY(ARG3,2)=ARG1              ! STORE N1
NARAY(ARG3,3)=ARG2              ! STORE N2
NARAY(ARG3,4)=MAXN*2            ! CALCULATE NO. DEGREES OF FREEDOM
NSEL,S,LOC,Y,0
DSYM,SYMM,Y,1                   ! APPLY BOUNDARY CONDITIONS
NSEL,S,LOC,X,0
DSYM,SYMM,Y,1
CSYS,12
NSEL,S,LOC,X,3.25
SF,ALL,PRES,-10E6               ! APPLY PRESSURE LOAD
NSEL,ALL

/VIEW,1,,,1
/ANG,1
/AUTO,1
/DEVICE,VECTOR,1
/DEVICE,DITHER,1
/TYPE,ALL,4
/COLOR,NUM,BLUE,1
*IF,ETYP,EQ,42,THEN
*IF,ARG1,EQ,1,THEN
 *IF,ARG2,EQ,2,THEN
  /TITLE,VMC2 - QUADRILATERAL MESH: (N1 = 1, N2 = 2)
  EPLOT
 *ENDIF
*ENDIF
*ENDIF
*IF,ETYP,EQ,42,THEN
*IF,ARG1,EQ,3,THEN
 *IF,ARG2,EQ,4,THEN
  /TITLE,VMC2 - QUADRILATERAL MESH: (N1 = 3, N2 = 4)
  EPLOT
 *ENDIF
*ENDIF
*ENDIF
 *IF,ETYP,EQ,42,THEN
 *IF,ARG1,EQ,8,THEN
 *IF,ARG2,EQ,10,THEN
  /TITLE,VMC2 - QUADRILATERAL MESH: (N1 = 8, N2 = 10)
  EPLOT
 *ENDIF
*ENDIF
*ENDIF
/SHOW,GRPH
/TITLE, VMC2, ELLIPTIC MEMBRANE UNDER A UNIFORMLY-DISTRIBUTED LOAD

OUTRES,STRS
OUTPR,BASIC
FINISH
/SOLU
SOLVE
FINISH
/POST1
NSEL,S,LOC,Y,0,.1
NSEL,R,LOC,X,2.0
NSORT,S,Y
*GET,MAXN,NODE,,NUM,MAX          ! GET MAX NODE NUMBER
*GET,SYM,NODE,MAXN,S,Y           ! GET DESIRED SY STRESS VALUE
```

```
  TARG=92.7E6                       ! TARGET SY VALUE
  NARAY(ARG3,6)=SYM/TARG            ! NORMALIZED SY VALUE
  *GET,NARAY(ARG3,5),PRERR,,SEPC  ! STORE PERCENT ENERGY ERROR NORM
  PARSAV,,PARAM
  FINISH
*END
  *DO,I,1,6                         ! INITIALIZE COLUMN 1 WITH ELEMENT TYPES
   NARAY(I,1)=42
   NARAY(I+6,1)=82
  *ENDDO
  *DO,I,1,2
    *IF,I,EQ,1,THEN
      ETYP=42
      JINDX=0
    *ELSEIF,I,EQ,2,THEN
      ETYP=82
      JINDX=6
    *ENDIF
    /COM, COMMENT:  CALL MACRO TO LOOP THROUGH DIFFERENT ELEMENT TYPES
    *DO,J,1,6
      *IF,J,EQ,1,THEN
        *USE,base,1,2,JINDX+J
      *ELSEIF,J,EQ,2,THEN
        *USE,base,2,3,JINDX+J
      *ELSEIF,J,EQ,3,THEN
        *USE,base,3,4,JINDX+J
      *ELSEIF,J,EQ,4,THEN
        *USE,base,5,7,JINDX+J
      *ELSEIF,J,EQ,5,THEN
        *USE,base,8,10,JINDX+J
      *ELSEIF,J,EQ,6,THEN
        *USE,base,10,12,JINDX+J
      *ENDIF
    *ENDDO
  *ENDDO
  SAVE,temp,db
  /OUT
  /SHOW,,GRPH
  /GRID,1
  /AXLAB,X,No. DOF'S
  /AXLAB,Y,% ERROR IN ENERGY NORM
  /GTHK,AXIS,2
  /GTHK,CURVE,3
  /GROPT,LOGX,ON
  /GROPT,LOGY,ON
  /XRANGE,10,1E5
  /YRANGE,0,1.25
  *VLEN,6,1
  *VPLOT,NARAY(1,4),NARAY(1,5)
  *VLEN,6,1
  *VPLOT,NARAY(7,4),NARAY(7,5)
  /AXLAB,Y,SY RATIO
  /GROPT,LOGY,OFF
  *VLEN,6,1
  *VPLOT,NARAY(1,4),NARAY(1,6)
  *VLEN,6,1
  *VPLOT,NARAY(7,4),NARAY(7,6)
finish
/delete,PARAM
/delete,base

/VERIFY,VMC2
/NOPR
*DIM,NARAY,TABLE,12,6          ! 2-D NARAY FOR RESULTS INFO
*DO,I,1,12
  *DO,J,1,6
    NARAY(I,J)=0.              ! INITIALIZE NARAY
  *ENDDO
*ENDDO
*CREATE,base,
  PARSAV,ALL
  /clear, nostart
```

```
PARRES,CHANGE
/PREP7 $smrt,off
/TITLE, VMC2, ELLIPTIC MEMBRANE UNDER A UNIFORMLY-DISTRIBUTED LOAD
/COM,   SEE "SELECTED FE BENCHMARKS FOR STRUCTURAL AND THERMAL ANALYSIS",
/COM,   NAFEMS REPORT NO. FEBSTA, REV. 1, OCT. 1986, TEST NO. LE1
/COM,
ET,1,ETYP,,,3                  ! DEFINE ELEMENT TYPE (PARAMETRICALLY)
MP,EX,1,210E9                  ! DEFINE MATERIAL PROPERTIES
MP,NUXY,1,.3
R,1,0.1                        ! SET THICKNESS
LOCAL,11,1,,,,,,,0.5           ! DEFINE ELLIPTICAL COORD. SYSTEM
K,1,2,90
K,4,2,0                        ! CREATE MODEL GEOMETRY
K,5,1.165,20
KMOVE,5,0,1.165,U,0.0,11,2.0,U,0.0
K,8,2.0,5.0
KMOVE,8,0,U,0.453,0.0,11,E,U,0.0
L,1,5
L,5,8
L,8,4
LOCAL,12,1,,,,,,,0.8461585
K,2,3.25,90
K,3,3.25,0.0
K,6,3.25,67
KMOVE,6,0,1.783,U,0.0,12,E,U,0.0
K,7,3.25,25
KMOVE,7,0,U,1.348,0.0,12,E,U,0.0
L,2,6
L,6,7
L,7,3
LESIZE,ALL,,,ARG1
CSYS,0
L,1,2,
L,4,3,
LSEL,S,LINE,,7,8
LESIZE,ALL,,,ARG2
LSEL,ALL
A,4,3,7,8
A,8,7,6,5
A,5,6,2,1
ESIZE,,ARG2
ESHAPE,2
AMESH,ALL                      ! MESH ALL AREAS
*GET,MAXN,NODE,,NUM,MAX        ! GET MAX NODE NUMBER
NARAY(ARG3,2)=ARG1             ! STORE N1
NARAY(ARG3,3)=ARG2             ! STORE N2
NARAY(ARG3,4)=MAXN*2           ! CALCULATE NO. DEGREES OF FREEDOM
NSEL,S,LOC,Y,0
DSYM,SYMM,Y,1                  ! APPLY BOUNDARY CONDITIONS
NSEL,S,LOC,X,0
DSYM,SYMM,Y,1
CSYS,12
NSEL,S,LOC,X,3.25
SF,ALL,PRES,-10E6              ! APPLY PRESSURE LOAD
NSEL,ALL

/VIEW,1,,,1
/ANG,1
/AUTO,1
/DEVICE,VECTOR,1
/DEVICE,DITHER,1
/TYPE,ALL,4
/COLOR,NUM,BLUE,1
*IF,ETYP,EQ,182,THEN
*IF,ARG1,EQ,1,THEN
 *IF,ARG2,EQ,2,THEN
  /TITLE,VMC2 - QUADRILATERAL MESH: (N1 = 1, N2 = 2)
  EPLOT
 *ENDIF
*ENDIF
*ENDIF
*IF,ETYP,EQ,183,THEN
```

```
  MSHAPE,1,2D
  *IF,ARG1,EQ,2,THEN
   *IF,ARG2,EQ,3,THEN
    /TITLE,VMC2 - TRIANGLE MESH: (N1 = 2, N2 = 3)
    EPLOT
   *ENDIF
  *ENDIF
  *ENDIF
  *IF,ETYP,EQ,182,THEN
  *IF,ARG1,EQ,3,THEN
   *IF,ARG2,EQ,4,THEN
    /TITLE,VMC2 - QUADRILATERAL MESH: (N1 = 3, N2 = 4)
    EPLOT
   *ENDIF
  *ENDIF
  *ENDIF
  *IF,ETYP,EQ,183,THEN
  MSHAPE,1,2D
  *IF,ARG1,EQ,5,THEN
   *IF,ARG2,EQ,7,THEN
    /TITLE,VMC2 - TRIANGLE MESH: (N1 = 5, N2 = 7)
    EPLOT
   *ENDIF
  *ENDIF
  *ENDIF
   *IF,ETYP,EQ,182,THEN
   *IF,ARG1,EQ,8,THEN
   *IF,ARG2,EQ,10,THEN
    /TITLE,VMC2 - QUADRILATERAL MESH: (N1 = 8, N2 = 10)
    EPLOT
   *ENDIF
  *ENDIF
  *ENDIF
  *IF,ETYP,EQ,183,THEN
  MSHAPE,1,2D
  *IF,ARG1,EQ,10,THEN
   *IF,ARG2,EQ,12,THEN
    /TITLE,VMC2 - TRIANGLE MESH: (N1 = 10, N2 = 12)
    EPLOT
   *ENDIF
  *ENDIF
  *ENDIF
  /SHOW,GRPH
  /TITLE, VMC2, ELLIPTIC MEMBRANE UNDER A UNIFORMLY-DISTRIBUTED LOAD

  OUTRES,STRS
  OUTPR,BASIC
  FINISH
  /SOLU
  SOLVE
  FINISH
  /POST1
  NSEL,S,LOC,Y,0,.1
  NSEL,R,LOC,X,2.0
  NSORT,S,Y
  *GET,MAXN,NODE,,NUM,MAX          ! GET MAX NODE NUMBER
  *GET,SYM,NODE,MAXN,S,Y           ! GET DESIRED SY STRESS VALUE
  TARG=92.7E6                      ! TARGET SY VALUE
  NARAY(ARG3,6)=SYM/TARG           ! NORMALIZED SY VALUE
  *GET,NARAY(ARG3,5),PRERR,,SEPC  ! STORE PERCENT ENERGY ERROR NORM
  PARSAV,,PARAM
  FINISH
*END
  *DO,I,1,6                        ! INITIALIZE COLUMN 1 WITH ELEMENT TYPES
   NARAY(I,1)=182
   NARAY(I+6,1)=183
  *ENDDO
  *DO,I,1,2
    *IF,I,EQ,1,THEN
      ETYP=182
      JINDX=0
    *ELSEIF,I,EQ,2,THEN
```

```
      ETYP=183
      JINDX=6
    *ENDIF
    /COM, COMMENT:  CALL MACRO TO LOOP THROUGH DIFFERENT ELEMENT TYPES
    *DO,J,1,6
      *IF,J,EQ,1,THEN
        *USE,base,1,2,JINDX+J
      *ELSEIF,J,EQ,2,THEN
        *USE,base,2,3,JINDX+J
      *ELSEIF,J,EQ,3,THEN
        *USE,base,3,4,JINDX+J
      *ELSEIF,J,EQ,4,THEN
        *USE,base,5,7,JINDX+J
      *ELSEIF,J,EQ,5,THEN
        *USE,base,8,10,JINDX+J
      *ELSEIF,J,EQ,6,THEN
        *USE,base,10,12,JINDX+J
      *ENDIF
    *ENDDO
  *ENDDO
  SAVE,temp2,db
  /SHOW,,GRPH
  /GRID,1
  /AXLAB,X,No. DOF'S
  /AXLAB,Y,% ERROR IN ENERGY NORM
  /GTHK,AXIS,2
  /GTHK,CURVE,3
  /GROPT,LOGX,ON
  /GROPT,LOGY,ON
  /XRANGE,10,1E5
  /YRANGE,0,1.25
  *VLEN,6,1
  *VPLOT,NARAY(1,4),NARAY(1,5)
  *VLEN,6,1
  *VPLOT,NARAY(7,4),NARAY(7,5)
  /AXLAB,Y,SY RATIO
  /GROPT,LOGY,OFF
  *VLEN,6,1
  *VPLOT,NARAY(1,4),NARAY(1,6)
  *VLEN,6,1
  *VPLOT,NARAY(7,4),NARAY(7,6)
  finish
  RESUME,temp,db
  /OUT,
  /OUT,vmc2,vrt
  /COM
  /COM,------------------- VMC2 RESULTS LISTING ------------------------------------
  /COM,
  /COM,| ETYP | N1  | N2   |   DOF  | %ERR NM  | SY RAT |
  /COM,
  *VWRITE,naray(1,1),naray(1,2),naray(1,3),NARAY(1,4),NARAY(1,5),NARAY(1,6)
  (F5.0,'  ',F5.0,'  ',F5.0,' ',F10.0,'  ',F7.3,'     ',F5.3)
  /COM,-----------------------------------------------------------------------------
  /OUT
  RESUME,temp2,db
  /OUT,vmc2,vrt,,append
  /COM
  /COM,------------------- VMC2 RESULTS LISTING ------------------------------------
  /COM,
  /COM,| ETYP | N1  | N2   |   DOF  | %ERR NM  | SY RAT |
  /COM,
  *VWRITE,naray(1,1),naray(1,2),naray(1,3),NARAY(1,4),NARAY(1,5),NARAY(1,6)
  (F5.0,'  ',F5.0,'  ',F5.0,' ',F10.0,'  ',F7.3,'     ',F5.3)
  /COM,-----------------------------------------------------------------------------
  /OUT
  *LIST,vmc2,vrt
/delete,PARAM
/delete,base
finish
```

Benchmark C3 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMC3
/SHOW
  /TITLE, VMC3, BARREL VAULT ROOF UNDER SELF WEIGHT
  /COM, REF:  COOK, CONCEPTS AND APPL OF F.E.A., 2ND ED., 1981, PP. 284-287.
  *DIM,NARAY,TABLE,12,7            ! 2-D NARAY FOR RESULTS INFO
  *DO,I,1,12
    *DO,J,1,7
      NARAY(I,J)=0.                ! INITIALIZE NARAY
    *ENDDO
  *ENDDO
*CREATE,base,
  PARSAV,ALL
  /clear, nostart
  PARRES,CHANGE
  /PREP7
  smrt,off
  /TITLE, VMC3, BARREL VAULT ROOF UNDER SELF WEIGHT
  /COM, REF:  COOK, CONCEPTS AND APPL OF F.E.A., 2ND ED., 1981, PP. 284-287.
 /OUT,SCRATCH
  ANTYPE,STATIC
  ET,1,ETYP                        ! DEFINE ELEMENT TYPE PARAMETRICALLY
  *IF,ETYP,EQ,181,THEN
   KEYOPT,1,3,2
  *ENDIF
  MP,EX,1,4.32E8                   ! DEFINE MATERIAL PROPERTIES
  MP,NUXY,1,0.0
  R,1,0.25
  MP,DENS,1,36.7347
  CSYS,1                           ! DEFINE CYLINDRICAL C.S.
  K,1,25,50
  K,2,25,70                        ! DEFINE KEYPOINTS
  K,3,25,90
  KGEN,3,1,3,1,,,12.5
  A,1,2,5,4
  A,2,3,6,5                        ! DEFINE AREAS
  A,4,5,8,7
  A,5,6,9,8
  ESIZE,,ARG1/2
  ESHAPE,ARG2
  AMESH,ALL                        ! MESH ALL AREAS
  /VIEW,1,1,1,1
  NARAY(ARG3,2)=ARG1               ! STORE N1
  NARAY(ARG3,3)=ARG2               ! STORE N2
  *GET,MAXN,NODE,,NUM,MAX          ! GET MAX NODE NUMBER
  NARAY(ARG3,4)=MAXN*6             ! CALCULATE NO. DEGREES OF FREEDOM
  NSEL,S,LOC,Z,0
  NSEL,R,LOC,Y,50                  ! SELECT NODE OF INTEREST
  *GET,N1,NODE,,NUM,MAX            ! GET NODE NUMBER
  NSEL,S,LOC,Z,0
  NSEL,R,LOC,Y,90
  *GET,N2,NODE,,NUM,MAX            ! GET NODE NUMBER
  NSEL,ALL
  CSYS,0                           ! SWITCH TO GLOBAL CARTESIAN C.S.
  NSEL,S,LOC,X,0
  DSYM,SYMM,X,0
  NSEL,S,LOC,Z,0
  DSYM,SYMM,Z,0
  NSEL,S,LOC,Z,25
  D,ALL,UX,0,,,,UY,ROTZ            ! CONSTRAIN MODEL EDGE
  NSEL,ALL
  ACEL,,9.8                        ! DEFINE GRAVITATIONAL ACCELERATION
  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
  !!  SETUP AND PLOT ELEMENTS FOR DOCUMENTATION !!
  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
  /AUTO,1
  /VIEW,1,0.5,0.5,0.5
```

```
  /ANG,1,6.28
  /DEVICE,VECTOR,1
  /DEVICE,DITHER,1
  /TYPE,ALL,4
  /COLOR,NUM,BLUE,1
  *IF,ETYP,NE,43,OR,ETYP,NE,63,THEN,
  *IF,ARG1,EQ,4,THEN
  *IF,ARG2,EQ,2,THEN
  /TITLE,VMC3 - QUADRILATERAL MESH (N = 4)
  EPLOT
  *ENDIF
  *ENDIF
  *ENDIF
  *IF,ETYP,NE,43,OR,ETYP,NE,63,THEN
  *IF,ARG1,EQ,8,THEN
  *IF,ARG2,EQ,2,THEN
  /TITLE,VMC3 - QUADRILATERAL MESH (N = 8)
  EPLOT
  *ENDIF
  *ENDIF
  *ENDIF
  *IF,ETYP,NE,43,OR,ETYP,NE,63,THEN
  *IF,ARG1,EQ,4,THEN
  *IF,ARG2,EQ,1,THEN
  /TITLE,VMC3 - TRIANGLE MESH (N = 4)
  EPLOT
  *ENDIF
  *ENDIF
  *ENDIF
  *IF,ETYP,NE,43,OR,ETYP,NE,63,THEN
  *IF,ARG1,EQ,8,THEN
  *IF,ARG2,EQ,1,THEN
  /TITLE,VMC3 - TRIANGLE MESH (N = 8)
  EPLOT
  *ENDIF
  *ENDIF
  *ENDIF
  /SHOW,GRPH
  /TITLE, VMC3, BARREL VAULT ROOF UNDER SELF WEIGHT
  FINISH
  /SOLU
  SOLVE
  FINISH
  /POST1
  SHELL,MID                        ! SELECT BOTTOM SURFACE
  *GET,UY1,NODE,N1,U,Y             ! GET UY AT NODE N1
  NARAY(ARG3,5)=-(UY1/.3016)       ! CALCULATE NORMALIZED UY1 W/R TO TARGET
  RSYS,1                           ! ACTIVATE CYLINDRICAL C.S. FOR RESULTS
  SHELL,BOT                        ! SELECT BOTTOM SURFACE
  *GET,SY2B,NODE,N2,S,Y            ! GET CIRCUMFERENTIAL (Y) STRESS AT BOTTOM
  NARAY(ARG3,7)=(SY2B/(-213400))   ! CALCULATE NORMALIZED SY2B
  *GET,SZ1B,NODE,N1,S,Z            ! GET AXIAL (Z) STRESS AT BOTTOM
  NARAY(ARG3,6)=(SZ1B/358420)      ! CALCULATE NORMALIZED SZ1B
  PARSAV,,PARAM
  FINISH
*END
  *DO,I,1,4                        ! INITIALIZE COLUMN 1 WITH ELEMENT TYPES
   NARAY(I,1)=63
   NARAY(I+4,1)=181
   NARAY(I+8,1)=281
*ENDDO
  *DO,I,1,3
    *IF,I,EQ,1,THEN
      ETYP=63
      JINDX=0
    *ELSEIF,I,EQ,2,THEN
      ETYP=181
      JINDX=4
    *ELSEIF,I,EQ,3,THEN
      ETYP=281
      JINDX=8
  *ENDIF
```

```
     /COM, COMMENT:  CALL MACRO TO LOOP THROUGH DIFFERENT ELEMENT TYPE
     *DO,J,1,4
       *IF,J,EQ,1,THEN
         *USE,base,4,2,JINDX+J
       *ELSEIF,J,EQ,2,THEN
         *USE,base,8,2,JINDX+J
       *ELSEIF,J,EQ,3,THEN
         *USE,base,4,1,JINDX+J
  *ELSEIF,J,EQ,4,THEN
         *USE,base,8,1,JINDX+J
     *ENDIF
     *ENDDO
   *ENDDO
 SAVE,temp,db
 finish
   RESUME,temp,db

   /OUT,vmc3,vrt
   /OUT
   /COM
   /COM,------------------- VMC3 RESULTS LISTING -----------------------------------
   /COM,
   /COM,| ETYP | N  | DOF   |  UY(1)  | SIG-z  | SIG-th  |
   /COM,
   *VWRITE,naray(1,1),naray(1,2),naray(1,4),NARAY(1,5),NARAY(1,6),NARAY(1,7)
   (F5.0,'  ',F5.0,'  ',F5.0,' ',F10.3,'  ',F7.3,'     ',F5.3)
   /COM,-----------------------------------------------------------------------------
   /OUT
   *LIST,vmc3,vrt
 finish
```

Benchmark C4 Input Listing

```
 /COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
 /VERIFY,VMC4
 /SHOW
   *DIM,NARAY,TABLE,6,13          ! 2-D NARAY FOR RESULTS INFO
   *DO,I,1,6
     *DO,J,1,13
       NARAY(I,J)=0.               ! INITIALIZE NARAY
     *ENDDO
   *ENDDO
 *CREATE,base,
   PARSAV,ALL
   /clear, nostart
   PARRES,CHANGE
   /PREP7
 smrt,off
   /TITLE, VMC4, SIMPLY-SUPPORTED THIN ANNULAR PLATE
   /COM,   SEE "SELECTED BENCHMARKS FOR NATURAL FREQUENCY ANALYSIS", REPORT TO
   /COM,   NAFEMS BY W.S. ATKINS ENGINEERING SCIENCES, REPORT NO. 20939.01, ISSUE
   /COM,   JUNE 1987, TEST CASE NO. 14. (MODIFIED)
   /COM,
   /OUT,SCRATCH
   ANTYPE,MODAL
   MODOPT,LANB,9       ! LANB EXTRACTION METHOD
   ET,1,ARG1                       ! DEFINE ELEMENT TYPE PARAMETRICALLY
   NARAY(ARG5,1)=ARG1              ! STORE ETYPE
   SECTYPE,1,SHELL
   SECDATA,0.06,1,0,3
   MP,EX,1,200E9                   ! SPECIFY MATERIAL PROPERTIES
   MP,NUXY,1,.3
   MP,DENS,1,8000
   CSYS,1                          ! SPECIFY CYLINDRICAL COORDINATES
   K,1,1.8
   K,2,6                           ! DEFINE KEYPOINTS (FIRST QUADRANT)
   K,3,6,90
   K,4,1.8,90
```

```
L,1,2
L,2,3                          ! DEFINE LINES SEGMENTS
L,3,4
L,4,1
LSEL,S,LINE,,1,3,2
LESIZE,ALL,,,ARG2
LSEL,INVE
LESIZE,ALL,,,ARG3/4
LSEL,ALL
MSHAPE,ARG4,2D
A,1,2,3,4                      ! DEFINE AREA
MAT,1
SECNUM,1
AMESH,1                        ! MESH AREA
CSYS,0                         ! SPECIFY CARTESIAN COORDINATE SYSTEM
ARSYM,1,1                      ! REFLECT AREA AND MESH ABOUT Y AXIS
ARSYM,2,1,2                    ! REFLECT AREAS AND MESH ABOUT X AXIS
NUMMRG,ALL                     ! MERGE ALL ENTITIES
D,ALL,UX,0,,,,UY,ROTZ          ! FIX ALL IN-PLANE DISP. AND ROTATIONS
CSYS,1                         ! SPECIFY CYLINDRICAL COORDINATE SYSTEM
NSEL,S,LOC,X,6                 ! SELECT NODES AT OUTER RADIUS
NROTAT,ALL                     ! ROTATE NODES INTO CYLINDRICAL C.S.
D,ALL,UZ,0,,,,ROTX             ! FIX UZ AND ROTX IN CSYS,1
NSEL,ALL
NARAY(ARG5,2)=ARG2             ! STORE N1
NARAY(ARG5,3)=ARG3             ! STORE N2
*GET,MAXN,NODE,,NUM,MAX        ! GET MAX NODE NUMBER
NARAY(ARG5,4)=MAXN*6           ! CALCULATE NO. DEGREES OF FREEDOM
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!  SETUP AND PLOT ELEMENTS FOR DOCUMENTATION !!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
/VIEW,1,,,1
/ANG,1
/AUTO,1
/DEVICE,VECTOR,1
/DEVICE,DITHER,1
/TYPE,ALL,4
/COLOR,NUM,BLUE,1
*IF,ARG1,EQ,181,THEN
*IF,ARG2,EQ,3,THEN
*IF,ARG3,EQ,16,THEN
*IF,ARG4,EQ,0,THEN
/TITLE,VMC4 - QUADRILATERAL MESH (N1 = 3, N2 = 16)
EPLOT
*ENDIF
*ENDIF
*ENDIF
*ENDIF
*IF,ARG1,EQ,181,THEN
*IF,ARG2,EQ,5,THEN
*IF,ARG3,EQ,32,THEN
*IF,ARG4,EQ,0,THEN
/TITLE,VMC4 - QUADRILATERAL MESH (N1 = 5, N2 = 32)
EPLOT
*ENDIF
*ENDIF
*ENDIF
*ENDIF
*IF,ARG1,EQ,181,THEN
*IF,ARG2,EQ,3,THEN
*IF,ARG3,EQ,16,THEN
*IF,ARG4,EQ,1,THEN
/TITLE,VMC4 - TRIANGLE MESH (N1 = 3, N2 = 16)
EPLOT
*ENDIF
*ENDIF
*ENDIF
*ENDIF
*IF,ARG1,EQ,181,THEN
*IF,ARG2,EQ,5,THEN
*IF,ARG3,EQ,32,THEN
*IF,ARG4,EQ,1,THEN
```

```
/TITLE,VMC4 - TRIANGLE MESH (N1 = 5, N2 = 32)
EPLOT
*ENDIF
*ENDIF
*ENDIF
*ENDIF
/TITLE, VMC4, SIMPLY-SUPPORTED THIN ANNULAR PLATE

FINISH
/SOLU
SOLVE
FINISH
/POST1
/DEVICE,VECTOR,1
/DEVICE,DITHER,1
/TYPE,ALL,4
/COLOR,NUM,BLUE,1
*GET,MOD1,MODE,1,FREQ            ! GET MODE 1 FREQUENCY
NARAY(ARG5,5)=MOD1/1.870         ! CALCULATE NORMALIZED FREQUENCY
/VIEW,1,0.9,0,0.369
/ANG,1,270
*IF,I,EQ,1,THEN
SET,1,1
/TITLE,VMC 4 - MODE 1
PLDISP,0
*ENDIF
*GET,MOD2,MODE,2,FREQ            ! GET MODE 2 FREQUENCY
NARAY(ARG5,6)=MOD2/5.137         ! CALCULATE NORMALIZED FREQUENCY
*IF,I,EQ,2,THEN
SET,1,2
/TITLE,VMC4 - MODE 2
PLDISP,0
*ENDIF

*GET,MOD3,MODE,3,FREQ            ! GET MODE 3 FREQUENCY
NARAY(ARG5,7)=MOD3/5.137         ! CALCULATE NORMALIZED FREQUENCY
*IF,I,EQ,3,THEN
SET,1,3
/TITLE,VMC4 - MODE 3
PLDISP,0
*ENDIF
*GET,MOD4,MODE,4,FREQ            ! GET MODE 4 FREQUENCY
NARAY(ARG5,8)=MOD4/9.673         ! CALCULATE NORMALIZED FREQUENCY
*IF,I,EQ,4,THEN
SET,1,4
/TITLE,VMC4 - MODE 4
PLDISP,0
*ENDIF
*GET,MOD5,MODE,5,FREQ            ! GET MODE 5 FREQUENCY
NARAY(ARG5,9)=MOD5/9.673         ! CALCULATE NORMALIZED FREQUENCY
*IF,I,EQ,5,THEN
SET,1,5
/TITLE,VMC4 - MODE 5
PLDISP,0
*ENDIF
*GET,MOD6,MODE,6,FREQ            ! GET MODE 6 FREQUENCY
NARAY(ARG5,10)=MOD6/14.850       ! CALCULATE NORMALIZED FREQUENCY
*IF,I,EQ,6,THEN
SET,1,6
/TITLE,VMC4 - MODE 6
PLDISP,0
*ENDIF
*GET,MOD7,MODE,7,FREQ            ! GET MODE 7 FREQUENCY
NARAY(ARG5,11)=MOD7/15.573       ! CALCULATE NORMALIZED FREQUENCY
*IF,I,EQ,7,THEN
SET,1,7
/TITLE,VMC4 - MODE 7
PLDISP,0
*ENDIF
*GET,MOD8,MODE,8,FREQ            ! GET MODE 8 FREQUENCY
NARAY(ARG5,12)=MOD8/15.573       ! CALCULATE NORMALIZED FREQUENCY
*IF,I,EQ,8,THEN
```

```
  SET,1,8
  /TITLE,VMC4 - MODE 8
  PLDISP,0
  *ENDIF
  *GET,MOD9,MODE,9,FREQ           ! GET MODE 9 FREQUENCY
  NARAY(ARG5,13)=MOD9/18.382      ! CALCULATE NORMALIZED FREQUENCY
  *IF,I,EQ,9,THEN
  SET,1,9
  /TITLE,VMC4 - MODE 9
  PLDISP
  *ENDIF
  /TITLE, VMC4, SIMPLY-SUPPORTED THIN ANNULAR PLATE
  PARSAV,,PARAM
  FINISH
*END
  /COM, COMMENT:  CALL MACRO TO LOOP THROUGH DIFFERENT ELEMENT TYPES, MESHES
  *DO,I,1,6
    *IF,I,EQ,1,THEN
      *USE,base,181,3,16,0,I,       ! QUAD MESH
    *ELSEIF,I,EQ,2,THEN
      *USE,base,181,5,32,0,I,      ! QUAD MESH
    *ELSEIF,I,EQ,3,THEN
      *USE,base,281,3,16,0,I,       ! QUAD MESH
    *ELSEIF,I,EQ,4,THEN
      *USE,base,281,5,32,0,I,       ! QUAD MESH
    *ELSEIF,I,EQ,5,THEN
      *USE,base,281,3,16,1,I       ! TRI MESH
    *ELSEIF,I,EQ,6,THEN
      *USE,base,281,5,32,1,I       ! TRI MESH
    *ENDIF
  *ENDDO
  /OUT,
  /OUT,vmc4,vrt
  /COM
  /COM,------------------- VMC4 RESULTS LISTING ------------------------------------
  /COM,
  /COM,| ETYP | N1 | N2 | DOF |  RAT1 | RAT2 | RAT3 |
  /COM,
  *VWRITE,naray(1,1),naray(1,2),naray(1,3),NARAY(1,4),NARAY(1,5),NARAY(1,6),NARAY(1,7)
  (F5.0,' ',F5.0,' ',F6.0,' ',F5.0,' ',F6.3,' ',F6.3,' ',F7.3)
  /COM,-----------------------------------------------------------------------------
  /COM,
  /COM,------------------- VMC4 RESULTS CONT... ------------------------------------
  /COM,
  /COM,| RAT4  | RAT5  | RAT6  | RAT7  | RAT8  | RAT9  |
  /COM,
  *VWRITE,NARAY(1,8),NARAY(1,9),NARAY(1,10),naray(1,11),naray(1,12),naray(1,13)
  (F7.3,' ',F7.3,' ',F7.3,' ',F7.3,' ',F7.3,' ',F7.3)

  /COM,-----------------------------------------------------------------------------
  /OUT
*LIST,vmc4,vrt
FINISH
```

Benchmark C5 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMC5
/SHOW
/DEVICE,VECTOR,ON
  *DIM,NARAY,TABLE,2,10        ! 2-D NARAY FOR RESULTS INFO
  *DO,I,1,2
    *DO,J,1,10
      NARAY(I,J)=0.             ! INITIALIZE NARAY
    *ENDDO
  *ENDDO

*CREATE,base,
```

```
  PARSAV,ALL
  /clear, nostart
  PARRES,CHANGE
  /PREP7
smrt,off
  /TITLE, VMC5, SIMPLY-SUPPORTED SOLID SQUARE PLATE
  /COM,   SEE NAFEMS "THE STANDARD NAFEMS BENCHMARKS",
  /COM,   REV. NO. TSNB, NATIONAL ENGNG. LABORATORY, UK
  /COM,   AUG. 1989, TEST NO. FV52
  /COM,
 /OUT,SCRATCH
  ANTYPE,MODAL                  ! MODE-FREQUENCY ANALYSIS
  ET,1,ARG1                     ! ELEMENT TYPE PARAMETRICALLY
  *IF,ARG1,EQ,185,THEN
    KEYOPT,1,2,3
  *ELSE
    KEYOPT,1,6,0
  *ENDIF
  NARAY(ARG5,1)=ARG1            ! STORE ETYPE
  MODOPT,LANB,10               ! BLOCK LANCZOS EXTRACTION
  MXPAND,10                     ! EXPAND FIRST 10 MODES
  MP,EX,1,200E9                 ! DEFINE MATERIAL PROPERTIES
  MP,NUXY,1,.3
  MP,DENS,1,8000
  K,1
  K,2,10
  K,3,10,10
  K,4,,10                       ! DEFINE KEYPOINTS
  KGEN,2,1,4,1,,,1
  L,1,5
  *REPEAT,4,1,1                 ! DEFINE LINE SEGMENTS AND DIVISIONS
  LESIZE,ALL,,,ARG3
  V,1,2,3,4,5,6,7,8             ! DEFINE VOLUME
  ESIZE,,ARG2                   ! SET NUMVER OF ELEMENT DIVISIONS
  NARAY(ARG5,2)=ARG2            ! STORE N1
  NARAY(ARG5,3)=ARG3            ! STORE N2
  VMESH,1                ! MESH VOLUME

  NSEL,S,LOC,Y,0                ! SELECT NODES FOR CONSTRAINING
  NSEL,A,LOC,Y,10
  NSEL,A,LOC,X,0
  NSEL,A,LOC,X,10
  NSEL,R,LOC,Z,0
  D,ALL,UZ,0                    ! CONSTRAIN NODES
  NSEL,ALL
  WAVES
  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
  !!  SETUP AND PLOT ELEMENTS FOR DOCUMENTATION !!
  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
  /VIEW,1,0.5,-0.5,0.5
  /ANG,1,-63
  /AUTO,1
  /DEVICE,VECTOR,1
  /DEVICE,DITHER,1
  /TYPE,ALL,4
  /COLOR,NUM,BLUE,1
  *IF,I,EQ,1,THEN
  *IF,ARG1,EQ,185,THEN
  *IF,ARG2,EQ,8,THEN
  *IF,ARG3,EQ,3,THEN
  /TITLE,VMC5 - BRICK MESH (N1 = 8, N2 = 3)
  EPLOT
  *ENDIF
  *ENDIF
  *ENDIF
  *ENDIF
  *IF,I,EQ,2,THEN
  *IF,ARG1,EQ,187,THEN
  *IF,ARG2,EQ,6,THEN
  *IF,ARG3,EQ,1,THEN
  /TITLE,VMC5 - TETRAHEDRAL MESH (N1 = 6, N2 = 1)
  EPLOT
```

```
*ENDIF
*ENDIF
*ENDIF
*ENDIF

FINISH
/SOLU
SOLVE
*GET,F1,MODE,1,FREQ           ! GET MODE 1 FREQUENCY
*GET,F2,MODE,2,FREQ           ! GET MODE 2 FREQUENCY
*GET,F3,MODE,3,FREQ           ! GET MODE 3 FREQUENCY
*GET,F4,MODE,4,FREQ           ! GET MODE 4 FREQUENCY
NARAY(ARG5,4)=F4/45.897       ! CALCULATE NORMALIZED FREQUENCY
*GET,F5,MODE,5,FREQ           ! GET MODE 5 FREQUENCY
NARAY(ARG5,5)=F5/109.44       ! CALCULATE NORMALIZED FREQUENCY
*GET,F6,MODE,6,FREQ           ! GET MODE 6 FREQUENCY
NARAY(ARG5,6)=F6/109.44       ! CALCULATE NORMALIZED FREQUENCY
*GET,F7,MODE,7,FREQ           ! GET MODE 7 FREQUENCY
NARAY(ARG5,7)=F7/167.89       ! CALCULATE NORMALIZED FREQUENCY
*GET,F8,MODE,8,FREQ           ! GET MODE 8 FREQUENCY
NARAY(ARG5,8)=F8/193.59      ! CALCULATE NORMALIZED FREQUENCY
*GET,F9,MODE,9,FREQ           ! GET MODE 9 FREQUENCY
NARAY(ARG5,9)=F9/206.19      ! CALCULATE NORMALIZED FREQUENCY
*GET,F10,MODE,10,FREQ         ! GET MODE 10 FREQUENCY
NARAY(ARG5,10)=F10/206.19     ! CALCULATE NORMALIZED FREQUENCY
PARSAV,,PARAM
FINISH
/POST1
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!  SET UP POST TO PRODUCE PLDISP PLOTS  !!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

/VIEW,1,,,-1
/ANG,1
/DEVICE,VECTOR,1
/DEVICE,DITHER,1
/TYPE,ALL,4
/COLOR,NUM,BLUE,1
*IF,I,EQ,2,THEN
SET,1,1
/TITLE,VMC5 - RIGID BODY - MODE 1
PLDISP,1
*ENDIF
*IF,I,EQ,2,THEN
SET,1,2
/TITLE,VMC5 - RIGID BODY - MODE 2
PLDISP,1
*ENDIF
*IF,I,EQ,2,THEN
SET,1,3
/TITLE,VMC5 - RIGID BODY - MODE 3
PLDISP,1
*ENDIF
/VIEW,1,-0.677530527371,-0.68876415506,0.257985122023
/ANG,1,76.7942822618
*IF,I,EQ,2,THEN
SET,1,4
/TITLE,VMC5 - OUT OF PLANE - MODE 4
PLDISP,0
*ENDIF
*IF,I,EQ,2,THEN
SET,1,5
/TITLE,VMC5 - OUT OF PLANE - MODE 5
PLDISP,0
*ENDIF
*IF,I,EQ,2,THEN
SET,1,6
/TITLE,VMC5 - OUT OF PLANE - MODE 6
PLDISP,0
*ENDIF
*IF,I,EQ,2,THEN
SET,1,7
```

```
  /TITLE,VMC5 - OUT OF PLANE - MODE 7
  PLDISP,0
  *ENDIF
  /VIEW,1,,,-1
  /ANG,1
  *IF,I,EQ,2,THEN
  SET,1,8
  /TITLE,VMC5 - IN PLANE - MODE 8
  PLDISP,0
  *ENDIF
  *IF,I,EQ,2,THEN
  SET,1,9
  /TITLE,VMC5 - IN PLANE - MODE 9
  PLDISP,0
  *ENDIF
  *IF,I,EQ,2,THEN
  SET,1,10
  /TITLE,VMC5 - IN PLANE - MODE 10
  PLDISP,0
  *ENDIF
  /TITLE, VMC5, SIMPLY-SUPPORTED SOLID SQUARE PLATE
  FINISH
*END
  /COM, COMMENT:  CALL MACRO TO LOOP THROUGH DIFFERENT ELEMENT TYPES
  *DO,I,1,2
    *IF,I,EQ,1,THEN
      *USE,base,185,8,3,,I,
    *ELSEIF,I,EQ,2,THEN
      *USE,base,187,6,1,,I,
    *ENDIF
  *ENDDO
  /OUT,
  !*STAT,NARAY
  /OUT,vmc5,vrt
  /COM,
  /COM,---------------------- VMC5 RESULTS LISTING -----------------------
  /COM,
  /COM,| ETYP | N1 |  N2 |  RAT4 |  RAT5 |
  /COM,
  *VWRITE,NARAY(1,1),NARAY(1,2),NARAY(1,3),NARAY(1,4),NARAY(1,5)
  (F5.0,'  ',F5.0,'  ',F5.0,'  ',F5.3,'  ',F5.3)
  /COM,
  /COM,-------------------------------------------------------------------
  /COM,
  /COM,---------------------- VMC5 RESULTS CONT.... ----------------------
  /COM,
  /COM,| RAT6 |  RAT7 |  RAT8 |  RAT9 |  RAT10
  /COM,
  *VWRITE,NARAY(1,6),NARAY(1,7),NARAY(1,8),NARAY(1,9),NARAY(1,10)
  ('  ',F5.3,'   ',F5.3,'   ',F5.3,'   ',F5.3,'   ',F5.3,'   ')
  /COM,
  /COM,-------------------------------------------------------------------
  /OUT
FINISH
/delete,PARAM
/delete,base
*LIST,vmc5,vrt
finish
```

Benchmark C6 Input Listing

```
/COM,ANSYS MEDIA REL. 140 (11/26/2011) REF. VERIF. MANUAL: REL. 140
/VERIFY,VMC6
/SHOW
  /OUT,SCRATCH
  *DIM,NARAY,TABLE,16,6         ! 2-D NARAY FOR RESULTS INFO
  *DO,I,1,16
    *DO,J,1,6
```

```
      NARAY(I,J)=0.             ! INITIALIZE NARAY
    *ENDDO
  *ENDDO
*CREATE,base,
  PARSAV,ALL
  /clear, nostart
  PARRES,CHANGE
  /PREP7
smrt,off
  /TITLE, VMC6, TWO-DIMENSIONAL HEAT TRANSFER WITH CONVECTION
  /COM,   SEE "SELECTED FE BENCHMARKS IN STRUCTURAL AND THERMAL
  /COM,   ANALYSIS", NAFEMS REPT. FEBSTA REV. 1, OCT. 1986
  /COM,   TEST NO. T4
  ANTYPE,STATIC                 ! THERMAL ANALYSIS
  ET,1,ARG1                     ! DEFINE ELEMENT TYPE PARAMETRICALLY
  NARAY(ARG4,1)=ARG1            ! STORE ETYPE
  MP,KXX,1,52.0                 ! DEFINE CONDUCTIVITY
  *IF,I,LE,10,THEN
    K,1                         ! DEFINE KEYPOINTS
    K,2,.6
    K,3,.6,1.0
    K,4,,1.0
    A,1,2,3,4
    ESIZE,ARG2                  ! DEFINE ELEMENT SIZE, & SHAPE PARAMETRICALLY
    ESHAPE,ARG3
    NARAY(ARG4,2)=ARG2          ! STORE N1 (ELEMENT EDGE LENGTH)
    NARAY(ARG4,3)=ARG3          ! STORE N2 (ELEMENT SHAPE)
    AMESH,1                     ! MESH AREA
  *ELSE
    G1=(.6/ARG2)+1              ! DEFINE PARAMETERS FOR MESH GENERATION
    G2=(1/ARG2)+1
    G3=(G2-1)
    N,1
    NGEN,G1,1,ALL,,,ARG2
    NGEN,G2,G1,ALL,,,,ARG2
    *IF,ARG1,EQ,77,THEN
      E,1,2,(G1+2),(G1+2)
      EGEN,(G1-1),1,ALL
      E,1,(G1+2),(G1+1),(G1+1)
      EGEN,(G1-1),1,G1
      EGEN,G3,G1,ALL
      NARAY(ARG4,2)=ARG2          ! STORE N1 (ELEMENT EDGE LENGTH)
      NARAY(ARG4,3)=ARG3          ! STORE N2 (ELEMENT SHAPE)
    *ELSE
      E,1,2,(G1+2)
      EGEN,(G1-1),1,ALL
      E,1,(G1+2),(G1+1)
      EGEN,(G1-1),1,G1
      EGEN,G3,G1,ALL
      NARAY(ARG4,2)=ARG2          ! STORE N1 (ELEMENT EDGE LENGTH)
      NARAY(ARG4,3)=ARG3          ! STORE N2 (ELEMENT SHAPE)
    *ENDIF
    *IF,ARG1,NE,55,THEN
      EMID
      NARAY(ARG4,2)=ARG2          ! STORE N1 (ELEMENT EDGE LENGTH)
      NARAY(ARG4,3)=ARG3          ! STORE N2 (ELEMENT S)
    *ENDIF
  *ENDIF
  *GET,MAXE,ELEM,,NUM,MAX
  *GET,MAXN,NODE,,NUM,MAX
  NARAY(ARG4,4)=MAXN*1          ! CALCULATE NO. DEGREES OF FREEDOM
  T1=NODE(.6,.2,0)              ! GET NODE NUMBER OF INTEREST
  NSEL,S,LOC,Y,0
  D,ALL,TEMP,100.               ! SPECIFY EDGE TEMPERATURE
  NSEL,S,LOC,X,0.6
  SF,ALL,CONV,750.0,0.0         ! SPECIFY CONVECTION SURFACES
  NSEL,A,LOC,Y,1.0
  SF,ALL,CONV,750.0,0.0
  NSEL,ALL

  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
  !!  SETUP AND PLOT ELEMENTS FOR DOCUMENTATION !!
```

```
  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
  /AUTO,1
  /VIEW,1,,,1
  /ANG,1
  /DEVICE,VECTOR,1
  /DEVICE,DITHER,1
  /TYPE,ALL,4
  /COLOR,NUM,BLUE,1
  *IF,ARG1,EQ,77,THEN
   *IF,ARG2,EQ,0.2,THEN
   *IF,ARG3,EQ,2,THEN
   /TITLE,VMC6 - QUADRILATERAL MESH (N1 = 0.2)
   EPLOT
   *ENDIF
   *ENDIF
   *IF,ARG2,EQ,0.1,THEN
   *IF,ARG3,EQ,2,THEN
   /TITLE,VMC6 - QUADRILATERAL MESH (N1 = 0.1)
   EPLOT
   *ENDIF
   *ENDIF
   *IF,ARG2,EQ,0.2,THEN
   *IF,ARG3,EQ,1,THEN
   *IF,I,EQ,15,THEN
   /TITLE,VMC6 - UNIFORM TRIANGLE MESH (N1 = 0.2)
   EPLOT
   *ENDIF
   *ENDIF
   *ENDIF
   *IF,ARG2,EQ,0.1,THEN
   *IF,ARG3,EQ,1,THEN
   *IF,I,EQ,16,THEN
   /TITLE,VMC6 - UNIFORM TRIANGLE MESH (N1 = 0.1)
   EPLOT
   *ENDIF
   *ENDIF
   *ENDIF
   *IF,ARG2,EQ,0.2,THEN
   *IF,ARG3,EQ,1,THEN
   *IF,I,EQ,9,THEN
   /TITLE,VMC6 - TRIANGLE MESH (N1 = 0.2)
   EPLOT
   *ENDIF
   *ENDIF
   *ENDIF
   *IF,ARG2,EQ,0.1,THEN
   *IF,ARG3,EQ,1,THEN
   *IF,I,EQ,10,THEN
   /TITLE,VMC6 - TRIANGLE MESH (N1 = 0.1)
   EPLOT
   *ENDIF
   *ENDIF
   *ENDIF
*ENDIF


  FINISH
  /SOLU
  SOLVE
  *GET,NTEM,TEMP,T1              ! GET TEMERATURE AT NODE OF INTEREST
  NARAY(ARG4,5)=NTEM             ! STORE TEMPERATURE
  NARAY(ARG4,6)=NTEM/18.3        ! CALCULATE TEMPERATURE RATIO
  PARSAV,,PARAM
  FINISH
*END
  /COM, COMMENT:  CALL MACRO TO LOOP THROUGH DIFFERENT ELEMENT TYPES, MESHES
  *DO,I,1,16
    *IF,I,EQ,1,THEN
      *USE,base,55,.2,2,I        ! QUAD MESH
    *ELSEIF,I,EQ,2,THEN
      *USE,base,55,.1,2,I        ! QUAD MESH
    *ELSEIF,I,EQ,3,THEN
```

```
      *USE,base,77,.2,2,I       ! QUAD MESH
    *ELSEIF,I,EQ,4,THEN
      *USE,base,77,.1,2,I       ! QUAD MESH
    *ELSEIF,I,EQ,5,THEN
      *USE,base,35,.2,1,I       ! TRIANGLE MESH
    *ELSEIF,I,EQ,6,THEN
      *USE,base,35,.1,1,I       ! TRIANGLE MESH
    *ELSEIF,I,EQ,7,THEN
      *USE,base,55,.2,1,I       ! TRIANGLE MESH
    *ELSEIF,I,EQ,8,THEN
      *USE,base,55,.1,1,I       ! TRIANGLE MESH
    *ELSEIF,I,EQ,9,THEN
      *USE,base,77,.2,1,I       ! TRIANGLE MESH
    *ELSEIF,I,EQ,10,THEN
      *USE,base,77,.1,1,I       ! TRIANGLE MESH
    *ELSEIF,I,EQ,11,THEN
      *USE,base,35,.2,1,I ! TRIANGLE MESH
    *ELSEIF,I,EQ,12,THEN
      *USE,base,35,.1,1,I ! TRIANGLE MESH
    *ELSEIF,I,EQ,13,THEN
      *USE,base,55,.2,1,I ! TRIANGLE MESH
    *ELSEIF,I,EQ,14,THEN
      *USE,base,55,.1,1,I ! TRIANGLE MESH
    *ELSEIF,I,EQ,15,THEN
      *USE,base,77,.2,1,I ! TRIANGLE MESH
    *ELSEIF,I,EQ,16,THEN
      *USE,base,77,.1,1,I ! TRIANGLE MESH
    *ENDIF
  *ENDDO
  /OUT,
  !*STAT,NARAY                   ! GET STATUS OF NARAY
  *VLEN,4
  *VCOL,6
  /OUT,vmc6,vrt
  /COM,
  /COM,------------------- VMC6 RESULTS LISTING ---------------------
  /COM
  /COM, QUAD MESH
  /COM,
  /COM,| ETYP | N1  | DOF  | TEMP(C) | TEMP RATIO |
  /COM,
  *VWRITE,NARAY(1,1),NARAY(1,2),NARAY(1,4),NARAY(1,5),NARAY(1,6)
  (F5.0,'   ',F5.2,'  ',F5.0,'   ',F5.1,'    ',F5.2)
  /COM,
  /OUT
  *VLEN,6
  /OUT,vmc6,vrt,,append
  /COM, TRIANGLE MESH
  /COM,
  /COM,| ETYP | N1  | DOF  | TEMP(C) | TEMP RATIO |
  /COM,
  *VWRITE,NARAY(5,1),NARAY(5,2),NARAY(5,4),NARAY(5,5),NARAY(5,6)
  (F5.0,'   ',F5.2,'  ',F5.0,'   ',F5.1,'    ',F5.2)
  /COM,
  /COM, UNIFORM TRIANGLE MESH
  /COM,
  /COM,| ETYP | N1  | DOF  | TEMP(C) | TEMP RATIO |
  /COM,
  *VWRITE,NARAY(11,1),NARAY(11,2),NARAY(11,4),NARAY(11,5),NARAY(11,6)
  (F5.0,'   ',F5.2,'  ',F5.0,'   ',F5.1,'    ',F5.2)
  /COM,
  /COM,---------------------------------------------------------------
/OUT
FINISH
*LIST,vmc6,vrt
/DELETE,PARAM
/DELETE,base
FINISH
```

Benchmark C7 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMC7
/SHOW
  /OUT,SCRATCH
  *DIM,NARAY,TABLE,9,6            ! 2-D NARAY FOR RESULTS INFO
    *DO,I,1,9
      *DO,J,1,6
        NARAY(I,J)=0.             ! INITIALIZE NARAY
      *ENDDO
    *ENDDO
*CREATE,base,
  PARSAV,ALL
  /clear, nostart
  PARRES,CHANGE
  /PREP7
smrt,off
  /TITLE, VMC7, ONE-DIMENSIONAL TRANSIENT HEAT TRANSFER WITH CONVECTION
  /COM,   SEE HOLMAN: "HEAT TRANSFER", MCGRAW HILL CO., 4TH EDITION,
  /COM,   PG. 106, 1976.
  /COM,
  ANTYPE,TRANS
  ET,1,ARG1                       ! DEFINE ELEMENT TYPE PARAMETRICALLY
  NARAY(ARG4,1)=ARG1              ! STORE ETYPE
  MP,KXX,1,54                     ! DEFINE MATERIAL PROPERTIES
  MP,DENS,1,7833
  MP,C,1,.465
  K,1
  K,2,(1/(ARG2*2))                ! DEFINE KEYPOINTS
  K,3,(1/(ARG2*2)),1
  K,4,,1
  L,1,2
  L,4,3                           ! DEFINE LINE SEGMENTS
  LESIZE,ALL,,,1
  A,1,2,3,4                       ! DEFINE AREAS
  ESIZE,,ARG2                     ! SET ELEMENT DIVISIONS PARAMETRICALLY
  NARAY(ARG4,2)=ARG2              ! STORE ELEMENT DIVISIONS
  AMESH,1                         ! MESH AREA
  NSEL,S,LOC,Y,1
  NSEL,R,LOC,X,0
  *GET,N1,NODE,,NUM,MAX           ! GET NODE NUMBER ON TOP SURFACE
  NSEL,ALL
  TUNIF,0                         ! DEFINE INITIAL TEMPERATURE
  NSEL,S,LOC,Y,1
  SF,ALL,CONV,50,1000             ! APPLY CONVECTION H=50 TBULK=1000
  NSEL,ALL
  KBC,1                           ! STEP BOUNDARY CONDITION
  TIME,2.0                        ! END TIME= 2 SEC.
  DELTIM,ARG3
  NARAY(ARG4,3)=ARG3              ! STORE DELTA T MIN

  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
  !!  SETUP AND PLOT ELEMENTS FOR DOCUMENTATION !!
  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
  /AUTO,1
  /VIEW,1,,,1
  /ANG,1
  /DEVICE,VECTOR,1
  /DEVICE,DITHER,1
  /TYPE,ALL,4
  /COLOR,NUM,BLUE,1

  *IF,ARG1,EQ,77,THEN
   *IF,ARG2,EQ,6,THEN
   /TITLE,VMC7 - QUADRILATERAL MESH (N = 6)
   EPLOT
   *ENDIF
   *IF,ARG2,EQ,8,THEN
```

```
    /TITLE,VMC7 - QUADRILATERAL MESH (N = 8)
    EPLOT
    *ENDIF
    *IF,ARG2,EQ,16,THEN
    /TITLE,VMC7 - QUADRILATERAL MESH (N = 16)
    EPLOT
    *ENDIF
   *ENDIF

   *IF,ARG1,EQ,35,THEN
    *IF,ARG2,EQ,6,THEN
    /TITLE,VMC7 - TRIANGLE MESH (N = 6)
    EPLOT
    *ENDIF
    *IF,ARG2,EQ,8,THEN
    /TITLE,VMC7 - TRIANGLE MESH (N = 8)
    EPLOT
    *ENDIF
    *IF,ARG2,EQ,16,THEN
    /TITLE,VMC7 - TRIANGLE MESH (N = 16)
    EPLOT
    *ENDIF
   *ENDIF

   /TITLE, VMC7, ONE-DIMENSIONAL TRANSIENT HEAT TRANSFER WITH CONVECTION
   FINISH
   /SOLU
   AUTOTS,ON                       ! INVOKE AUTO TIME STEPPING
   SOLVE
   *GET,CIT,ACTIVE,,SOLU,NCMIT     ! GET CUMULATIVE ITERATIONS
   NARAY(ARG4,4)=CIT               ! STORE CUMULATIVE ITERATIONS
   FINISH
   /POST1
   *GET,TN1,NODE,N1,TEMP           ! GET SURFACE NODE TEMPERATURE
   NARAY(ARG4,5)=TN1               ! STORE TEMPERATURE
   NARAY(ARG4,6)=TN1/157.25        ! NORMALIZE TEMPERATURE TO TARGET VALUE
   PARSAV,,PARAM
   FINISH
 *END
   /COM, COMMENT:  CALL MACRO TO LOOP THROUGH DIFFERENT ELEMENT TYPES
   *DO,I,1,9
     *IF,I,EQ,1,THEN
       *USE,base,55,6,.5,I
     *ELSEIF,I,EQ,2,THEN
       *USE,base,55,8,.25,I
     *ELSEIF,I,EQ,3,THEN
       *USE,base,55,16,.0667,I
     *ELSEIF,I,EQ,4,THEN
       *USE,base,77,6,.5,I
     *ELSEIF,I,EQ,5,THEN
       *USE,base,77,8,.25,I
     *ELSEIF,I,EQ,6,THEN
       *USE,base,77,16,.0667,I
     *ELSEIF,I,EQ,7,THEN
       *USE,base,35,6,.5,I
     *ELSEIF,I,EQ,8,THEN
       *USE,base,35,8,.25,I
     *ELSEIF,I,EQ,9,THEN
       *USE,base,35,16,.0667,I
     *ENDIF
   *ENDDO
   /OUT,
   !*STAT,NARAY
   /OUT,vmc7,vrt
   /COM
   /COM,------------------- VMC7 RESULTS LISTING -----------------------------------
   /COM,
   /COM, TARGET SOLUTION: T = 157.25
   /COM,
   /COM,| ETYP | N  | DELTA-T  | CUM ITR  | SURF-TEMP  | TEMP RAT  |
   /COM,
   *VWRITE,naray(1,1),naray(1,2),naray(1,3),NARAY(1,4),NARAY(1,5),NARAY(1,6)
```

```
  (F5.0,'  ',F5.0,'   ',F5.4,'     ',F5.0,'        ',F7.3,'     ',F5.3)
  /COM,-----------------------------------------------------------------------------
  /OUT

FINISH
*LIST,vmc7,vrt
/DELETE,PARAM
/DELETE,base
FINISH
```

Benchmark C8 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMC8
/config,nlco,0
/SHOW
/DEVICE,VECTOR,ON
OKEY=1
/TITLE, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY
/COM
/COM   Ref: Wilkins M.L and Guinan M.W., "Impact of Cylinders on a Rigid
/COM        Boundary", J. Appl. Phys., Vol. 44, No. 3, 1973.
/COM
/UNITS,SI                       ! (KG, Ne, M , SEC)

*dim,LFA,,2,6
*do,i,1,6

*if,i,eq,1,then
  atype=2
  etyp=2
  /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY - PLANE2
*elseif,i,eq,2,then
  atype=2
  etyp=42
  /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY - PLANE42
*elseif,i,eq,3,then
  atype=2
  etyp=82
  /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY - PLANE82
*elseif,i,eq,4,then
  atype=2
  etyp=106
  /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY - VISCO106
*elseif,i,eq,5,then
  atype=2
  etyp=182
  /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY - PLANE182
*elseif,i,eq,6,then
  atype=2
  etyp=183
  /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY - PLANE183
*endif

/PREP7
RAD = 0.00381                   ! BAR RADIUS [m]
L = 0.02347                     ! BAR LENGTH
DI = 0.0001                     ! INTERFACE BETWEEN THE BAR AND THE WALL
VEL = 478                       ! INITIAL VELOCITY [M/SEC]
CVEL= (70E9/2700)**0.5          ! ELASTIC WAVE PROPAGATION SPEED
TEL=(RAD/4)/CVEL                ! TIME STEP INCREMENT (4 ELEMENTS ALONG RADIUS)
NLS=NINT(1.1*(4.5E-5/TEL))      ! MINIMUM NUMBER OF SUBSTEPS FOT TIME=4.5E-5
ET,1,ETYP                       ! ELEMENT TYPE
*IF,ATYPE,EQ,2,THEN
KEYOPT,1,3,1                    ! AXISYMMETIRC OPTION
*ENDIF
*IF,ETYP,EQ,42,THEN
KEYOPT,1,1,1   ! REDUCED INTEGRATION FOR 42
```

```
*ENDIF
*IF,ETYP,EQ,182,THEN
KEYOPT,1,1,1   ! REDUCED INTEGRATION FOR 182
*ENDIF
MP,EX,1,70E9                    ! ELASTIC MODULUS [Pa]
MP,NUXY,1,0.3
MP,DENS,1,2700                  ! DENSITY (KG/M^3)
TB,BISO,1                       ! BILINEAR ISOTROPIC HARDENING
TBDAT,1,420E6,100E6             ! YEILD STRESS [Pa], TANGENT MODULUS [Pa]
K,1,0,DI                        ! SOLID MODEL
K,2,RAD,DI
K,3,RAD,(DI+L)
K,4,0,(DI+L)
L,1,2
L,3,4
LESIZE,ALL,,,4
L,1,4
L,2,3
LESIZE,ALL,,,12,3
A,1,2,3,4
AMESH,1
EPLOT
NSEL,S,LOC,X,0
D,ALL,UX
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,L+DI
*GET,NTOP,NODE,,NUM,MIN
NSEL,ALL
NBOT=NODE(0,0,0)
NSEL,S,,,NBOT
ESLN,S
*GET,EBOT,ELEM,,NUM,MIN
NSEL,ALL
ESEL,ALL
SAVE
FINISH

/OUT,SCRATCH
/SOLU
ANTYPE,TRANS
NLGEOM,ON
NROPT,FULL
AUTOTS,ON
TIMINT,OFF                      ! STATIC LOAD STEP - DEFINE INITIAL VELOCITY
T1=DI/VEL                       ! TIME INCREMENT
TIME,T1
DELTIM,T1
NSEL,S,LOC,Y,DI
D,ALL,UY,-DI
NSEL,ALL
D,ALL,UZ
NCNV,2
CNVTOL,U,1,0.001
OUTPR,ALL,NONE
OUTRES,ALL,10
SOLVE                           ! LOAD STEP 1 - STATIC
TIMINT,ON
NEQIT,40
CNVTOL,U
CNVTOL,F,0.01,0.001
NSUBSTEP,NLS,10*NLS,NLS
TIME,(T1+4.5E-5)
SOLVE                           ! LOAD STEP 1 - DYNAMIC
SAVE
FINISH

/POST1
SET,LAST
/DSCAL,1,1
PLDISP                          ! PLOT DEFORMED SHAPE
*GET,DYTP,UY,NTOP               ! NODAL DISPLACEMENT OF TOP NODE
LF=(L+DI)+DYTP                  ! DEFORMED LENGTH
```

```
LFA(1,i)=LF
LFA(2,i)=LF/(L*0.562)
/OUT,
*STATUS,LF
FINISH

/OUT,SCRATCH
/POST26
/GRID,1
XVAR,1
NSOL,2,NTOP,U,Y                  ! DISPLACEMENT OF FREE END NODE
ESOL,3,EBOT,NBOT,EPPL,EQV        ! EQUIVALENT PLASTIC STRAIN
ADD,2,2,,,DISP,,,-1
/AXLAB,X,TIME [SEC]
/AXLAB,Y,FREE END DISPLACEMENT [M]
PLVAR,2                          ! PLOT DISPLACEMENT VS. TIME
/AXLAB,Y,EPPL-EQV AT NODE 1
PLVAR,3                          ! PLOT PLASTIC STRAIN
FINISH

PARSAV,ALL
/clear, nostart
PARRES

*ENDDO

FINISH
*VLEN,1
/OUT,vmc8,vrt
/COM
/COM,------------------- VMC8 RESULTS LISTING ------------------------------------
/COM,
/COM,
/COM,ETYP  |   2   |   42   |   82   |   106   |   182   |   183   |
/COM,
*VWRITE,LFA(1,1),LFA(1,2),LFA(1,3),LFA(1,4),LFA(1,5),LFA(1,6)
(' L (m)   ',F5.3,'   ',F5.3,'    ',F5.3,'     ',F5.3,'     ',F5.3,'     ',F5.3)
*VWRITE,LFA(2,1),LFA(2,2),LFA(2,3),LFA(2,4),LFA(2,5),LFA(2,6)
(' RATIO   ',F5.3,'   ',F5.3,'    ',F5.3,'     ',F5.3,'     ',F5.3,'     ',F5.3)
/COM,----------------------------------------------------------------------------------
/OUT
*LIST,vmc8,vrt
FINISH
```

Benchmark D1 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMD1
/DEVICE,VECTOR,ON
! ----------------------------------------------------------------------
! PARAMETER KEY:
!
! ATYP  - ANALYSIS TYPE (2=2D, 3=3D)
! ETYP  - ELEMENT TYPE NUMBER
! QUAD  - '1' IF QUADRILATERAL ELEMENT
! TRI   - '1' IF TRIANGULAR HIGHER ORDER ELEMENT
! BRICK - '1' IF BRICK ELEMENT
! TET   - '1' IF HIGHER ORDER TET ELEMENT
! LOW   - '1' IF LOWER ORDER QUAD OR BRICK ELEMENT
! HIGH  - '1' IF HIGHER ORDER QUAD OR BRICK ELEMENT
!
! NOTE: FOR QUAD, TRI, BRICK, & TET KEYS: ONLY ONE MAY BE SET TO
!       '1' (ACTIVE).  LOW & HIGH ARE APPLICABLE ONLY TFOR EITHER
!       QUAD OR BRICK ELEMENT TYPES.  SET LOW OR HIGH TO ZERO FOR
!       TRI OR TET ELEMENTS.
! ----------------------------------------------------------------------
/TITLE, VMD1, STRAIGHT BEAM UNDER VARIOUS LOADS
/COM
```

```
/COM    MACNEAL, R.H., AND HARDER R.L., "A PROPOSED STANDARD SET OF
/COM    PROBLEMS TO TEST FINITE ELEMENT ACCURACY
/COM
/NOPR
/OUT,SCRATCH
*CREATE,MAC1
 ARG1=(ARG1*3.141592654)/180.           ! ARG1=DISTORTION ANGLE (DEG.)
 DELX=(0.1*TAN(ARG1))
 NMODIF,ARG2,(1+DELX)
 *REPEAT,3,4,2
 NMODIF,ARG3,(2-DELX)
 *REPEAT,2,4,2
 NMODIF,ARG4,(1-DELX)
 *REPEAT,3,4,2
 NMODIF,ARG5,(2+DELX)
 *REPEAT,2,4,2
*END
*CREATE,MAC2
 ARG1=(ARG1*3.141592654)/180.
 DELX=(0.1*TAN(ARG1))
 NMODIF,ARG2,(1-DELX)
 *REPEAT,5,2,1
 NMODIF,ARG3,(1+DELX)
 *REPEAT,5,2,1
*END
*CREATE,MAC3                                   ! MACRO - EXTRACT DISP
  *DO,I,1,7
    *GET,X1,NODE,13+(I-1)*200,U,ARG1
    *GET,X2,NODE,53+(I-1)*200,U,ARG1
    DR(ARG2,I)=(ABS(X1)+ABS(X2))/2
  *ENDDO
*END
*CREATE,MAC4                                   ! MACRO - EXTRACT ERROR
  SET,ARG1
  *DO,J,1,7
    ESEL,S,,,EINC*(J-1)+1,EINC*(J-1)+EINC
    PRERR
 *GET,ER(ARG1,J),PRERR,,SEPC
  *ENDDO
*END
*DO,L,1,6
*IF,L,EQ,1,THEN
  ETYP=183
 ATYP=2
 QUAD=0
 TRI=1
 BRICK=0
 TET=0
 LOW=0
 HIGH=0
  ELAB='PLANE183 tri'
*ELSEIF,L,EQ,2,THEN
  ETYP=182
 ATYP=2
 QUAD=1
 TRI=0
 BRICK=0
 TET=0
 LOW=1
 HIGH=0
  ELAB='PLANE182'
*ELSEIF,L,EQ,3,THEN
  ETYP=183
 ATYP=2
 QUAD=1
 TRI=0
 BRICK=0
 TET=0
 LOW=0
 HIGH=1
  ELAB='PLANE183'
*ELSEIF,L,EQ,4,THEN
```

```
  ETYP=185
 ATYP=3
 QUAD=0
 TRI=0
 BRICK=1
 TET=0
 LOW=1
 HIGH=0
  ELAB='SOLID185'
*ELSEIF,L,EQ,5,THEN
  ETYP=187
 ATYP=3
 QUAD=0
 TRI=0
 BRICK=0
 TET=1
 LOW=0
 HIGH=0
  ELAB='SOLID187'
*ELSEIF,L,EQ,6,THEN
  ETYP=186
 ATYP=3
 QUAD=0
 TRI=0
 BRICK=1
 TET=0
 LOW=0
 HIGH=1
  ELAB='SOLID186'
*ENDIF
*DIM,DR,,4,7                            ! ARRAY - DISPLACEMENT RATIO
*DIM,ER,,4,7                            ! ARRAY - ENERY NORM ERROR
*DIM,LAB,CHAR,4
LAB(1)='EXTEND'
 LAB(2)='IP SHEAR'
 LAB(3)='OP SHEAR'
 LAB(4)='TWIST'

*IF,TRI,EQ,1,THEN                       ! DEFINE ELEMENTS PER MODEL
  EINC=12
*ELSEIF,TET,EQ,1,THEN
  EINC=30
*ELSE
  EINC=6
*ENDIF
/PREP7

*IF,BRICK,EQ,1,AND,LOW,EQ,1,THEN
  ET,1,ETYP,,3    !SIMPLIFIED ENHANCED STRAIN FORMULATION
*ELSEIF,BRICK,EQ,1,AND,HIGH,EQ,1,THEN
  ET,1,ETYP,,1    !FULL INTEGRATION
*ELSEIF,QUAD,EQ,1,AND,LOW,EQ,1,THEN
  ET,1,ETYP,3,,3   !SIMPLIFIED ENHANCED STRAIN FORMULATION
*ELSEIF,TET,EQ,1,THEN
  ET,1,ETYP
*ELSEIF,TRI,EQ,1,THEN
  ET,1,ETYP,1,,3
*ELSE,
  ET,1,ETYP,,,3
*ENDIF
R,1,0.1
MP,EX,1,1E7
MP,NUXY,1,0.3
N,1
 N,13,6,0
FILL,1,13,5,3,2
NGEN,3,20,1,13,2,0,0.1,0                ! DEFINE CORNER NODES
NGEN,4,200,1,53,2,0,0,0                 ! DEFINE NODES FOR TRAPIZOIDAL ELEMENTS
*USE,MAC1,15,203,205,243,245            ! MODIFY NODE LOCATIONS
*USE,MAC1,30,403,405,443,445
*USE,MAC1,45,603,605,643,645
NGEN,2,800,1,53,2,0,0,0                 ! DEFINE NODES PARALLELOGRAM ELEMENTS
```

```
NGEN,3,200,801,853,2
*USE,MAC2,15,803,843                   ! MODIFY NODE LOCATIONS
*USE,MAC2,30,1003,1043
*USE,MAC2,45,1203,1243
*IF,QUAD,EQ,1,THEN                     ! QUAD ELEMENT GENERATION
  E,1,3,43,41
  EGEN,6,2,-1
  EGEN,4,200,-6
  EGEN,4,200,-6
  *IF,HIGH,EQ,1,THEN
    EMID
  *ENDIF
  /VIEW,1,1,2,3
  EPLOT
*ENDIF
*IF,TRI,EQ,1,THEN                      ! HIGHER ORDER TRI ELEMENT GENERATION
  E,1,3,41
  E,3,43,41
  EGEN,6,2,-2
  EGEN,4,200,-12
  EGEN,4,200,-12
  EMID
  /VIEW,1,1,2,3
  EPLOT
*ENDIF
*IF,BRICK,EQ,1,THEN                    ! BRICK ELEMENT GENERATION
  NGEN,2,1300,1,1353,1,,,.1
  E,1,3,43,41,1301,1303,1343,1341
  EGEN,6,2,-1
  EGEN,4,200,-6
  EGEN,4,200,-6
  *IF,HIGH,EQ,1,THEN
    EMID
  *ENDIF
  /VIEW,1,1,2,3
  EPLOT
*ENDIF
*IF,TET,EQ,1,THEN                      ! TET ELEMENT GENERATION
  NGEN,2,1300,1,1353,1,,,.1
  E,1,1301,1303,1341
  E,1,1303,3,43
  E,1303,1343,43,1341
  E,1,1303,43,1341
  E,1,43,1341,41
  E,3,1303,5,43
  E,1303,1305,5,1345
  E,1303,5,43,1345
  E,5,43,1345,45
  E,1303,1345,43,1343
  EGEN,3,4,-10
  EGEN,4,200,-30
  EGEN,4,200,-30
  EMID
  /VIEW,1,1,2,3
  EPLOT
*ENDIF
NSLE,S
NSEL,INVERT
NDELE,ALL
NSEL,ALL
NSEL,S,LOC,X,0
D,ALL,ALL                              ! FIX LEFT END
NSEL,ALL
WSORT,x
FINISH
/SOLU
*IF,QUAD,EQ,1,THEN                     ! QUAD ELEMENT LOADS
  *IF,LOW,EQ,1,THEN
    /TITLE, STRAIGHT BEAM -  EXTENSION (DISP = 3E-5)
    F,13,FX,.50,,53,40
 *REPEAT,7,200,,,,200
    SOLVE
```

```
     /TITLE, STRAIGHT BEAM -  IN-PLANE LOAD (DISP = .1081)
     FDEL,ALL
     F,13,FY,.50,,53,40
  *REPEAT,7,200,,,,200
     SOLVE
   *ELSE
     /TITLE, STRAIGHT BEAM -  EXTENSION (DISP = 3E-5)
     NSEL,S,LOC,X,6
     F,ALL,FX,(1/6)
     NSEL,R,LOC,Y,.1
     F,ALL,FX,(2/3)
     NSEL,ALL
     SOLVE
     /TITLE, STRAIGHT BEAM -  IN-PLANE LOAD (DISP = .1081)
     FDEL,ALL
     NSEL,S,LOC,X,6
     F,ALL,FY,(1/6)
     NSEL,R,LOC,Y,.1
     F,ALL,FY,(2/3)
     NSEL,ALL
     SOLVE
   *ENDIF
 *ENDIF
 *IF,TRI,EQ,1,THEN                       ! HIGHER ORDER TRAINGLE LOADS
   /TITLE, STRAIGHT BEAM -  EXTENSION (DISP = 3E-5)
   NSEL,S,LOC,X,6
   F,ALL,FX,(1/6)
   NSEL,R,LOC,Y,.1
   F,ALL,FX,(2/3)
   NSEL,ALL
   SOLVE
   /TITLE, STRAIGHT BEAM -  IN-PLANE LOAD (DISP = .1081)
   FDEL,ALL
   NSEL,S,LOC,X,6
   F,ALL,FY,(1/6)
   NSEL,R,LOC,Y,.1
   F,ALL,FY,(2/3)
   NSEL,ALL
   SOLVE
 *ENDIF
 *IF,BRICK,EQ,1,THEN                     ! BRICK ELEMENT LOADS
   *IF,LOW,EQ,1,THEN
     /TITLE, STRAIGHT BEAM -  EXTENSION (DISP = 3E-5)
     F,13,FX,.25,,53,40
  *REPEAT,7,200,,,,200
     F,1313,FX,.25,,1353,40
  *REPEAT,7,200,,,,200
     SOLVE
     /TITLE, STRAIGHT BEAM -  IN-PLANE LOAD (DISP = .1081)
     FDEL,ALL
     F,13,FY,.25,,53,40
  *REPEAT,7,200,,,,200
     F,1313,FY,.25,,1353,40
  *REPEAT,7,200,,,,200
     SOLVE
     /TITLE, STRAIGHT BEAM -  OUT-OF-PLANE LOAD (DISP. = .4321)
     FDEL,ALL
     F,13,FZ,.25,,53,40
  *REPEAT,7,200,,,,200
     F,1313,FZ,.25,,1353,40
  *REPEAT,7,200,,,,200
     SOLVE
     /TITLE, STRAIGHT BEAM -  TWIST LOAD (ROT = .03208)
     FDEL,ALL
     F,13,FZ,2.5,,1213,200
     F,53,FZ,-2.5,,1253,200  *UNIT TWISTING MOMENT (0.2*5)
     F,1313,FZ,2.5,,2513,200
     F,1353,FZ,-2.5,,2553,200
     SOLVE
   *ELSE
     /TITLE, STRAIGHT BEAM -  EXTENSION (DISP = 3E-5)
     NSEL,S,LOC,X,6
```

```
   F,ALL,FX,(1/3)
   NSEL,R,LOC,Z,0
NSEL,R,LOC,Y,0
   F,ALL,FX,(-1/12)
   NSEL,S,LOC,X,6
NSEL,R,LOC,Z,0
NSEL,R,LOC,Y,.2
   F,ALL,FX,(-1/12)
   NSEL,S,LOC,X,6
NSEL,R,LOC,Z,.1
NSEL,R,LOC,Y,0
   F,ALL,FX,(-1/12)
   NSEL,S,LOC,X,6
NSEL,R,LOC,Z,.1
NSEL,R,LOC,Y,.2
   F,ALL,FX,(-1/12)
   NSEL,ALL
   SOLVE
   /TITLE, STRAIGHT BEAM -  IN-PLANE LOAD (DISP = .1081)
   FDEL,ALL
   NSEL,S,LOC,X,6
   F,ALL,FY,(1/3)
   NSEL,R,LOC,Z,0
NSEL,R,LOC,Y,0
   F,ALL,FY,(-1/12)
   NSEL,S,LOC,X,6
NSEL,R,LOC,Z,0
NSEL,R,LOC,Y,.2
   F,ALL,FY,(-1/12)
   NSEL,S,LOC,X,6
NSEL,R,LOC,Z,.1
NSEL,R,LOC,Y,0
   F,ALL,FY,(-1/12)
   NSEL,S,LOC,X,6
NSEL,R,LOC,Z,.1
NSEL,R,LOC,Y,.2
   F,ALL,FY,(-1/12)
   NSEL,ALL
   SOLVE
   /TITLE, STRAIGHT BEAM -  OUT-OF-PLANE LOAD (DISP. = .4321)
   FDEL,ALL
   NSEL,S,LOC,X,6
   F,ALL,FZ,(1/3)
   NSEL,R,LOC,Z,0
NSEL,R,LOC,Y,0
   F,ALL,FZ,(-1/12)
   NSEL,S,LOC,X,6
NSEL,R,LOC,Z,0
NSEL,R,LOC,Y,.2
   F,ALL,FZ,(-1/12)
   NSEL,S,LOC,X,6
NSEL,R,LOC,Z,.1
NSEL,R,LOC,Y,0
   F,ALL,FZ,(-1/12)
   NSEL,S,LOC,X,6
NSEL,R,LOC,Z,.1
NSEL,R,LOC,Y,.2
   F,ALL,FZ,(-1/12)
   NSEL,ALL
   SOLVE
   /TITLE, STRAIGHT BEAM -  TWIST LOAD (ROT = .03208)
   FDEL,ALL
   NSEL,S,LOC,X,6
NSEL,R,LOC,Z,0
NSEL,R,LOC,Y,.1
   F,ALL,FY,-5
   NSEL,S,LOC,X,6
NSEL,R,LOC,Z,.05
NSEL,R,LOC,Y,0
   F,ALL,FZ,5
   NSEL,S,LOC,X,6
NSEL,R,LOC,Z,.1
```

```
  NSEL,R,LOC,Y,.1
     F,ALL,FY,5
     NSEL,S,LOC,X,6
  NSEL,R,LOC,Z,.05
  NSEL,R,LOC,Y,.2
     F,ALL,FZ,-5
     NSEL,S,LOC,X,6
  NSEL,R,LOC,Z,0
  NSEL,R,LOC,Y,0
     F,ALL,FZ,(-15/12)
     NSEL,S,LOC,X,6
  NSEL,R,LOC,Z,0
  NSEL,R,LOC,Y,.2
     F,ALL,FZ,(15/12)
     NSEL,S,LOC,X,6
  NSEL,R,LOC,Z,.1
  NSEL,R,LOC,Y,0
     F,ALL,FZ,(-15/12)
     NSEL,S,LOC,X,6
  NSEL,R,LOC,Z,.1
  NSEL,R,LOC,Y,.2
     F,ALL,FZ,(15/12)
     NSEL,ALL
     SOLVE
   *ENDIF
 *ENDIF
 *IF,TET,EQ,1,THEN                     ! HIGHER ORDER TET ELEMENT LOADS
   /TITLE, STRAIGHT BEAM -  EXTENSION (DISP = 3E-5)
   NSEL,S,LOC,X,6
  NSEL,R,LOC,Z,.05
   F,ALL,FX,(1/6)
   NSEL,S,LOC,X,6
  NSEL,R,LOC,Y,.1
   F,ALL,FX,(1/6)
   NSEL,S,LOC,X,6
  NSEL,R,LOC,Z,.05
  NSEL,R,LOC,Y,.1
   F,ALL,FX,(1/3)
   NSEL,ALL
   SOLVE
   /TITLE, STRAIGHT BEAM -  IN-PLANE LOAD (DISP = .1081)
   FDEL,ALL
   NSEL,S,LOC,X,6
  NSEL,R,LOC,Z,.05
   F,ALL,FY,(1/6)
   NSEL,S,LOC,X,6
  NSEL,R,LOC,Y,.1
   F,ALL,FY,(1/6)
   NSEL,S,LOC,X,6
  NSEL,R,LOC,Z,.05
  NSEL,R,LOC,Y,.1
   F,ALL,FY,(1/3)
   NSEL,ALL
   SOLVE
   /TITLE, STRAIGHT BEAM -  OUT-OF-PLANE LOAD (DISP. = .4321)
   FDEL,ALL
   NSEL,S,LOC,X,6
  NSEL,R,LOC,Z,.05
   F,ALL,FZ,(1/6)
   NSEL,S,LOC,X,6
  NSEL,R,LOC,Y,.1
   F,ALL,FZ,(1/6)
   NSEL,S,LOC,X,6
  NSEL,R,LOC,Z,.05
  NSEL,R,LOC,Y,.1
   F,ALL,FZ,(1/3)
   NSEL,ALL
   SOLVE
   /TITLE, STRAIGHT BEAM -  TWIST LOAD (ROT = .03208)
   FDEL,ALL
   NSEL,S,LOC,X,6
  NSEL,R,LOC,Z,0
```

```
 NSEL,R,LOC,Y,.1
  F,ALL,FY,-(1/.3)
  NSEL,S,LOC,X,6
 NSEL,R,LOC,Z,.05
 NSEL,R,LOC,Y,0
  F,ALL,FZ,(1/.3)
  NSEL,S,LOC,X,6
 NSEL,R,LOC,Z,.1
 NSEL,R,LOC,Y,.1
  F,ALL,FY,(1/.3)
  NSEL,S,LOC,X,6
 NSEL,R,LOC,Z,.05
 NSEL,R,LOC,Y,.2
  F,ALL,FZ,-(1/.3)
  NSEL,ALL
  SOLVE
*ENDIF
FINISH
/POST1
! --  DISPLACEMENT RATIOS --
LCDEF,1,1
 LCFACT,1,(1/3E-5)
 LCASE,1          ! LOAD CASE 1
NSEL,S,LOC,X,6
 NSEL,R,LOC,Z,0
PRNSOL,U,X
*USE,MAC3,'X',1
LCDEF,2,2,$ LCFACT,2,(1/0.1081)
 LCASE,2        ! LOAD CASE 2
NSEL,S,LOC,X,6
 NSEL,R,LOC,Z,0
PRNSOL,U,Y
*USE,MAC3,'Y',2
*IF,ATYP,EQ,3,THEN
  LCDEF,3,3
 LCFACT,3,(1/0.4321)
 LCASE,3      ! LOAD CASE 3
  NSEL,S,LOC,X,6
 NSEL,R,LOC,Z,0
  PRNSOL,U,Z
  *USE,MAC3,'Z',3
  LCDEF,4,4
 LCFACT,4,(1/0.003208)
 LCASE,4    ! LOAD CASE 4
  NSEL,S,LOC,X,6
 NSEL,R,LOC,Z,0
  *USE,MAC3,'Z',4
*ENDIF
! -- ENERGRY ERROR NORMS --
*USE,MAC4,1
*USE,MAC4,2
*IF,ATYP,EQ,3,THEN
  *USE,MAC4,3
  *USE,MAC4,4
*ENDIF
/OUT
/COM
/COM ===============================================================
/COM
*MSG,INFO,ELAB
ELEMENT TYPE: %C
/COM
/COM DISPLACEMENT RATIO
/COM
/COM  LOADING  | RECT   TRAP15  TRAP30  TRAP45  PARL15  PARL30  PARL45
/COM ---------------------------------------------------------------
*VWRITE,LAB(1),DR(1,1),DR(1,2),DR(1,3),DR(1,4),DR(1,5),DR(1,6),DR(1,7)
(2X,A8,2X,7(F5.3,3X))
/COM
/COM ENERGY NORM ERROR
/COM
/COM  LOADING  | RECT   TRAP15  TRAP30  TRAP45  PARL15  PARL30  PARL45
```

```
/COM ----------------------------------------------------------------
*VWRITE,LAB(1),ER(1,1),ER(1,2),ER(1,3),ER(1,4),ER(1,5),ER(1,6),ER(1,7)
(2X,A8,3X,7(F4.0,4X))
/OUT,SCRATCH
FINISH
PARSAV                                           ! SAVE LOOP PARAMETERS
/clear, nostart
/NOPR
PARRES
*ENDDO
```

Benchmark D2 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMD2
/DEVICE,VECTOR,ON
/TITLE, VMD2, BARREL VAULT ROOF UNDER SELF-WEIGHT

/COM
/COM    COOK, CONCEPTS AND APPL OF F.E.A., 2ND ED., 1981, PP. 284-287.
/COM
/NOPR
/OUT,SCRATCH

*DIM,R,,5,5                          ! ARRAY PARAMETER FOR RESULTS
*DO,I,1,3

*IF,I,EQ,1,THEN                      ! DEFINE ELEMENT TYPE
  ETYP=63
*ELSEIF,I,EQ,2,THEN
  ETYP=181
*ELSEIF,I,EQ,3,THEN
  ETYP=281
*ENDIF

*DO,J,1,5
*IF,J,EQ,1,THEN                      ! DEFINE SKEW ANGLE
  BETA=65.0
*ELSEIF,J,EQ,2,THEN
  BETA=77.5
*ELSEIF,J,EQ,3,THEN
  BETA=90.0
*ELSEIF,J,EQ,4,THEN
  BETA=110.0
*ELSEIF,J,EQ,5,THEN
  BETA=130.0
*ENDIF

/PREP7 $smrt,off
ANTYPE,STATIC                        ! STATIC ANALYSIS
ET,1,ETYP                            ! DEFINE ELEMENT TYPE PARAMETRICALLY
*IF,ETYP,EQ,181,THEN
KEYOPT,1,3,2
*ENDIF
MP,EX,1,4.32E8                       ! DEFINE MATERIAL PROPERTIES
MP,NUXY,1,0.0
MP,DENS,1,36.7347
R,1,0.25
CSYS,1                               ! DEFINE CYLINDRICAL C.S.
A=6.25
K,1,25,50 $ K,2,25,60                ! DEFINE KEYPOINTS
K,3,25,70 $ K,4,25,80
K,5,25,90 $ KGEN,5,1,5,1,,,A
GAM=(135-(BETA/2))                   ! CALCULATE SKEWED KEYPOINT COORDINATES
DEGR=(3.14159/180)
TGAM=TAN((GAM*DEGR))
*IF,BETA,GE,90.0,THEN
  ZZ=((A*TGAM)/(1+TGAM))
```

```
  TAU=ATAN((A-ZZ)/((2*A)-ZZ))
  TAU=TAU/DEGR
  ALPA=(90-(2*TAU))               ! CALCULATE ANGLE ALPHA (ALPA)
*ELSE
  GAM=(180-GAM)
  TGAM=TAN((GAM*DEGR))
  ZZ=((A*TGAM)/(TGAM-1))
  TAU=ATAN((ZZ-A)/((2*A)-ZZ))
  TAU=TAU/DEGR
  ALPA=(90+(2*TAU))               ! CALCULATE ANGLE ALPHA (ALPA)
*ENDIF
R(J,4)=BETA                       ! STORE SKEW ANGLES
R(J,5)=ALPA
RAT=ZZ/A
Z1=ZZ                             ! Z COORDINATES OF SKEWED KEYPOINTS
Z2=((2*A)-Z1)
Z3=((2*A)+Z1)
Z4=((4*A)-Z1)
ANG=(RAT*10)                      ! CALCULATE ANGLE OF SKEWED KEYPOINTS
K,7,25,(ANG+50),Z1                ! DEFINE SKEWED KEYPOINT
K,9,25,(ANG+70),Z2
K,17,25,(70-ANG),Z3
K,19,25,(90-ANG),Z4
A,1,2,7,6     $ *REPEAT,4,1,1,1,1  ! GENERATE AREAS
A,6,7,12,11   $ *REPEAT,4,1,1,1,1
A,11,12,17,16 $ *REPEAT,4,1,1,1,1
A,16,17,22,21 $ *REPEAT,4,1,1,1,1
ESIZE,,1                          ! DEFINE ELEMENT SIZE
ESHAPE,2                          ! MAPPED MESHING
AMESH,ALL                         ! MESH ALL AREAS
/VIEW,1,1,1,1
EPLOT
NSEL,S,LOC,Z,0 $ NSEL,R,LOC,Y,50   ! SELECT NODE OF INTEREST
*GET,N1,NODE,,NUM,MAX             ! GET NODE NUMBER
NSEL,S,LOC,Z,0 $ NSEL,R,LOC,Y,90   ! SELECT NODE OF INTEREST
*GET,N2,NODE,,NUM,MAX             ! GET NODE NUMBER
NSEL,ALL
CSYS,0                            ! SWITCH TO GLOBAL CARTESIAN C.S.
NSEL,S,LOC,Z,0
DSYMM,SYMM,Z                      ! APPLY SYMMETRY B.C.
NSEL,S,LOC,X,0
DSYMM,SYMM,X
NSEL,S,LOC,Z,25
D,ALL,UX,0,,,,UY,ROTZ             ! CONSTRAIN MODEL EDGE
NSEL,ALL
ACEL,,9.8                         ! DEFINE GRAVITATIONAL ACCELERATION
WSORT,Z                           ! REORDER ELEMENTS
CHECK                             ! CHECK ELEMENTS FOR EXCESSIVE WARPING
FINISH
/SOLU
SOLVE
FINISH
/POST1
SET,1,1
UY1T=-.3016                       ! TARGET DISPLACEMENT SOLUTION
SZ1T=358420                       ! TARGET SZ STRESS
SY2T=-213400                      ! TARGET SY STRESS
SHELL,MID                         ! PROCESS MIDDLE STRESSES
*GET,UY1,NODE,N1,U,Y              ! GET UY AT NODE N1
UYN=UY1/UY1T                      ! CALCULATE NORMALIZED DISPLACEMENT
R(J,1)=UYN
RSYS,1                            ! ACTIVATE CYLINDRICAL RESULTS C.S.
SHELL,BOT                         ! PROCESS BOTTOM STRESSES
*GET,SZ1B,NODE,N1,S,Z             ! GET AXIAL (Z) STRESS AT BOTTOM
SZN=SZ1B/SZ1T                     ! CALCULATE NORMALIZED SZ STRESS
R(J,2)=SZN
*GET,SY2B,NODE,N2,S,Y             ! GET CIRCUMFERENTIAL (Y) STRESS AT BOTTOM
SYN=SY2B/SY2T                     ! CALCULATE NORMALIZED SY STRESS
R(J,3)=SYN
FINISIH
PARSAV,ALL                        ! SAVE LOOP PARAMETERS
/CLEAR, NOSTART ! CLEAR DATABASE
```

```
PARRES
*ENDDO
/GOPR
/OUT
/COM
/COM
*MSG,INFO,ETYP
 ELEMENT: SHELL %I
/COM
/COM     SKEW ANGLE                     RATIO
/COM   BETA     ALPHA  |   UY(1)      S AXIAL(1)  S THETA(2)
/COM --------------------------------------------------------
*VWRITE,R(1,4),R(1,5),R(1,1),R(1,2),R(1,3)
(2X,F5.1,5X,F5.1,5X,3(F6.3,6X))
/NOPR
/OUT,SCRATCH
*ENDDO
```

Benchmark D3 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMD3
/DEVICE,VECTOR,ON
/TITLE, VMD3, FREE-FREE VIBRATION OF A SOLID BEAM
/COM
/COM    BLEVINS "FORMULAS FOR NATURAL FREQUENCY AND MODE SHAPE"
/COM    TABLE 8-1, PG. 108, AND TABLE 8-16, PG. 183.
/COM
! ------------------------------------------------------------------------
! PARAMETER KEY:
!
! ETYP   - ELEMENT TYPE
! ATYP     ANALYSIS OPTION (0=BENDING MODE, 1=AXIAL MODE)
! QUAD     '1' IF QUADRILATERAL ELEMENTS
! TRI      '1' IF TRIANGULAR HIGHER ORDER ELEMENTS
! BRICK    '1' IF BRICK ELEMENTS
! TET      '1' IF HIGHER ORDER TET ELEMENTS
! LOW      '1' LOWER ORDER QUAD OR BRICK ELEMENTS
! HIGH     '1' HIGHER ORDER QUAD OR BRICK ELEMENTS
! AD       ANALYSIS TYPE (2=2D, 3=3D)
!
! NOTE: FOR QUAD, TRI, BRICK, AND TET ELEMENTS: ONLY ONE BE ACTIVE ('1').
!       LOW OR HIGH ARE APPLICABLE ONLY FOR QUAD OR BRICK ELEMENTS. SET
!       LOW AND HIGH TO ZERO FOR TRI AND TET ELEMENTS.
! -----------------------------------------------------------------------
/NOPR
/OUTPUT,SCRATCH

*DIM,NF,,7,6
*DIM,LAB,CHAR,7
LAB(1)='RECT'    $ LAB(2)='TRAP 15' $ LAB(3)='TRAP 30' $ LAB(4)='TRAP 45'
LAB(5)='PARL 15' $ LAB(6)='PARL 30' $ LAB(7)='PARL 45'

*CREATE,MAC1                         ! CREATE MACRO TO MODIFY NODES
  ARG1=(ARG1*3.141592654)/180.
  DELX=(0.1*TAN(ARG1))
  NMODIF,ARG2,(1+DELX) $ *REPEAT,3,4,2
  NMODIF,ARG3,(2-DELX) $ *REPEAT,2,4,2
  NMODIF,ARG4,(1-DELX) $ *REPEAT,3,4,2
  NMODIF,ARG5,(2+DELX) $ *REPEAT,2,4,2
*END

*CREATE,MAC2                         ! CREATE MACRO TO MODIFY NODES
  ARG1=(ARG1*3.141592654)/180.
  DELX=(0.1*TAN(ARG1))
  NMODIF,ARG2,(1-DELX) $ *REPEAT,5,2,1
  NMODIF,ARG3,(1+DELX) $ *REPEAT,5,2,1
*END
```

```
*CREATE,MAC3                          ! CREATE MACRO TO PERFORM ANALYSIS
  /PREP7
  ESEL,S,,,E1,E2                      ! SELECT APPROPRIATE (MODEL) ELEMENTS
  NSLE,S $ ESEL,INVERT $ NSEL,INVERT  ! SELECT UNUSED NODES & ELEMENTS
  DDELE,ALL,ALL                       ! DELETE EXTRANEOUS CONTRAINTS
  EDELE,ALL $ NDELE,ALL               !    "        "     NODES & ELEMENTS
  NSEL,ALL  $ ESEL,ALL
  FINISH
  /SOLU
  ANTYPE,MODAL                        ! MODAL ANALYSIS
  MODOPT,LANB,2                     ! LANB EXTRACTION METHOD
  MXPAND,2                            ! EXPAND FIRST MODE
  SOLVE
  FINISH
  /POST1
  *IF,ATYP,EQ,1,THEN
    SET,,2                            ! SKIP 1ST FREQUENCY - RIGID BODY MOTION
  *ELSE
    SET,,1
  *ENDIF
  *GET,NF1,ACTIVE,,SET,FREQ           ! GET 1ST NATURAL FREQUENCY
  NF(ARG1,J)=NF1/TF                   ! NORMALIZE
  FINISH
  E1=E2+1                             ! INCREMENT ELEMENTS
  E2=E2+EINC
  PARSAV,ALL                          ! SAVE PARAMETES
  RESUME                              ! RESTORE DATABASE
  PARRES                              ! RESTORE PARAMETERS
*END

*DO,I,1,2
*IF,I,EQ,1,THEN                       ! AXIAL MODE
  ATYP=0 $ MTYPE='AXIAL'
*ELSE                                 ! BENDING MODE
  ATYP=1 $ MTYPE='BENDING'
*ENDIF
*DO,J,1,5
*IF,J,EQ,1,THEN                       ! PLANE183
  ETYP=183 $ QUAD=1 $ TRI=0 $ BRICK=0 $ TET=0 $ LOW=0 $ HIGH=1 $ AD=2
*ELSEIF,J,EQ,2,THEN                   ! PLANE 182
  ETYP=182 $ QUAD=1 $ TRI=0 $ BRICK=0 $ TET=0 $ LOW=1 $ HIGH=0 $ AD=2
*ELSEIF,J,EQ,3,THEN                   ! SOLID185
  ETYP=185 $ QUAD=0 $ TRI=0 $ BRICK=1 $ TET=0 $ LOW=1 $ HIGH=0 $ AD=3
*ELSEIF,J,EQ,4,THEN                   ! SOLID187
  ETYP=187 $ QUAD=0 $ TRI=0 $ BRICK=0 $ TET=1 $ LOW=0 $ HIGH=0 $ AD=3
*ELSEIF,J,EQ,5,THEN                   ! SOLID186
  ETYP=186 $ QUAD=0 $ TRI=0 $ BRICK=1 $ TET=0 $ LOW=0 $ HIGH=1 $ AD=3
*ENDIF
/PREP7

*IF,BRICK,EQ,1,AND,LOW,EQ,1,THEN
  ET,1,ETYP,,3    !SIMPLIFIED ENHANCED STRAIN FORMULATION
*ELSEIF,BRICK,EQ,1,AND,HIGH,EQ,1,THEN
  ET,1,ETYP,,1    !FULL INTEGRATION
*ELSEIF,TET,EQ,1,THEN
  ET,1,ETYP
*ELSEIF,QUAD,EQ,1,AND,LOW,EQ,1,THEN
  ET,1,ETYP,3,,3   !ENHANCED STRAIN FORMULATION
*ELSE
  ET,1,ETYP,,,3
*ENDIF
R,1,.1

MP,EX,1,200E9                         ! MATERIAL PROPERTIES
MP,NUXY,1,0.3
MP,DENS,1,8000

N,1 $ N,13,6,0
FILL,1,13,5,3,2
NGEN,3,20,1,13,2,0,0.1,0              ! DEFINE CORNER NODES
NGEN,4,200,1,53,2,0,0,0               ! DEFINE NODES FOR TRAPIZOIDAL ELEMENTS
```

```
*USE,MAC1,15,203,205,243,245          ! MODIFY NODE LOCATIONS
*USE,MAC1,30,403,405,443,445
*USE,MAC1,45,603,605,643,645
NGEN,2,800,1,53,2,0,0,0               ! DEFINE NODES FOR PARALLALOGRAM ELEMENTS
NGEN,3,200,801,853,2
*USE,MAC2,15,803,843                  ! MODIFY NODE LOCATIONS
*USE,MAC2,30,1003,1043
*USE,MAC2,45,1203,1243

*IF,QUAD,EQ,1,THEN                    ! QUAD ELEMENT
  E,1,3,43,41
  EGEN,6,2,-1
  EGEN,4,200,-6
  EGEN,4,200,-6
  *IF,HIGH,EQ,1,THEN
    EMID
  *ENDIF
  EPLOT
*ENDIF

*IF,TRI,EQ,1,THEN                     ! HIGHER ORDER TRIANGLE ELEMENT
  E,1,3,41
  E,3,43,41
  EGEN,6,2,-2
  EGEN,4,200,-12
  EGEN,4,200,-12
  EMID
  EPLOT
*ENDIF

*IF,BRICK,EQ,1,THEN                   ! BRICK ELEMENT
  NGEN,2,1300,1,1353,1,,,.1
  E,1,3,43,41,1301,1303,1343,1341
  EGEN,6,2,-1
  EGEN,4,200,-6
  EGEN,4,200,-6
  *IF,HIGH,EQ,1,THEN
    EMID
  *ENDIF
  EPLOT
*ENDIF

*IF,TET,EQ,1,THEN                     ! HIGHER ORDER TET ELEMENT
  NGEN,2,1300,1,1353,1,,,.1
  E,1,1301,1303,1341
  E,1,1303,3,43
  E,1303,1343,43,1341
  E,1,1303,43,1341
  E,1,43,1341,41
  E,3,1303,5,43
  E,1303,1305,5,1345
  E,1303,5,43,1345
  E,5,43,1345,45
  E,1303,1345,43,1343
  EGEN,3,4,-10
  EGEN,4,200,-30
  EGEN,4,200,-30
  EMID
  EPLOT
*ENDIF

NSLE,S                                ! SELECT AND DELETE UNNECESSARY NODES
NSEL,INVERT
NDELE,ALL
NSEL,ALL

NSEL,S,LOC,X,6                        ! SYMMETRY CONSTRAINTS
DSYMM,SYMM,X

*IF,TET,EQ,1,THEN                     ! PREVENT OUT-OF-PLANE DISP (3D)
  NSEL,S,LOC,Z,0 $ D,ALL,UZ,0 $ NSEL,ALL
*ELSEIF,BRICK,EQ,1,THEN
```

```
  NSEL,S,LOC,Z,0 $ D,ALL,UZ,0 $ NSEL,ALL
*ENDIF

*IF,ATYP,EQ,1,THEN
  TF=7.138                            ! TARGET FREQUENCY - BENDING MODE
*ELSE
  TF=208.333                          ! TARGET FREQUENCY - AXIAL MODE
  NSEL,S,LOC,Y,0 $ D,ALL,UY,0 $ NSEL,ALL
  NSEL,U,LOC,Y,0 $ NSEL,U,LOC,X,6
  *IF,AD,EQ,3,THEN
    NSEL,U,LOC,Z,0
  *ENDIF
  NSEL,ALL
*ENDIF

*IF,TRI,EQ,1,THEN
  EINC=12
*ELSEIF,TET,EQ,1,THEN
  EINC=30
*ELSE
  EINC=6
*ENDIF

SAVE
FINISH

E1=1 $ E2=EINC
/TITLE, MODAL ANALYSIS - RECTANGULAR ELEMENTS
*USE,MAC3,1
/TITLE, MODAL ANALYSIS - TRAPEZOIDAL ELEMENTS - 15 DEG.
*USE,MAC3,2
/TITLE, MODAL ANALYSIS - TRAPEZOIDAL ELEMENTS - 30 DEG.
*USE,MAC3,3
/TITLE, MODAL ANALYSIS - TRAPEZOIDAL ELEMENTS - 45 DEG.
*USE,MAC3,4
/TITLE, MODAL ANALYSIS - PARALLELOGRAM ELEMENTS - 15 DEG.
*USE,MAC3,5
/TITLE, MODAL ANALYSIS - PARALLELOGRAM ELEMENTS - 30 DEG.
*USE,MAC3,6
/TITLE, MODAL ANALYSIS - PARALLELOGRAM ELEMENTS - 45 DEG.
*USE,MAC3,7

*STAT,NF

PARSAV,ALL
/clear, nostart
PARRES

*IF,J,EQ,5,THEN
/OUT
/COM
/COM
/COM
*MSG,INFO,MTYPE
 MODE: %C
/COM
/COM                      1ST NATURAL FREQUENCY RATIO
/COM
/COM  SHAPE    | PLANE183  PLANE182  SOLID185  SOLID187  SOLID186
/COM -------------------------------------------------------------
*VWRITE,LAB(1),NF(1,1),NF(1,2),NF(1,3),NF(1,4),NF(1,5)
(2X,A8,2X,6(F6.3,3X))
*ENDIF
/OUT,SCRATCH
*ENDDO
*ENDDO
/OUT

/TITLE, VMD3, FREE-FREE VIBRATION OF A SOLID BEAM
/COM
/COM    BLEVINS "FORMULAS FOR NATURAL FREQUENCY AND MODE SHAPE"
/COM    TABLE 8-1, PG. 108, AND TABLE 8-16, PG. 183.
```

```
/COM
/NOPR
/OUTPUT,SCRATCH
*DIM,NF,,7,6
*DIM,LAB,CHAR,7
LAB(1)='RECT'    $ LAB(2)='TRAP 15' $ LAB(3)='TRAP 30' $ LAB(4)='TRAP 45'
LAB(5)='PARL 15' $ LAB(6)='PARL 30' $ LAB(7)='PARL 45'
*CREATE,MAC1                          ! CREATE MACRO TO MODIFY NODES
  ARG1=(ARG1*3.141592654)/180.
  DELX=(0.1*TAN(ARG1))
  NMODIF,ARG2,(1+DELX) $ *REPEAT,3,4,2
  NMODIF,ARG3,(2-DELX) $ *REPEAT,2,4,2
  NMODIF,ARG4,(1-DELX) $ *REPEAT,3,4,2
  NMODIF,ARG5,(2+DELX) $ *REPEAT,2,4,2
*END
*CREATE,MAC2                          ! CREATE MACRO TO MODIFY NODES
  ARG1=(ARG1*3.141592654)/180.
  DELX=(0.1*TAN(ARG1))
  NMODIF,ARG2,(1-DELX) $ *REPEAT,5,2,1
  NMODIF,ARG3,(1+DELX) $ *REPEAT,5,2,1
*END
*CREATE,MAC3                          ! CREATE MACRO TO PERFORM ANALYSIS
  /PREP7
  ESEL,S,,,E1,E2                      ! SELECT APPROPRIATE (MODEL) ELEMENTS
  NSLE,S $ ESEL,INVERT $ NSEL,INVERT  ! SELECT UNUSED NODES & ELEMENTS
  DDELE,ALL,ALL                       ! DELETE EXTRANEOUS CONSTRAINTS
  EDELE,ALL $ NDELE,ALL               !    "        "     NODES & ELEMENTS
  NSEL,ALL  $ ESEL,ALL
  FINISH
  /SOLU
  ANTYPE,MODAL                        ! MODAL ANALYSIS
  MODOPT,LANB,2                       ! LANB EXTRACTION METHOD
  MXPAND,2                            ! EXPAND FIRST MODE
  SOLVE                               ! PERFORM MODAL ANALYSIS
  FINISH
  /POST1
  *IF,ATYP,EQ,1,THEN
    SET,,2                            ! SKIP 1ST MODE - RIGID BODY MOTION
  *ELSE
    SET,,1
  *ENDIF
  *GET,NF1,ACTIVE,,SET,FREQ           ! GET 1ST NATURAL FREQUENCY
  NF(ARG1,1)=NF1/TF                   ! NORMALIZE
  FINISH
  E1=E2+1                             ! INCREMENT ELEMENTS
  E2=E2+EINC
  PARSAV,ALL                          ! SAVE PARAMETERS
  RESUME                              ! RESTORE DATABASE
  PARRES                              ! RESTORE PARAMETERS
*END
ETYP=2
ATYP=0                                ! 0=BENDING MODE, 1=AXIAL MODE
/PREP7
ET,1,ETYP,,,3
R,1,.1
MP,EX,1,200E9                         ! MATERIAL PROPERTIES
MP,NUXY,1,0.3
MP,DENS,1,8000
N,1 $ N,13,6,0
FILL,1,13,5,3,2
NGEN,3,20,1,13,2,0,0.1,0              ! DEFINE CORNER NODES
NGEN,4,200,1,53,2,0,0,0               ! DEFINE NODES FOR TRAPEZOIDAL ELEMENTS
*USE,MAC1,15,203,205,243,245          ! MODIFY NODE LOCATIONS
*USE,MAC1,30,403,405,443,445
*USE,MAC1,45,603,605,643,645
NGEN,2,800,1,53,2,0,0,0               ! DEFINE NODES FOR PARALLELOGRAM ELEMENTS
NGEN,3,200,801,853,2
*USE,MAC2,15,803,843                  ! MODIFY NODE LOCATIONS
*USE,MAC2,30,1003,1043
*USE,MAC2,45,1203,1243
E,1,3,41                              ! ELEMENT GENERATION
E,3,43,41
```

```
EGEN,6,2,-2
EGEN,4,200,-12
EGEN,4,200,-12
EMID
NSLE,S                              ! SELECT AND DELETE UNNECESSARY NODES
NSEL,INVERT
NDELE,ALL
NSEL,ALL
WSORT,X
NSEL,S,LOC,X,6                      ! SYMMETRY CONSTRAINTS
DSYMM,SYMM,X
*IF,ATYP,EQ,1,THEN
  TF=7.138                          ! TARGET FREQUENCY - BENDING MODE
*ELSE
  TF=208.333                        ! TARGET FREQUENCY - AXIAL MODE
  NSEL,S,LOC,Y,0 $ D,ALL,UY,0 $ NSEL,ALL
  NSEL,U,LOC,Y,0 $ NSEL,U,LOC,X,6
  NSEL,ALL
*ENDIF
EINC=12
SAVE
FINISH
E1=1 $ E2=EINC
/TITLE, MODAL ANALYSIS - RECTANGULAR ELEMENTS
*USE,MAC3,1
/TITLE, MODAL ANALYSIS - TRAPEZOIDAL ELEMENTS - 15 DEG.
*USE,MAC3,2
/TITLE, MODAL ANALYSIS - TRAPEZOIDAL ELEMENTS - 30 DEG.
*USE,MAC3,3
/TITLE, MODAL ANALYSIS - TRAPEZOIDAL ELEMENTS - 45 DEG.
*USE,MAC3,4
/TITLE, MODAL ANALYSIS - PARALLELOGRAM ELEMENTS - 15 DEG.
*USE,MAC3,5
/TITLE, MODAL ANALYSIS - PARALLELOGRAM ELEMENTS - 30 DEG.
*USE,MAC3,6
/TITLE, MODAL ANALYSIS - PARALLELOGRAM ELEMENTS - 45 DEG.
*USE,MAC3,7
/OUTPUT
/COM
/COM  1ST NATURAL FREQUENCY RATIO
/COM
/COM  SHAPE     |    RATIO
/COM -----------------------
*VWRITE,LAB(1),NF(1,1)
(2X,A8,6X,F6.3)
```

Appendix C. ANSYS LS-DYNA Input Listings

This appendix contains all of the input listings for the ANSYS LS-DYNA problems documented in Part III: ANSYS LS-DYNA Study Descriptions (p. 875).

VME1 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VME1
/TITLE,VME1, Spring-Mass System Response to Step Input

/PREP7          !Enter preprocessor
M=1             !The mass is 1 kg.
K=100           !The system spring constant is 100 N/m
W=SQRT(K/M)     !The system natural frequnecy is w


N,1,0,0,0        !Define nodes
N,2,1,0,0

!Define element type 1 as MASS166
ET,1,166
!Define element type 2 as COMBIN165
ET,2,165

R,1,M   !Real constant set one is for the mass
R,2

!Although the discrete lumped mass and stiffness elements
!are used, a material model is still required, and it is
!defined below.
MP,EX,1,30E6
MP,DENS,1,.000733
MP,NUXY,1,0.29

TYPE,1   !Create the MASS166 element at node 2
REAL,1
E,2

MP,EX,2,30E6
MP,DENS,2,.000733
MP,NUXY,2,0.29
TB,discrete,2,,,0
tbdata,1,K
TYPE,2   !Create the COMBIN165 spring element
REAL,2
mat,2
E,1,2

NSEL,S,NODE,,2   !Create a nodal component
CM,MASS,NODE
ALLSEL
```

```
D,1,UX,0    !Constrain deflections.
D,1,UY,0
D,1,UZ,0
D,2,UY,0
D,2,UZ,0

FINISH

!Enter solution processor.
/SOLU

!Generate 1000 time history points.
EDRST,1000
EDHTIME,1000

!Specify the mass component for time history output.
EDHIST,MASS


!Set the time step scaling factor to 0.01.  The default
!for solution stability considerations is 0.9, however, for this
!small dof system, the solution time is small, and a smoother response
!curve can be obtained in minimal time with a reduced time step size.
EDCTS,,0.01

!Dimension the arrays that will be used for specifying the
!load on the mass at node 2.
*DIM,T,ARRAY,3
*DIM,F,ARRAY,3

!Enter the force vs. time values in the arrays.
T(1)=0,1,10
F(1)=0,3,3

EDLOAD,ADD,FX,,MASS,T,F   !Specify the load
TIME,2                    !Specify the solution time

/COM  &COMPARE,NOCOMPARE
SOLVE
/COM  &COMPARE,NORMAL

FINI

/POST26     !Enter the time history post-processor.

!Define variable number 2 as the node 2 deflection in the
!x-direction.
NSOL,2,2,U,X,MASS-UX
PLVAR,2
EXTREM,2
*GET,RES1,VARI,2,EXTREM,VMAX, ,
*DIM,LABEL,CHAR,1
*DIM,RES,,1,3
LABEL(1) = 'PEAK Uz'
*VFILL,RES(1,1),DATA,3.575E-2
*VFILL,RES(1,2),DATA,ABS(RES1)
*VFILL,RES(1,3),DATA,ABS(RES(1,2)/RES(1,1))
/OUT,vme1,vrt
/OUT,
/COM,
/COM,-------------------- VME1 DYNA RESULTS COMPARISION --------------------
/COM,
/COM,         |  TARGET  |  ANSYS  |  RATIO  |
/COM,
*VWRITE,LABEL(1),RES(1,1),RES(1,2),RES(1,3)
(1X,A8,'   ',F5.4,'      ',F5.4,'     ',F5.3)
/COM,
/COM,----------------------------------------------------------------------
!/OUT
*LIST,vme1,vrt
```

```
FINISH
```

VME2 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VME2

/title,VME2, Drop Analysis Of A Block Onto A Spring Scale
! Beer and Johnson, Vector Mechanics for Engineers, pg 635
/PREP7
ET,1,164
R,1
MP,EX,1,207E9
MP,NUXY,1,.29
MP,DENS,1,60
BLOCK,-.5,.5,8.25,8.75,-.5,.5,
VMESH,1
CM,BLOCK,NODE

ET,2,164
R,2
MP,EX,2,207E9
MP,NUXY,2,.29
MP,DENS,2,10
EDMP,RIGID,2,6,7
TYPE,2
REAL,2
MAT,2
BLOCK,-1,1,6,6.25,-1,1,
VMESH,2
ET,3,165
R,3
MP,EX,3,207E9
MP,NUXY,3,.29
MP,DENS,3,10
TB,DISC,3,,,0
TBDATA,1,20000

TYPE,3
REAL,3
MAT,3
N,1000
E,143,1000
NSEL,S,NODE,,1000
D,ALL,ALL
ALLS

NSEL,S,LOC,Y,6.25
CM,N1,NODE
NSEL,S,LOC,Y,8.25
CM,N2,NODE
EDCGEN,NTS,N2,N1
ALLS

*DIM,TIME,ARRAY,2
*DIM,ACCL,ARRAY,2
TIME(1)=0
TIME(2)=1.5
ACCL(1)=9.81
ACCL(2)=9.81
EDLOAD,ADD,ACLY,,BLOCK,TIME(1),ACCL(1)
/VIEW,1,1,1,1
/ANG,1
/AUTO,1
EPLOT
FINI

/SOLU
```

```
TIME,.75
EDRST,10
EDHT,50
NSEL,S,NODE,,143
CM,SCALE,NODE
EDHIST,SCALE
ALLS
SAVE
/COM  &COMPARE,NOCOMPARE
SOLVE
/COM  &COMPARE,NORMAL

/POST26
FILE,,his
NSOL,2,143,U,Y,DISPY
PLVAR,2
PRVAR,2
*GET,RES1,VARI,2,EXTREM,VMIN, ,
*DIM,LABEL,CHAR,1
*DIM,RES,,1,3
LABEL(1) = 'MAX Uy'
*VFILL,RES(1,1),DATA,0.225
*VFILL,RES(1,2),DATA,ABS(RES1)
*VFILL,RES(1,3),DATA,ABS(RES(1,2)/RES(1,1))
/OUT,vme2,vrt
/COM,
/COM,-------------------- VME2 DYNA RESULTS COMPARISION --------------------
/COM,
/COM,          |  TARGET  |  ANSYS   |  RATIO  |
/COM,
*VWRITE,LABEL(1),RES(1,1),RES(1,2),RES(1,3)
(1X,A8,'   ',F5.3,'      ',F5.3,'     ',F5.3)
/COM,
/COM,-----------------------------------------------------------------------
/OUT
*LIST,vme2,vrt
*DELETE,vme2,db
FINISH
```

VME3 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vme3

/TITLE,VME3,Response of Spring-Mass-Damper System
! Modeling And Analysis of Dynamic Systems,
! Close and Frederick, page 314
PI=3.1415927
ZETA=0.21545376         ! zeta=damping ratio.
M=1.0                   ! m=mass.
K=(4*PI)**2.0           ! k=spring stiffness.
WN=SQRT(K/M)            ! wn=system undamped natural frequency.
C=M*(2*ZETA*WN)         ! c=damping constant.
/PREP7                  ! Enter preprocessor.
N,1,0,0,0  ! Node 1 will be the fixed end.
N,2,1,0,0  ! The applied force will be at node 2.
ET,1,166  ! Define element type 1 as MASS166.
ET,2,165  ! Define element type 2 as COMBIN165.
R,1,M   ! Real constant for MASS166 is the value of the mass.
R,2
MP,EX,1,30E6            ! Define modulus of elasticity.
MP,DENS,1,.000733 ! Define density.
MP,NUXY,1,0.29          ! Define poisson's ratio.

MP,EX,2,30E6
MP,DENS,2,.000733
MP,NUXY,2,0.29
TB,discrete,2,,,0
```

```
tbdata,1,K
TYPE,1
REAL,1
E,2   ! Create the MASS166 element at node 2.

TYPE,2
REAL,2
MAT,2
E,1,2   ! Create the COMBIN165 element with end nodes 1 and 2.
NSEL,S,NODE,,2
CM,MASS,NODE            ! Create a nodal component at node 2 named "mass"
ALLSEL
D,1,UX,0  ! Constrain all deflections at node 1.
D,1,UY,0
D,1,UZ,0
D,2,UY,0  ! Constrain uy and uz deflections at node 2.
D,2,UZ,0
EDDAMP,ALL,0,C/M ! Define alpha damping.
FINI
/SOLU
EDRST,1000
EDHTIME,1000
EDHIST,MASS  ! Specify the mass component for time history output.
EDCTS,,0.001            ! Set a time step scaling factor to 0.001.
*DIM,T,ARRAY,2  ! Dimension array for time values.
*DIM,FSTEP,ARRAY,2 ! Dimension array for step force input.
*DIM,FRAMP,ARRAY,2 ! Dimension array for ramp force input.
T(1)=0,1
FSTEP(1)=K,K ! The step input magnitude equals k so x=1 at steady-state.
FRAMP(1)=0,K ! The ramp input is the integral of the step input.
EDLOAD,ADD,FX,,MASS,T,FSTEP !Specify the load for the step input solution.
TIME,1    !Specify the solution time.
/COM  &COMPARE,NOCOMPARE
SOLVE
/COM  &COMPARE,NORMAL
FINI
/POST26    !Enter the time history post-processor.
NSOL,2,2,U,X,DISPLACE  !Define variable 2 - node 2 ux deflection
EXTREM,2                        !Print the max deflection and peak time
*GET,RES1,VARI,2,EXTREM,VMAX,,
*GET,TMAX1,VARI,2,EXTREM,TMAX,,
/solu                           !Return to the solution processor.
EDLOAD,ADD,FX,,MASS,T,FRAMP !Redefine the load for a ramp input.
/COM  &COMPARE,NOCOMPARE
SOLVE
/COM  &COMPARE,NORMAL
FINI
/POST26
NSOL,2,2,V,X,VELOCITY   !Define variable 2 - node 2 velocity.
PLVAR,2
EXTREM,2                        !Print the max velocity and peak time
*GET,RES2,VARI,2,EXTREM,VMAX,,
*GET,TMAX2,VARI,2,EXTREM,TMAX,,
save
*DIM,LABEL,CHAR,4
*DIM,RES,,4,3
LABEL(1) = 'MAX Ux','PK TIME','MAX Vx','PK TIME'
*VFILL,RES(1,1),DATA,1.5,0.256,1.5,0.256
*VFILL,RES(1,2),DATA,RES1,TMAX1,RES2,TMAX2
*DO,I,1,4
  *VFILL,RES(I,3),DATA,(RES(I,2)/RES(I,1))
*ENDDO
/OUT,vme3,vrt
/COM,
/COM,-------------------- VME3 DYNA RESULTS COMPARISION --------------------
/COM,
/COM,        |  TARGET  |  ANSYS  |  RATIO  |
/COM,
*VWRITE,LABEL(1),RES(1,1),RES(1,2),RES(1,3)
(1X,A8,'   ',F5.3,'      ',F5.3,'    ',F5.3)
/COM,
/COM,-----------------------------------------------------------------------
```

```
/OUT
*LIST,vme3,vrt
/GOPR
FINISH
```

VME4 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vme4
/TITLE,VME4, Undamped Vibration Absorber
! Elements of Vibration Analysis, Meirovitch, pp. 131-134

PI=3.1415927
M1=5             !The main mass is 5 kg
K1=10            !The main system spring constant is 10 N/m
WN=SQRT(K1/M1)   !The main system natural frequency is wn
M2=1             !The absorber mass is 1 kg.
K2=100           !The absorber system spring constant is 100 N/m
WA=SQRT(K2/M2)   !The absorber system alone natural frequnecy is wa
W=WA             !The forcing frequency is w

/PREP7           !Enter preprocessor

N,1,0,0,0        !Define nodes
N,2,1,0,0
N,3,2,0,0

!Define element type 1 as MASS166
ET,1,166
!Define element type 2 as COMBIN165
ET,2,165

R,1,M1   !Real constant set one is for the main mass
R,2,M2   !Real constant set two is for the absorber mass
R,3
R,4

MP,EX,1,30E6
MP,DENS,1,.000733
MP,NUXY,1,0.29

TYPE,1   !Create the main system MASS166 element at node 2 and
REAL,1   !the absorber mass at node 3.
E,2
REAL,2
E,3

MP,EX,2,30E6
MP,DENS,2,.000733
MP,NUXY,2,0.29
TB,disc,2,,,0
TBDATA,1,K1
TYPE,2         !Create the COMBIN165 spring elements between the masses.
REAL,3
MAT,2
E,1,2


MP,EX,3,30E6
MP,DENS,3,.000733
MP,NUXY,3,0.29
TB,disc,3,,,0
TBDATA,1,K2
TYPE,2         !Create the COMBIN165 spring elements between the masses.
REAL,4
MAT,3
E,2,3
```

```
NSEL,S,NODE,,2,3  !Create nodal components
CM,MASSES,NODE
ALLSEL
NSEL,S,NODE,,2
CM,MASS1,NODE
ALLSEL
NSEL,S,NODE,,3
CM,MASS2,NODE
ALLSEL

D,1,UX,0     !Constrain deflections.
D,1,UY,0
D,1,UZ,0
D,2,UY,0
D,2,UZ,0
D,3,UY,0
D,3,UZ,0

FINISH

!Enter solution processor.
/SOLU

!Generate 1000 time history points.
EDRST,1000
EDHTIME,1000

!Specify the mass component for time history output.
EDHIST,MASSES


!Set the time step scaling factor to 0.01.  The default
!for solution stability considerations is 0.9, however, for this
!small dof system, the solution time is small, and a smoother response
!curve can be obtained in minimal time with a reduced time step size.
edcts,,0.01

!Dimension the arrays that will be used for specifying the
!sinusoidal load on the mass at node 2.
*dim,t,array,8000
*dim,f,array,8000

!Enter the force vs. time values in the arrays.
*do,i,1,8000,1
 t(i)=(i-1)/4000
 f(i)=sin(w*t(i))
*enddo

edload,add,fx,,mass1,t,f   !Specify the load
time,2                     !Specify the solution time
EDVEL,VELO,MASS2,-W/k2 !Specify the initial velocity for mass 2, it is at steady-state.

/COM  &COMPARE,NOCOMPARE
solve
/COM  &COMPARE,NORMAL
fini

/post26     !Enter the time history post-processor.

!Define variable number 2 as the node 2 deflection in the
!x-direction.
nsol,2,2,u,x,MAIN
nsol,3,3,u,x,ABSORBER
plvar,2,3

extrem,2,3  !List the maximum and minimum values of the variables.
*GET,RES1,VARI,2,EXTREM,VMAX, ,
*GET,RES2,VARI,3,EXTREM,VMAX, ,
*DIM,LABEL,CHAR,2
*DIM,RES,,2,3
LABEL(1) = 'ABS AMP','MAX DEFL'
*VFILL,RES(1,1),DATA,0.01,0.00
```

```
*VFILL,RES(1,2),DATA,RES2,RES1
*VFILL,RES(1,3),DATA,RES(1,2)/RES(1,1)
/OUT,vme4,vrt
/COM,
/COM,-------------------- VME4 DYNA RESULTS COMPARISION --------------------
/COM,
/COM,         |  TARGET  |  ANSYS  |  RATIO  |
/COM,
*VWRITE,LABEL(1),RES(1,1),RES(1,2),RES(1,3)
(1X,A8,'   ',F5.3,'      ',F5.3,'    ',F5.3)
/COM,
/COM,----------------------------------------------------------------------
/OUT
*LIST,vme4,vrt
/GOPR
FINISH
```

VME5 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vme5
/TITLE,VME5, Pinned Bar Under Gravity Loading
/com, Ref: Maclean and Nelson, page 336

/PREP7             ! ENTER PREPROCESSOR
*AFUN,DEG    ! SET MODE TO DEGREE
N,1,0.25*COS(120),0.25*SIN(120)  ! DEFINE NODES
N,8,0,0,0
FILL,1,8
N,29,0.75*COS(-60),0.75*SIN(-60)
FILL,8,29
N,30,1
ET,1,161    ! SET ELEMENT TYPE TO EXPLICIT BEAM
R,1,5/6,0.1,0.1,0.1,0.1   ! REAL CONSTANT SET
E,1,2,30    ! DEFINE ELEMENTS
*REPEAT,28,1,1,0
MP,EX,1,10E6    ! DEFINE YOUNG'S MODULUS
MP,DENS,1,1.0    ! DEFINE DENSITY
MP,NUXY,1,0.3    ! DEFINE POISSON'S RATIO
D,8,UX     ! CONSTRAIN PIVOT ALONG
D,8,UY     ! UX AND UY
D,ALL,UZ    ! CONTSRAIN ALL NODES ALONG UZ
NSEL,S,NODE,,8
NSEL,A,NODE,,30
NSEL,INVE
CM,GNODES,NODE    ! CREATE NODAL COMPONENT
ALLSEL
FINISH
/SOLUTION    ! ENTER SOLUTION
EDRST,100    ! SPECIFY OUTPUT INTERVAL
EDHTIME,100    ! SPECIFY TIME-HISTORY OUTPUT INTERVAL
NSEL,S,NODE,,29    ! SELECT THE NODE AT THE END OF THE BEAM
CM,NODE29,NODE    ! CREATE NODAL COMPONENT
ALLSEL
EDHIST,NODE29    ! SPECIFY TIME-HISTORY OUTPUT FOR NODE 29
EDCTS,,0.4    ! DEFINE SCALE FATOR FOR COMPUTED TIME STEP
*DIM,T,ARRAY,2    ! DEFINE TIME ARRAY
*DIM,G,ARRAY,2    ! DEFINE GRAVITY ARRAY
T(1)=0,0.5    ! INITIALIZE THE TIME ARRAY
G(1)=9.8,9.8    ! INITIALIZE THE GRAVITY ARRAY
EDLOAD,ADD,ACLY,,GNODES,T,G     ! SPECIFY THE LOAD
TIME,0.5                        ! SPECIFY THE SOLUTION TIME
/COM  &COMPARE,NOCOMPARE
SOLVE     ! SOLVE THE PROBLEM
/COM  &COMPARE,NORMAL
FINISH
/POST26         ! ENTER TIME-HISTORY POSTPROCESSOR
FILE,vme5,his   ! READ THE HISTORY FILE
```

```
NSOL,2,29,U,X    ! DEFINE VARIABLE 2 AS UX AT NODE 29
DERIV,3,2,1,,VX    ! DEFINE VARIABLE 3 AS VELOCITY AT NODE 29
NSOL,4,29,U,Y    ! DEFINE VARIABLE 4 AS UY AT NODE 29
EXTREM,3,4
*GET,TEMP1,VARI,3,EXTREM,VMIN, ,
RES1 = ABS(TEMP1/0.75)
*DIM,RES,,1,3
*VFILL,RES(1,1),DATA,2.121
*VFILL,RES(1,2),DATA,ABS(RES1)
*VFILL,RES(1,3),DATA,ABS(RES(1,2)/RES(1,1))
/COM,
/OUT,vme5,vrt
/COM,-------------------- VME5 DYNA RESULTS COMPARISION --------------------
/COM,
/COM,                 TARGET   |  ANSYS   |  RATIO
/COM,
/COM, |w| THTA = 0 deg
/COM,
*VWRITE,RES(1,1),RES(1,2),RES(1,3)
('                 ','   ',F5.3,'      ',F5.3,'     ',F5.3)
/COM,
/COM,-----------------------------------------------------------------------
/OUT
*LIST,vme5,vrt
FINISH
```

VME6 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vme6
/TITLE,VME6, Projectile with Air Resistance
/COM, REF: Marion and Thornton, Pages 60-63
G=386.4                  ! DEFINE ACCELERATION DUE TO GRAVITY
VX=100.0   ! DEFINE INTIAL VELOCITY IN X DIRECTION
VY=500.0   ! DEFINE INTIAL VELOCITY IN Y DIRECTION
/PREP7    ! ENTER PREPROCESSOR
BLOCK,0,1,0,1,0,1        ! CREATE THE PROJECTILE
ET,1,164   ! SET ELEMENT TYPE TO EXPLICIT 3D SOLID
MP,EX,1,1.0   ! DEFINE YOUNG'S MODULUS
MP,DENS,1,1.0            ! DEFINE DENSITY
MP,NUXY,1,0.3            ! DEFINE POISSON'S RATIO
ESIZE,,1
TYPE,1
REAL,1
VMESH,ALL   ! MESH THE PROJECTILE
NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0
NSEL,R,LOC,Z,0
CM,NODE0,NODE    ! CREATE NODAL COMPONENT OF NODE AT ORIGIN
*GET,NODENUM,NODE,0,NUM,MAX  ! STORE THE NODE NUMBER
ALLSEL
CM,NODES,NODE   ! CREATE NODAL COMPONENT OF ALL NODES
ALLSEL
EDDAMP,ALL,0,1.0                ! DEFINE ALPHA DAMPING
FINISH
/SOLUTION   ! ENTER SOLUTION PROCESSOR
EDRST,100   ! SPECIFY OUTPUT INTERVAL
EDHTIME,100   ! SPECIFY TIME-HISTORY OUTPUT INTERVAL
EDHIST,NODE0   ! SPECIFY TIME-HISTORY OUTPUT FOR NODE0
EDCTS,,0.00025   ! SPECIFY SCALE FACTOR FOR COMPUTED TIME STEP
*DIM,T,ARRAY,2   ! DEFINE TIME ARRAY
*DIM,ACCELY,ARRAY,2  ! DEFINE ACCELERATION ARRAY
T(1)=0.0,2.0             ! INTIALIZE TIME ARRAY
ACCELY(1)=G,G             ! INTIALIZE ACCELERATION ARRAY

!***EDLOAD,ADD,AY,,NODES,T,ACCELY   ! SPECIFY THE ACCELERATION DUE TO GRAVITY LOAD
edload,add,acly,,nodes,T,ACCELY     ! apply a -g to the base to simulate gravity
```

```
TIME,2.0                 ! SPECIFY SOLUTION TIME
EDVEL,VELO,NODES,VX,VY  ! SPECIFY INITIAL VELOCITY ON ALL LOADS
/COM  &COMPARE,NOCOMPARE
SOLVE    ! PERFORM SOLUTION
/COM  &COMPARE,NORMAL
FINISH
/POST26    ! ENTER TIME-HISTORY POSTPROCESSOR
FILE,vme6,his   ! READ THE HISTORY FILE
NSOL,2,NODENUM,U,Y,dISPL-Y ! DEFINE VARIABLE 2 AS UY OF NODENUM
NSOL,3,NODENUM,U,X,dISPL-X ! DEFINE VARIABLE 3 AS UX OF NODENUM
*DIM,TIME,ARRAY,3000  ! DEFINE TIME ARRAY
*DIM,YDISP,ARRAY,3000  ! DEFINE Y-DISPLACEMENT ARRAY
*DIM,XDISP,ARRAY,3000  ! DEFINE X-DISPLACEMENT ARRAY
VGET,TIME(1),1   ! STORE TIME VECTOR IN THE ARRAY
VGET,YDISP(1),2   ! STORE Y-DISPLACEMENT VECTOR IN THE ARRAY
VGET,XDISP(1),3   ! STORE X-DISPLACEMENT VECTOR IN THE ARRAY

! SORT THROUGH THE ARRAY YDISP AND FIND THE TIME STEP INCREMENT
! AT WHICH THE Y-DIRECTION DEFLECTION WOULD REACH ZERO. THE
! PROJECTILE BEGINS AT Y = 0, AND THEN TRAVELS INTO POSITIVE
! Y-VALUES, THEN FALLS BACK TO Y = 0. THE TIME AT WHICH
! IT REACHES Y = 0 AGAIN IS THE TOTAL TRAVEL TIME OF THE PROJECTILE.
*DO,I,1,1000,1
  *IF,YDISP(I),LT,0,THEN
    *EXIT
  *ENDIF
*ENDDO

Z=(0.0-YDISP(I-1))/(YDISP(I)-YDISP(I-1))
TRAVELT=TIME(I-1)+Z*(TIME(I)-TIME(I-1))  ! LINEAR INTERPOLATION OF TRAVEL TIME
TRAVELD=XDISP(I-1)+Z*(XDISP(I)-XDISP(I-1)) ! LINEAR INTERPOLATION OF TRAVEL DISTANCE
CHECK=((VY+G)/G)*(1.0-EXP(-TRAVELT))  ! COMPUTE THEORETICAL SOLUTION

*VWRITE,CHECK,TRAVELT,TRAVELD
('TRAVELT=',E10.4,' CHECK=',E10.4,' TRAVELD=',E10.4)
*DIM,LABEL,CHAR,2
*DIM,RES,,2,3
LABEL(1) = 'TRAV TM','DIST TRA'
*VFILL,RES(1,1),DATA,1.976,86.138
*VFILL,RES(1,2),DATA,TRAVELT,TRAVELD
*VFILL,RES(1,3),DATA,(RES(1,2)/RES(1,1)),(RES(2,2)/RES(2,1))
/OUT,vme6,vrt
/COM,
/COM,-------------------- VME6 DYNA RESULTS COMPARISION --------------------
/COM,
/COM,          |  TARGET  |   ANSYS   |  RATIO  |
/COM,
*VWRITE,LABEL(1),RES(1,1),RES(1,2),RES(1,3)
(1X,A8,'    ',F7.4,'      ',F7.4,'    ',F5.3)
/COM,
/COM,-----------------------------------------------------------------------
/OUT
*LIST,vme6,vrt
/GOPR
FINISH
```

Appendix D. NAFEMS Input Listings

This appendix contains all of the input listings for the NAFEMS problems documented in Part IV: NAFEMS Benchmarks (p. 897).

VM-P09-t2 188 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T2-188
/TITLE, VMP09-T2-188,PIN ENDED DOUBLE CROSS: IN-PLANE VIBRATION
/COM,NAFEMS EIGENVALUE SET, TEST NO. 2 (LANCZOS)
/COM REFERENCE: THE STANDARD NAFEMS BENCHMARKS FVB REPORT:TEST 2(C)  NOVEMBER 1987

/PREP7
ET,1,BEAM188
KEYOPT,1,3,2
ET,2,30
SECTYPE,1,BEAM,RECT
SECDATA,0.125,0.125,4,4
MP,EX,1,200E9
MP,NUXY,1,0
MP,DENS,1,8000
DIAG=3.535533906
K,1
K,2,5
K,3,DIAG,DIAG
K,4,,5
K,5,-DIAG,DIAG
K,6,-5
K,7,-DIAG,-DIAG
K,8,,-5
K,9,DIAG,-DIAG
L,1,2,4
*REPEAT,8,0,1,0
LMESH,ALL
CSYS,1
NSEL,X,4.99,5.01
D,ALL,UX
D,ALL,UY
NSEL,S,LOC,Z,0
DSYM,SYMM,Z,0
NSEL,ALL
CSYS,0
FINISH
/out,scratch
/SOLU
```

```
LUMPM,ON
ANTYPE,2
MODOPT,UNSYM,32
MXPAND,16
SOLVE
FINISH
/out
/POST1
SET,1,1
*GET,F1,FREQ
HF1=F1/11.336
SET,1,2
*GET,F2,FREQ
HF2=F2/17.709
SET,1,3
*GET,F3,FREQ
HF3=F3/17.709
SET,1,4
*GET,F4,FREQ
HF4=F4/17.709
SET,1,5
*GET,F5,FREQ
HF5=F5/17.709
SET,1,6
*GET,F6,FREQ
HF6=F6/17.709
SET,1,7
*GET,F7,FREQ
HF7=F7/17.709
SET,1,8
*GET,F8,FREQ
HF8=F8/17.709
SET,1,9
*GET,F9,FREQ
HF9=F9/45.345
SET,1,10
*GET,F10,FREQ
HF10=F10/57.390
SET,1,11
*GET,F11,FREQ
HF11=F11/57.390
SET,1,12
*GET,F12,FREQ
HF12=F12/57.390
SET,1,13
*GET,F13,FREQ
HF13=F13/57.390
SET,1,14
*GET,F14,FREQ
HF14=F14/57.390
SET,1,15
*GET,F15,FREQ
HF15=F15/57.390
SET,1,16
*GET,F16,FREQ
HF16=F16/57.390
/GOPR
*STATUS,PARM
FINISH
*DIM,VALUE,,10,3
*DIM,VALUE2,,6,3
*DIM,LABEL,CHAR,10
*DIM,LABEL2,CHAR,10
LABEL(1) = 'FREQ 1','FREQ 2', 'FREQ 3', 'FREQ 4', 'FREQ 5', 'FREQ 6','FREQ 7','FREQ 8','FREQ 9','FREQ 10'
LABEL2(1) = 'FREQ 11','FREQ 12','FREQ 13','FREQ 14','FREQ 15','FREQ 16'
*VFILL,VALUE(1,1),DATA,11.336,17.709,17.709,17.709,17.709,17.709,17.709,17.709,45.345,57.390
*VFILL,VALUE2(1,1),DATA,57.390,57.390,57.390,57.390,57.390,57.390
*VFILL,VALUE(1,2),DATA,F1,F2,F3,F4,F5,F6,F7,F8,F9,F10
*VFILL,VALUE2(1,2),DATA,F11,F12,F13,F14,F15,F16
*VFILL,VALUE(1,3),DATA,HF1,HF2,HF3,HF4,HF5,HF6,HF7,HF8,HF9,HF10
*VFILL,VALUE2(1,3),DATA,HF11,HF12,HF13,HF14,HF15,HF16
/COM
```

```
/COM,--------- VMP09-T2-188 RESULTS COMPARISON-----------
/COM,
/COM,        | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F14.3,'   ',1F15.3)
*VWRITE,LABEL2(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'   ',F14.3,'   ',1F15.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,1
*DIM,LABEL4,CHAR,8
*DIM,VALUE1,,6,3
LABEL1(1) = ' MODE'
LABEL4(1) = '1','2,3','4,5,6,7,',','8','9','10,11','12,13,14',',15,16'
*VFILL,VALUE1(1,1),DATA,F1,F3,F8,F9,F11,F16
*VFILL,VALUE1(1,2),DATA,HF1,HF3,HF8,HF9,HF11,HF16
*DIM,LABEL3,CHAR,2
LABEL3(1) = 'vmp09-t2','-188'

/OUT,vmp09-t2-188,vrt
/COM
/COM,------------------- VMP09-T2 RESULTS COMPARISON ---------------------
/COM,
/COM,                    |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, BEAM188
*VWRITE,LABEL1(1),LABEL4(1),VALUE1(1,1),VALUE1(1,2),LABEL3(1),LABEL3(2)
(1X,A5,A1,'                ',F13.4,'    ',F9.4,'        ',A8,A4)
*VWRITE,LABEL1(1),LABEL4(2),VALUE1(2,1),VALUE1(2,2),LABEL3(1),LABEL3(2)
(1X,A5,A3,'              ',F13.4,'    ',F9.4,'        ',A8,A4)
*VWRITE,LABEL1(1),LABEL4(3),LABEL4(4),VALUE1(3,1),VALUE1(3,2),LABEL3(1),LABEL3(2)
(1X,A5,A8,A1,'        ',F13.4,'    ',F9.4,'        ',A8,A4)
*VWRITE,LABEL1(1),LABEL4(5),VALUE1(4,1),VALUE1(4,2),LABEL3(1),LABEL3(2)
(1X,A5,A1,'                ',F13.4,'    ',F9.4,'        ',A8,A4)
*VWRITE,LABEL1(1),LABEL4(6),VALUE1(5,1),VALUE1(5,2),LABEL3(1),LABEL3(2)
(1X,A5,A5,'            ',F13.4,'    ',F9.4,'        ',A8,A4)
*VWRITE,LABEL1(1),LABEL4(7),LABEL4(8),VALUE1(6,1),VALUE1(6,2),LABEL3(1),LABEL3(2)
(1X,A5,A8,A6,'   ',F13.4,'    ',F9.4,'        ',A8,A4)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmp09-t2-188,vrt
```

VM-P09-t2 189 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T2-189
/TITLE, VMP09-T2-189,PIN ENDED DOUBLE CROSS: IN-PLANE VIBRATION
/COM,NAFEMS EIGENVALUE SET, TEST NO. 2 (LANCZOS)
/COM REFERENCE: THE STANDARD NAFEMS BENCHMARKS FVB REPORT:TEST 2(C)  NOVEMBER 1987

/PREP7
ET,1,BEAM189
ET,2,30
SECTYPE,1,BEAM,RECT
SECDATA,0.125,0.125,4,4
MP,EX,1,200E9
MP,NUXY,1,0
MP,DENS,1,8000
DIAG=3.535533906
K,1
K,2,5
K,3,DIAG,DIAG
K,4,,5
```

```
K,5,-DIAG,DIAG
K,6,-5
K,7,-DIAG,-DIAG
K,8,,-5
K,9,DIAG,-DIAG
L,1,2,4
*REPEAT,8,0,1,0
LMESH,ALL
CSYS,1
NSEL,X,4.99,5.01
D,ALL,UX
D,ALL,UY
NSEL,S,LOC,Z,0
DSYM,SYMM,Z,0
NSEL,ALL
CSYS,0
FINISH
/out,scratch
/SOLU
LUMPM,ON
ANTYPE,2
MODOPT,UNSYM,32
MXPAND,16
SOLVE
FINISH
/out
/POST1
SET,1,1
*GET,F1,FREQ
HF1=F1/11.336
SET,1,2
*GET,F2,FREQ
HF2=F2/17.709
SET,1,3
*GET,F3,FREQ
HF3=F3/17.709
SET,1,4
*GET,F4,FREQ
HF4=F4/17.709
SET,1,5
*GET,F5,FREQ
HF5=F5/17.709
SET,1,6
*GET,F6,FREQ
HF6=F6/17.709
SET,1,7
*GET,F7,FREQ
HF7=F7/17.709
SET,1,8
*GET,F8,FREQ
HF8=F8/17.709
SET,1,9
*GET,F9,FREQ
HF9=F9/45.345
SET,1,10
*GET,F10,FREQ
HF10=F10/57.390
SET,1,11
*GET,F11,FREQ
HF11=F11/57.390
SET,1,12
*GET,F12,FREQ
HF12=F12/57.390
SET,1,13
*GET,F13,FREQ
HF13=F13/57.390
SET,1,14
*GET,F14,FREQ
HF14=F14/57.390
SET,1,15
*GET,F15,FREQ
HF15=F15/57.390
```

```
SET,1,16
*GET,F16,FREQ
HF16=F16/57.390
/GOPR
*STATUS,PARM
FINISH
*DIM,VALUE,,10,3
*DIM,VALUE2,,6,3
*DIM,LABEL,CHAR,10
*DIM,LABEL2,CHAR,10
LABEL(1) = 'FREQ 1','FREQ 2', 'FREQ 3', 'FREQ 4', 'FREQ 5', 'FREQ 6','FREQ 7','FREQ 8','FREQ 9','FREQ 10'
LABEL2(1) = 'FREQ 11','FREQ 12','FREQ 13','FREQ 14','FREQ 15','FREQ 16'
*VFILL,VALUE(1,1),DATA,11.336,17.709,17.709,17.709,17.709,17.709,17.709,17.709,45.345,57.390
*VFILL,VALUE2(1,1),DATA,57.390,57.390,57.390,57.390,57.390,57.390
*VFILL,VALUE(1,2),DATA,F1,F2,F3,F4,F5,F6,F7,F8,F9,F10
*VFILL,VALUE2(1,2),DATA,F11,F12,F13,F14,F15,F16
*VFILL,VALUE(1,3),DATA,HF1,HF2,HF3,HF4,HF5,HF6,HF7,HF8,HF9,HF10
*VFILL,VALUE2(1,3),DATA,HF11,HF12,HF13,HF14,HF15,HF16
/COM
/COM,--------- VMP09-T2-189 RESULTS COMPARISON-----------
/COM,
/COM,       | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F14.3,'   ',1F15.3)
*VWRITE,LABEL2(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'   ',F14.3,'   ',1F15.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,1
*DIM,LABEL4,CHAR,8
*DIM,VALUE1,,6,3
LABEL1(1) = ' MODE'
LABEL4(1) = '1','2,3','4,5,6,7,','8','9','10,11','12,13,14',',15,16'
*VFILL,VALUE1(1,1),DATA,F1,F3,F8,F9,F11,F16
*VFILL,VALUE1(1,2),DATA,HF1,HF3,HF8,HF9,HF11,HF16
*DIM,LABEL3,CHAR,1
*DIM,LABEL5,CHAR,1
LABEL3(1) = 'vmp09-t2'
LABEL5(1) = '-189'

/OUT,vmp09-t2-189,vrt
/COM
/COM,------------------- VMP09-T2 RESULTS COMPARISON ---------------------
/COM,
/COM,                   |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, BEAM189
*VWRITE,LABEL1(1),LABEL4(1),VALUE1(1,1),VALUE1(1,2),LABEL3(1),LABEL5(1)
(1X,A5,A1,'                ',F13.4,'    ',F9.4,'        ',A8,A4)
*VWRITE,LABEL1(1),LABEL4(2),VALUE1(2,1),VALUE1(2,2),LABEL3(1),LABEL5(1)
(1X,A5,A3,'              ',F13.4,'    ',F9.4,'        ',A8,A4)
*VWRITE,LABEL1(1),LABEL4(3),LABEL4(4),VALUE1(3,1),VALUE1(3,2),LABEL3(1),LABEL5(1)
(1X,A5,A8,A1,'        ',F13.4,'    ',F9.4,'        ',A8,A4)
*VWRITE,LABEL1(1),LABEL4(5),VALUE1(4,1),VALUE1(4,2),LABEL3(1),LABEL5(1)
(1X,A5,A1,'                ',F13.4,'    ',F9.4,'        ',A8,A4)
*VWRITE,LABEL1(1),LABEL4(6),VALUE1(5,1),VALUE1(5,2),LABEL3(1),LABEL5(1)
(1X,A5,A5,'            ',F13.4,'    ',F9.4,'        ',A8,A4)
*VWRITE,LABEL1(1),LABEL4(7),LABEL4(8),VALUE1(6,1),VALUE1(6,2),LABEL3(1),LABEL5(1)
(1X,A5,A8,A6,'   ',F13.4,'    ',F9.4,'        ',A8,A4)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmp09-t2-189,vrt
```

VM-P09-t4 188 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T4-188
/TITLE,VMP09-T4-188, CANTILEVER WITH OFF-CENTRE POINT MASSES
/COM,REFERENCE: TEST 4 FROM NAFEMS FVB

/PREP7
N,1,0.0
N,2,1.0
N,3,2.0
N,4,3.0
N,5,4.0
N,6,5.0
N,7,6.0
N,8,7.0
N,9,8.0
N,10,9.0
N,11,10.0
ET,1,188
SECN,1
N,101,5.0,5.0
N,201,10.0,0.0,5.0
E,1,2,101
E,2,3,101
E,3,4,101
E,4,5,101
E,5,6,101
E,6,7,101
E,7,8,101
E,8,9,101
E,9,10,101
E,10,11,101
SECT,1,BEAM,CSOLID
SECD,0.25
MP,EX,1,200E9
MP,NUXY,1,0.3
MP,DENS,1,8000.0
D,1,ALL
ET,2,188
TYPE,2
MP,EX,2,1.0E16
MP,NUXY,2,0.0
MP,DENS,2,0.0
MAT,2
REAL,2
SECN,2
SECT,2,BEAM,CSOLID
SECD,1.0
N,21,10.0,2.0
N,31,10.0,-2.0
E,11,21,201
E,11,31,201
ET,3,MASS21
TYPE,3
REAL,3
SECN,3
R,3,10000.0,10000.0,10000.0
E,21
ET,4,MASS21
TYPE,4
REAL,4
SECN,4
R,4,1000.0,1000.0,1000.0
E,31
/out,scratch
/SOLU
ANTYPE,MODAL
MODOPT,LANB,6
```

```
MXPAND,6
LUMPM,ON
SOLVE
FINISH
/out
/POST1
*DIM,FREQ,ARRAY,6
*GET,FREQ(1,1),MODE,1,FREQ
*GET,FREQ(2,1),MODE,2,FREQ
*GET,FREQ(3,1),MODE,3,FREQ
*GET,FREQ(4,1),MODE,4,FREQ
*GET,FREQ(5,1),MODE,5,FREQ
*GET,FREQ(6,1),MODE,6,FREQ
R1=FREQ(1,1)/1.723
R2=FREQ(2,1)/1.727
R3=FREQ(3,1)/7.413
R4=FREQ(4,1)/9.971
R5=FREQ(5,1)/18.155
R6=FREQ(6,1)/26.957

*DIM,VALUE,,6,2
*DIM,LABEL,CHAR,6
*DIM,RATIO,,6,1
LABEL(1) = 'FREQ 1','FREQ 2','FREQ 3','FREQ 4','FREQ 5','FREQ 6'
*VFILL,VALUE(1,1),DATA,1.723,1.727,7.413,9.972,18.155,26.957
*VFILL,VALUE(1,2),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6

/COM
/COM
/COM,------------- VMP09-T4-188 RESULTS COMPARISON ---------------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F14.3,'   ',1F13.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,6
LABEL1(1) = ' MODE1',' MODE2',' MODE3',' MODE4',' MODE5',' MODE6'
*DIM,LABEL2,CHAR,6
*DIM,LABEL3,CHAR,6
LABEL2(1) = 'vmp09-t4','vmp09-t4','vmp09-t4','vmp09-t4','vmp09-t4','vmp09-t4'
LABEL3(1) = '-188','-188','-188','-188','-188','-188'

/OUT,vmp09-t4-188,vrt
/COM
/COM,-------------------- VMP09-T4 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, BEAM188
*VWRITE,LABEL1(1),VALUE(1,2),RATIO(1,1),LABEL2(1),LABEL3(1)
(1X,A8,'      ',F12.4,'      ',F7.4,'        ',A8,A4)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmp09-t4-188,vrt
```

VM-P09-t4 189 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T4-189
/TITLE,VMP09-T4-189, CANTILEVER WITH OFF-CENTRE POINT MASSES
/COM,REFERENCE: NAFEMS FVB MANUAL TEST 4
```

```
/PREP7
N,1,0.0
N,2,1.0
N,3,2.0
N,4,3.0
N,5,4.0
N,6,5.0
N,7,6.0
N,8,7.0
N,9,8.0
N,10,9.0
N,11,10.0
ET,1,189
SECN,1
N,101,5.0,5.0
N,201,10.0,0.0,5.0
E,1,3,2,101
E,3,5,4,101
E,5,7,6,101
E,7,9,8,101
E,9,11,10,101
SECT,1,BEAM,CSOLID
SECD,0.25
MP,EX,1,200E9
MP,NUXY,1,0.3
MP,DENS,1,8000.0
D,1,ALL
ET,2,188
TYPE,2
MP,EX,2,1.0E16
MP,NUXY,2,0.0
MP,DENS,2,0.0
MAT,2
REAL,2
SECN,2
SECT,2,BEAM,CSOLID
SECD,1.0
N,21,10.0,2.0
N,31,10.0,-2.0
E,11,21,201
E,11,31,201
ET,3,MASS21
TYPE,3
REAL,3
SECN,3
R,3,10000.0,10000.0,10000.0
E,21
ET,4,MASS21
TYPE,4
REAL,4
SECN,4
R,4,1000.0,1000.0,1000.0
E,31
FINISH
/out,scratch
/SOLU
ANTYPE,MODAL
MODOPT,LANB,6
MXPAND,6
LUMPM,ON
SOLVE
FINISH
/out
/POST1
*DIM,FREQ,ARRAY,6
*GET,FREQ(1,1),MODE,1,FREQ
*GET,FREQ(2,1),MODE,2,FREQ
*GET,FREQ(3,1),MODE,3,FREQ
*GET,FREQ(4,1),MODE,4,FREQ
*GET,FREQ(5,1),MODE,5,FREQ
*GET,FREQ(6,1),MODE,6,FREQ
```

```
R1=FREQ(1,1)/1.723
R2=FREQ(2,1)/1.727
R3=FREQ(3,1)/7.413
R4=FREQ(4,1)/9.971
R5=FREQ(5,1)/18.155
R6=FREQ(6,1)/26.957
*DIM,VALUE,,6,3
*DIM,RATIO,,6,1
*DIM,LABEL,CHAR,6
LABEL(1) = 'FREQ 1','FREQ 2','FREQ 3','FREQ 4','FREQ 5','FREQ 6'
*VFILL,VALUE(1,1),DATA,1.723,1.727,7.413,9.972,18.155,26.957
*VFILL,VALUE(1,2),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6

/COM
/COM
/COM,-------------- VMP09-T4-189 RESULTS COMPARISON ------------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F14.3,'   ',1F13.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,6
LABEL1(1) = ' MODE1',' MODE2',' MODE3',' MODE4',' MODE5',' MODE6'
*DIM,LABEL2,CHAR,6
*DIM,LABEL3,CHAR,6
LABEL2(1) = 'vmp09-t4','vmp09-t4','vmp09-t4','vmp09-t4','vmp09-t4','vmp09-t4'
LABEL3(1) = '-189','-189','-189','-189','-189','-189'
/OUT,vmp09-t4-189,vrt
/COM
/COM,------------------- VMP09-T4 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, BEAM189
*VWRITE,LABEL1(1),VALUE(1,2),RATIO(1,1),LABEL2(1),LABEL3(1)
(1X,A8,'      ',F12.4,'      ',F7.4,'        ',A8,A4)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmp09-t4-189,vrt
```

VM-P09-t5 188 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T5-188
/TITLE,VMP09-T5-188, DEEP SIMPLY SUPPORTED BEAM
/COM,REFERENCE NAFEMS FVB TEST 5

/PREP7
N,1,0.0
N,2,1.0
N,3,2.0
N,4,3.0
N,5,4.0
N,6,5.0
N,7,6.0
N,8,7.0
N,9,8.0
N,10,9.0
N,11,10.0
ET,1,188
SECN,1
```

```
N,101,5.0,5.0
E,1,2,101
E,2,3,101
E,3,4,101
E,4,5,101
E,5,6,101
E,6,7,101
E,7,8,101
E,8,9,101
E,9,10,101
E,10,11,101
SECT,1,BEAM,RECT
SECD,2.0,2.0,4,4
MP,EX,1,200E9
MP,NUXY,1,0.3
MP,DENS,1,8000.0
D,1,UX
D,1,UY
D,1,UZ
D,1,ROTX
D,11,UY
D,11,UZ
FINISH
/out,scratch
/SOLU
ANTYPE,MODAL
MODOPT,LANB,9
MXPAND,9
LUMPM,ON
SOLVE
FINISH
/out
/POST1
*DIM,FREQ,ARRAY,9
*GET,FREQ(1,1),MODE,1,FREQ
*GET,FREQ(2,1),MODE,2,FREQ
*GET,FREQ(3,1),MODE,3,FREQ
*GET,FREQ(4,1),MODE,4,FREQ
*GET,FREQ(5,1),MODE,5,FREQ
*GET,FREQ(6,1),MODE,6,FREQ
*GET,FREQ(7,1),MODE,7,FREQ
*GET,FREQ(8,1),MODE,8,FREQ
*GET,FREQ(9,1),MODE,9,FREQ
R1=FREQ(1,1)/42.650
R2=FREQ(2,1)/42.650
R3=FREQ(3,1)/71.200
R4=FREQ(4,1)/125.000
R5=FREQ(5,1)/148.150
R6=FREQ(6,1)/148.150
R7=FREQ(7,1)/213.610
R8=FREQ(8,1)/283.470
R9=FREQ(9,1)/283.470
*DIM,VALUE,,9,2
*DIM,LABEL,CHAR,9
*DIM,RATIO,,9,1
LABEL(1) = 'FREQ 1','FREQ 2','FREQ 3','FREQ 4','FREQ 5','FREQ 6','FREQ 7','FREQ 8','FREQ 9'
*VFILL,VALUE(1,1),DATA,42.650,42.650,71.200,125.000,148.150,148.150,213.610,283.470,283.470
*VFILL,VALUE(1,2),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1),FREQ(7,1),FREQ(8,1),FREQ(9,1
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/COM,
/COM
/COM,------------- VMP09-T5-188 RESULTS COMPARISON -------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F15.3,'   ',1F8.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,6
*DIM,LABEL3,CHAR,6
```

```
LABEL1(1) = ' MODE',' MODE',' MODE',' MODE',' MODE',' MODE'
LABEL3(1) = '1,2','3','4','5,6','7','8,9'
*DIM,VALUE1,,6,3
*VFILL,VALUE1(1,1),DATA,FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(6,1),FREQ(7,1),FREQ(9,1)
*VFILL,VALUE1(1,2),DATA,R2,R3,R4,R6,R7,R9
*DIM,LABEL2,CHAR,6
*DIM,LABEL4,CHAR,6
LABEL2(1) = 'vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5'
LABEL4(1) = '-188','-188','-188','-188','-188','-188'

/OUT,vmp09-t5-188,vrt
/COM
/COM,------------------- VMP09-T5 RESULTS COMPARISON ---------------------
/COM,
/COM,                |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, BEAM188
*VWRITE,LABEL1(1),LABEL3(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL4(1)
(1X,A5,A3,'      ',F13.3,'     ',F9.4,'        ',A8,A4)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmp09-t5-188,vrt
```

VM-P09-t5 189 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T5-189
/TITLE,VMP09-T5-189, DEEP SIMPLY-SUPPORTED BEAM
/COM,REFERENCE: NAFEMS FVB MANUAL TEST 5

/PREP7
N,1,0.0
N,2,1.0
N,3,2.0
N,4,3.0
N,5,4.0
N,6,5.0
N,7,6.0
N,8,7.0
N,9,8.0
N,10,9.0
N,11,10.0
ET,1,189
SECN,1
N,101,5.0,5.0
E,1,3,2,101
E,3,5,4,101
E,5,7,6,101
E,7,9,8,101
E,9,11,10,101
SECT,1,BEAM,RECT
SECD,2.0,2.0
MP,EX,1,200E9
MP,NUXY,1,0.3
MP,DENS,1,8000.0
D,1,UX
D,1,UY
D,1,UZ
D,1,ROTX
D,11,UY
D,11,UZ
FINISH
/out,scratch
/SOLU
ANTYPE,MODAL
```

```
MODOPT,LANB,9
MXPAND,9
LUMPM,ON
SOLVE
FINISH
/out
/POST1
*DIM,FREQ,ARRAY,9
*GET,FREQ(1,1),MODE,1,FREQ
*GET,FREQ(2,1),MODE,2,FREQ
*GET,FREQ(3,1),MODE,3,FREQ
*GET,FREQ(4,1),MODE,4,FREQ
*GET,FREQ(5,1),MODE,5,FREQ
*GET,FREQ(6,1),MODE,6,FREQ
*GET,FREQ(7,1),MODE,7,FREQ
*GET,FREQ(8,1),MODE,8,FREQ
*GET,FREQ(9,1),MODE,9,FREQ
R1=FREQ(1,1)/42.650
R2=FREQ(2,1)/42.650
R3=FREQ(3,1)/71.200
R4=FREQ(4,1)/125.000
R5=FREQ(5,1)/148.150
R6=FREQ(6,1)/148.150
R7=FREQ(7,1)/213.610
R8=FREQ(8,1)/283.470
R9=FREQ(9,1)/283.470

*DIM,VALUE,,9,2
*DIM,RATIO,,9,1
*DIM,LABEL,CHAR,9
LABEL(1) = 'FREQ 1','FREQ 2','FREQ 3','FREQ 4','FREQ 5','FREQ 6','FREQ 7','FREQ 8','FREQ 9'
*VFILL,VALUE(1,1),DATA,42.650,42.650,71.200,125.000,148.150,148.150,213.610,283.470,283.470
*VFILL,VALUE(1,2),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1),FREQ(7,1),FREQ(8,1),FREQ(9,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9

/COM,
/COM,
/COM,-------------- VMP09-T5-189 RESULTS COMPARISON ------------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F15.3,'   ',1F8.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,6
*DIM,LABEL3,CHAR,6
LABEL1(1) = ' MODE',' MODE',' MODE',' MODE',' MODE',' MODE'
LABEL3(1) = '1,2','3','4','5,6','7','8,9'
*DIM,VALUE1,,6,2
*VFILL,VALUE1(1,1),DATA,FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(6,1),FREQ(7,1),FREQ(9,1)
*VFILL,VALUE1(1,2),DATA,R2,R3,R4,R6,R7,R9
*DIM,LABEL2,CHAR,6
LABEL2(1) = 'vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5'
*DIM,LABEL4,CHAR,6
LABEL4(1) = '-189','-189','-189','-189','-189','-189'

/OUT,vmp09-t5-189,vrt
/COM
/COM,------------------- VMP09-T5 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, BEAM189
*VWRITE,LABEL1(1),LABEL3(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL4(1)
(1X,A5,A3,'      ',F13.3,'     ',F9.4,'        ',A8,A4)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
```

```
*LIST,vmp09-t5-189,vrt
```

VM-P09-t12 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T12-181
/TITLE,VMP09-T12-181,FREE THIN SQUARE PLATE
/COM,REFERENCE: NAFEMS FVB MANUAL TEST 12

/NOPR
/PREP7
ET,1,181
SECTYPE,1,SHELL
SECDATA,0.05,1,0,3
MP,EX,1,200E9
MP,NUXY,1,0.3
MP,DENS,1,8000
K,1
K,2,10
K,3,10,10
K,4,,10
A,1,2,3,4
ESIZE,,8
AMESH,1
D,ALL,UX,0,0,,,UY,ROTZ
FINISH
/SOLU
ANTYPE,MODAL,NEW
MODOPT,LANB,10
MXPAND,10,0,0,0
/OUT,SCRATCH
SOLVE
/OUT
FINISH

/POST1
*DIM,FREQ,ARRAY,7
*GET,FREQ(1,1),MODE,4,FREQ
*GET,FREQ(2,1),MODE,5,FREQ
*GET,FREQ(3,1),MODE,6,FREQ
*GET,FREQ(4,1),MODE,7,FREQ
*GET,FREQ(5,1),MODE,8,FREQ
*GET,FREQ(6,1),MODE,9,FREQ
*GET,FREQ(7,1),MODE,10,FREQ
R1=FREQ(1,1)/1.622
R2=FREQ(2,1)/2.36
R3=FREQ(3,1)/2.922
R4=FREQ(4,1)/4.233
R5=FREQ(5,1)/4.233
R6=FREQ(6,1)/7.416
R7=FREQ(7,1)/8.027
*DIM,VALUE,,7,2
*DIM,LABEL,CHAR,10
*DIM,RATIO,,7,1
LABEL(1) = 'FREQ 4','FREQ 5','FREQ 6','FREQ 7','FREQ 8','FREQ 9','FREQ 10'
*VFILL,VALUE(1,1),DATA,1.622,2.36,2.922,4.233,4.233,7.416,8.027
*VFILL,VALUE(1,2),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1),FREQ(7,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6,R7
/COM
/COM,------------- VMP09-T12-181 RESULTS COMPARISON ------------------
/COM,
/COM,          |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F14.3,'   ',1F13.3)
FINISH

/POST26
```

```
*DIM,LABEL1,CHAR,6
*DIM,VALUE1,,6,2
LABEL1(1) = ' MODE4',' MODE5',' MODE6',' MODE7,8',' MODE9',' MODE10'
*VFILL,VALUE1(1,1),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(5,1),FREQ(6,1),FREQ(7,1)
*VFILL,VALUE1(1,2),DATA,R1,R2,R3,R5,R6,R7
*DIM,LABEL2,CHAR,6
*DIM,LABEL3,CHAR,6
LABEL2(1) = 'vmp09-t1','vmp09-t1','vmp09-t1','vmp09-t1','vmp09-t1','vmp09-t1'
LABEL3(1) = '2-181','2-181','2-181','2-181','2-181','2-181'

/OUT,vmp09-t12-181,vrt
/COM
/COM,------------------- VMP09-T12 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL3(1)
(1X,A8,'      ',F13.3,'      ',F9.4,'       ',A8,A5)
/COM,
/COM,---------------------------------------------------------------
/OUT

FINISH
*LIST,vmp09-t12-181,vrt
```

VM-P09-t12 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T12-281
/TITLE,VMP09-T12-281,FREE THIN SQUARE PLATE
/COM,REFERENCE: NAFEMS FVB MANUAL TEST 12
/NOPR
/PREP7
ET,1,281
SECTYPE,1,SHELL
SECDATA,0.05,1,0,3
MP,EX,1,200E9
MP,NUXY,1,0.3
MP,DENS,1,8000
K,1
K,2,10
K,3,10,10
K,4,,10
A,1,2,3,4
ESIZE,,8
AMESH,1
D,ALL,UX,0,0,,,UY,ROTZ
FINISH
/SOLU
ANTYPE,MODAL,NEW
MODOPT,LANB,10
MXPAND,10,0,0,0
/OUT,SCRATCH
SOLVE
/OUT
FINISH
/POST1
*DIM,FREQ,ARRAY,7
*GET,FREQ(1,1),MODE,4,FREQ
*GET,FREQ(2,1),MODE,5,FREQ
*GET,FREQ(3,1),MODE,6,FREQ
*GET,FREQ(4,1),MODE,7,FREQ
*GET,FREQ(5,1),MODE,8,FREQ
*GET,FREQ(6,1),MODE,9,FREQ
*GET,FREQ(7,1),MODE,10,FREQ
R1=FREQ(1,1)/1.622
R2=FREQ(2,1)/2.36
```

```
R3=FREQ(3,1)/2.922
R4=FREQ(4,1)/4.233
R5=FREQ(5,1)/4.233
R6=FREQ(6,1)/7.416
R7=FREQ(7,1)/8.027
*DIM,VALUE,,7,2
*DIM,LABEL,CHAR,10
*DIM,RATIO,,7,1
LABEL(1) = 'FREQ 4','FREQ 5','FREQ 6','FREQ 7','FREQ 8','FREQ 9','FREQ 10'
*VFILL,VALUE(1,1),DATA,1.622,2.36,2.922,4.233,4.233,7.416,8.027
*VFILL,VALUE(1,2),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1),FREQ(7,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6,R7
/COM
/COM,------------- VMP09-T12-281 RESULTS COMPARISON ------------------
/COM,
/COM,          |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F14.3,'   ',1F13.3)
FINISH
/POST26
*DIM,LABEL1,CHAR,6
*DIM,VALUE1,,6,2
LABEL1(1) = ' MODE4',' MODE5',' MODE6',' MODE7,8',' MODE9',' MODE10'
*VFILL,VALUE1(1,1),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(5,1),FREQ(6,1),FREQ(7,1)
*VFILL,VALUE1(1,2),DATA,R1,R2,R3,R5,R6,R7
*DIM,LABEL2,CHAR,6
*DIM,LABEL3,CHAR,6
LABEL2(1) = 'vmp09-t1','vmp09-t1','vmp09-t1','vmp09-t1','vmp09-t1','vmp09-t1'
LABEL3(1) = '2-281','2-281','2-281','2-281','2-281','2-281'
/OUT,vmp09-t12-281,vrt
/COM
/COM,------------------- VMP09-T12 RESULTS COMPARISON ---------------------
/COM,
/COM,             |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL3(1)
(1X,A8,'      ',F13.3,'      ',F9.4,'       ',A8,A5)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmp09-t12-281,vrt
```

VM-P09-t15 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T15-181
/TITLE,VMP09-T15-181, CLAMPED THIN RHOMBIC PLATE
/COM,REFERENCE NAFEMS FVB MANUAL TEST 15

/PREP7
MP,EX,1,2.000000000E+11,
MP,NUXY,1,0.300000000
MP,DENS,1,8000.00000
LOCAL,11,0,10,0,0,45,0,0,1,1
CSCIR,  11,   0,   0
LOCAL,12,0,0,0,0,45,0,0,1,1
CSCIR,  12,   0,   0
ET,1,181,,,2
R,1,0.5E-01
CSYS,12
K,1,0,0,0
K,4,10,0,0
CSYS,11
K,2,0,0,0
K,3,10,0,0
```

```
CSYS,0
A,1,2,3,4
LESIZE,ALL,,,12
AMESH,1
D,ALL,UX,0
D,ALL,UY,0
D,ALL,ROTZ,0
NSLL,S,1
D,ALL,ROTX,0
D,ALL,ROTY,0
D,ALL,UZ,0
ALLSEL,ALL
FINISH
/out,scratch
/SOLU
OUTRES,ALL,ALL,
ANTYPE,MODAL
MODOPT,LANB,22
MXPAND,8
SOLVE
FINISH
/out
/POST1
*DIM,FREQ,ARRAY,6
*GET,FREQ(1,1),MODE,1,FREQ
*GET,FREQ(2,1),MODE,2,FREQ
*GET,FREQ(3,1),MODE,3,FREQ
*GET,FREQ(4,1),MODE,4,FREQ
*GET,FREQ(5,1),MODE,5,FREQ
*GET,FREQ(6,1),MODE,6,FREQ
R1=FREQ(1,1)/7.938
R2=FREQ(2,1)/12.835
R3=FREQ(3,1)/17.941
R4=FREQ(4,1)/19.133
R5=FREQ(5,1)/24.009
R6=FREQ(6,1)/27.922
*DIM,VALUE,,6,2
*DIM,LABEL,CHAR,6
*DIM,RATIO,,6,1
LABEL(1) = 'FREQ 1','FREQ 2','FREQ 3','FREQ 4','FREQ 5','FREQ 6'
*VFILL,VALUE(1,1),DATA,7.938,12.835,17.941,19.133,24.009,27.922
*VFILL,VALUE(1,2),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6
/COM,
/COM,------------- VMP09-T15-181 RESULTS COMPARISON -----------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F14.3,'   ',1F13.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,6
LABEL1(1) = ' MODE1',' MODE2',' MODE3',' MODE4',' MODE5',' MODE6'
*DIM,LABEL2,CHAR,6
*DIM,LABEL3,CHAR,6
LABEL2(1) = 'vmp09-t1','vmp09-t1','vmp09-t1','vmp09-t1','vmp09-t1','vmp09-t1'
LABEL3(1) = '5-181','5-181','5-181','5-181','5-181','5-181'
/OUT,vmp09-t15-181,vrt
/COM
/COM,------------------- VMP09-T15 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL1(1),VALUE(1,2),RATIO(1,1),LABEL2(1),LABEL3(1)
(1X,A8,'       ',F13.4,'     ',F9.4,'       ',A8,A5)
/COM,
/COM,-----------------------------------------------------------------
/OUT
```

```
FINISH
*LIST,vmp09-t15-181,vrt
```

VM-P09-t15 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T15-281
/TITLE,VMP09-T15-281, CLAMPED THIN RHOMBIC PLATE
/COM,REFERENCE NAFEMS FVB MANUAL TEST 15
/PREP7
MP,EX,1,2.000000000E+11,
MP,NUXY,1,0.300000000
MP,DENS,1,8000.00000
LOCAL,11,0,10,0,0,45,0,0,1,1
CSCIR,  11,   0,   0
LOCAL,12,0,0,0,0,45,0,0,1,1
CSCIR,  12,   0,   0
ET,1,281
R,1,0.5E-01
CSYS,12
K,1,0,0,0
K,4,10,0,0
CSYS,11
K,2,0,0,0
K,3,10,0,0
CSYS,0
A,1,2,3,4
LESIZE,ALL,,,12
AMESH,1
D,ALL,UX,0
D,ALL,UY,0
D,ALL,ROTZ,0
NSLL,S,1
D,ALL,ROTX,0
D,ALL,ROTY,0
D,ALL,UZ,0
ALLSEL,ALL
FINISH
/out,scratch
/SOLU
OUTRES,ALL,ALL,
ANTYPE,MODAL
MODOPT,LANB,22
MXPAND,8
SOLVE
FINISH
/out
/POST1
*DIM,FREQ,ARRAY,6
*GET,FREQ(1,1),MODE,1,FREQ
*GET,FREQ(2,1),MODE,2,FREQ
*GET,FREQ(3,1),MODE,3,FREQ
*GET,FREQ(4,1),MODE,4,FREQ
*GET,FREQ(5,1),MODE,5,FREQ
*GET,FREQ(6,1),MODE,6,FREQ
R1=FREQ(1,1)/7.938
R2=FREQ(2,1)/12.835
R3=FREQ(3,1)/17.941
R4=FREQ(4,1)/19.133
R5=FREQ(5,1)/24.009
R6=FREQ(6,1)/27.922
*DIM,VALUE,,6,2
*DIM,LABEL,CHAR,6
*DIM,RATIO,,6,1
LABEL(1) = 'FREQ 1','FREQ 2','FREQ 3','FREQ 4','FREQ 5','FREQ 6'
*VFILL,VALUE(1,1),DATA,7.938,12.835,17.941,19.133,24.009,27.922
*VFILL,VALUE(1,2),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6
```

```
/COM,
/COM,------------- VMP09-T15-281 RESULTS COMPARISON -----------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F14.3,'   ',1F13.3)
FINISH
/POST26
*DIM,LABEL1,CHAR,6
LABEL1(1) = ' MODE1',' MODE2',' MODE3',' MODE4',' MODE5',' MODE6'
*DIM,LABEL2,CHAR,6
*DIM,LABEL3,CHAR,6
LABEL2(1) = 'vmp09-t1','vmp09-t1','vmp09-t1','vmp09-t1','vmp09-t1','vmp09-t1'
LABEL3(1) = '5-281','5-281','5-281','5-281','5-281','5-281'
/OUT,vmp09-t15-281,vrt
/COM
/COM,------------------- VMP09-T15 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),VALUE(1,2),RATIO(1,1),LABEL2(1),LABEL3(1)
(1X,A8,'       ',F13.4,'     ',F9.4,'       ',A8,A5)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmp09-t15-281,vrt
```

VM-P09-t33 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T33-182
/TITLE, VMP09-T33-182, FREE ANNULAR MEMBRANE
/COM,REFERENCE NAFEMS FVB MANUAL TEST 33

/PREP7
ETYP=182
RDIV=3
CDIV=16
ET,1,ETYP
MP,EX,1,200E9
MP,NUXY,1,.3
MP,DENS,1,8000
CSYS,1
K,1,1.8
K,2,6
K,3,6,90
K,4,1.8,90
L,1,2,RDIV
L,2,3,(CDIV/4)
L,3,4,RDIV
L,4,1,(CDIV/4)
ESIZ,,,2
A,1,2,3,4
AMESH,1
CSYS,0
ARSYM,1,1
ARSYM,2,1,2
NUMMRG,ALL
FINISH

/SOLU
ANTYPE,MODAL
MODOPT,SUBSPACE,14
MXPAND,14
RIGID,ALL
```

```
/OUT,SCRATCH
SOLVE
FINISH

/POST1
*DIM,FREQ,ARRAY,14
*GET,FREQ(1,1),MODE,1,FREQ
*GET,FREQ(2,1),MODE,2,FREQ
*GET,FREQ(3,1),MODE,3,FREQ
*GET,FREQ(4,1),MODE,4,FREQ
*GET,FREQ(5,1),MODE,5,FREQ
*GET,FREQ(6,1),MODE,6,FREQ
*GET,FREQ(7,1),MODE,7,FREQ
*GET,FREQ(8,1),MODE,8,FREQ
*GET,FREQ(9,1),MODE,9,FREQ
*GET,FREQ(10,1),MODE,10,FREQ
*GET,FREQ(11,1),MODE,11,FREQ
*GET,FREQ(12,1),MODE,12,FREQ
*GET,FREQ(13,1),MODE,13,FREQ
*GET,FREQ(14,1),MODE,14,FREQ
R1=1.00
R2=1.00
R3=1.00
R4=FREQ(4,1)/129.240
R5=FREQ(5,1)/129.240
R6=FREQ(6,1)/226.17
R7=FREQ(7,1)/234.74
R8=FREQ(8,1)/234.74
R9=FREQ(9,1)/264.66
R10=FREQ(10,1)/264.66
R11=FREQ(11,1)/336.61
R12=FREQ(12,1)/336.61
R13=FREQ(13,1)/376.79
R14=FREQ(14,1)/376.79

*DIM,VALUE,,7,4
*DIM,RATIO,,7,2
*DIM,LABEL,CHAR,7
*DIM,LABEL2,CHAR,7
LABEL(1)='FREQ 1','FREQ 2','FREQ 3','FREQ 4','FREQ 5','FREQ 6','FREQ 7'
LABEL2(1)='FREQ 8','FREQ 9','FREQ 10','FREQ 11','FREQ 12','FREQ 13','FREQ 14'
*VFILL,VALUE(1,1),DATA,0,0,0,129.240,129.240,226.170,234.740,
*VFILL,VALUE(1,2),DATA,234.740,264.660,264.660,336.610,336.610,376.790,376.790
*VFILL,VALUE(1,3),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1),FREQ(7,1)
*VFILL,VALUE(1,4),DATA,FREQ(8,1),FREQ(9,1),FREQ(10,1),FREQ(11,1),FREQ(12,1),FREQ(13,1),FREQ(14,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6,R7
*VFILL,RATIO(1,2),DATA,R8,R9,R10,R11,R12,R13,R14
/OUT,
/COM,
/COM,
/COM,------------- VMP09-T33-182 RESULTS COMPARISON ---------------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,3),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F14.3,'   ',1F14.3)
*VWRITE,LABEL2(1),VALUE(1,2),VALUE(1,4),RATIO(1,2)
(1X,A8,'   ',F10.3,'  ',F14.3,'   ',1F14.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,6
*DIM,LABEL4,CHAR,6
*DIM,VALUE1,,6,2
LABEL1(1) = ' MODE',' MODE',' MODE',' MODE',' MODE',' MODE'
LABEL4(1) = '4,5','6','7,8','9,10','11,12','13,14'
*VFILL,VALUE1(1,1),DATA,FREQ(5,1),FREQ(6,1),FREQ(8,1),FREQ(10,1),FREQ(12,1),FREQ(14,1)
*VFILL,VALUE1(1,2),DATA,R5,R6,R8,R10,R12,R14
*DIM,LABEL3,CHAR,6
*DIM,LABEL5,CHAR,6
LABEL3(1) = 'vmp09-t3','vmp09-t3','vmp09-t3','vmp09-t3','vmp09-t3','vmp09-t3'
LABEL5(1) = '3-182','3-182','3-182','3-182','3-182','3-182',
```

```
/OUT,vmp09-t33-182,vrt
/COM
/COM,------------------- VMP09-T33 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),LABEL4(1),VALUE1(1,1),VALUE1(1,2),LABEL3(1),LABEL5(1)
(1X,A5,A5,'     ',F13.3,'     ',F7.3,'       ',A8,A5)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vmp09-t33-182,vrt
```

VM-P09-t33 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T33-183
/TITLE, VMP09-T33-183, FREE ANNULAR MEMBRANE
/COM,REFERENCE NAFEMS FVB MANUAL TEST 33

/PREP7 $SMRT,OFF
ETYP=183
RDIV=3
CDIV=16
ET,1,ETYP
MP,EX,1,200E9
MP,NUXY,1,.3
MP,DENS,1,8000
CSYS,1
K,1,1.8
K,2,6
K,3,6,90
K,4,1.8,90
L,1,2,RDIV
L,2,3,(CDIV/4)
L,3,4,RDIV
L,4,1,(CDIV/4)
ESIZ,,,2
A,1,2,3,4
AMESH,1
CSYS,0
ARSYM,1,1
ARSYM,2,1,2
NUMMRG,ALL
FINISH

/SOLU
ANTYPE,MODAL
MODOPT,LANB,14
MXPAND,14
RIGID,ALL
/OUT,SCRATCH
SOLVE
FINISH

/POST1
*DIM,FREQ,ARRAY,14
*GET,FREQ(1,1),MODE,1,FREQ
*GET,FREQ(2,1),MODE,2,FREQ
*GET,FREQ(3,1),MODE,3,FREQ
*GET,FREQ(4,1),MODE,4,FREQ
*GET,FREQ(5,1),MODE,5,FREQ
*GET,FREQ(6,1),MODE,6,FREQ
*GET,FREQ(7,1),MODE,7,FREQ
```

```
*GET,FREQ(8,1),MODE,8,FREQ
*GET,FREQ(9,1),MODE,9,FREQ
*GET,FREQ(10,1),MODE,10,FREQ
*GET,FREQ(11,1),MODE,11,FREQ
*GET,FREQ(12,1),MODE,12,FREQ
*GET,FREQ(13,1),MODE,13,FREQ
*GET,FREQ(14,1),MODE,14,FREQ
R1=1.00
R2=1.00
R3=1.00
R4=FREQ(4,1)/129.240
R5=FREQ(5,1)/129.240
R6=FREQ(6,1)/226.17
R7=FREQ(7,1)/234.74
R8=FREQ(8,1)/234.74
R9=FREQ(9,1)/264.66
R10=FREQ(10,1)/264.66
R11=FREQ(11,1)/336.61
R12=FREQ(12,1)/336.61
R13=FREQ(13,1)/376.79
R14=FREQ(14,1)/376.79

*DIM,VALUE,,7,4
*DIM,RATIO,,7,2
*DIM,LABEL,CHAR,7
*DIM,LABEL2,CHAR,7
LABEL(1)='FREQ 1','FREQ 2','FREQ 3','FREQ 4','FREQ 5','FREQ 6','FREQ 7'
LABEL2(1)='FREQ 8','FREQ 9','FREQ 10','FREQ 11','FREQ 12','FREQ 13','FREQ 14'
*VFILL,VALUE(1,1),DATA,0,0,0,129.240,129.240,226.170,234.740,
*VFILL,VALUE(1,2),DATA,234.740,264.660,264.660,336.610,336.610,376.790,376.790
*VFILL,VALUE(1,3),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1),FREQ(7,1)
*VFILL,VALUE(1,4),DATA,FREQ(8,1),FREQ(9,1),FREQ(10,1),FREQ(11,1),FREQ(12,1),FREQ(13,1),FREQ(14,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6,R7
*VFILL,RATIO(1,2),DATA,R8,R9,R10,R11,R12,R13,R14
/OUT,
/COM,
/COM,
/COM,------------- VMP09-T33-183 RESULTS COMPARISON ---------------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,3),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F14.3,'   ',1F13.3)
*VWRITE,LABEL2(1),VALUE(1,2),VALUE(1,4),RATIO(1,2)
(1X,A8,'   ',F10.3,'  ',F14.3,'   ',1F13.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,6
*DIM,LABEL4,CHAR,6
*DIM,VALUE1,,6,2
LABEL1(1) = ' MODE',' MODE',' MODE',' MODE',' MODE',' MODE'
LABEL4(1) = '4,5','6','7,8','9,10','11,12','13,14'
*VFILL,VALUE1(1,1),DATA,FREQ(5,1),FREQ(6,1),FREQ(8,1),FREQ(10,1),FREQ(12,1),FREQ(14,1)
*VFILL,VALUE1(1,2),DATA,R5,R6,R8,R10,R12,R14
*DIM,LABEL3,CHAR,6
*DIM,LABEL5,CHAR,6
LABEL3(1) = 'vmp09-t3','vmp09-t3','vmp09-t3','vmp09-t3','vmp09-t3','vmp09-t3'
LABEL5(1) = '3-183','3-183','3-183','3-183','3-183','3-183',

/OUT,vmp09-t33-183,vrt
/COM
/COM,------------------- VMP09-T33 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),LABEL4(1),VALUE1(1,1),VALUE1(1,2),LABEL3(1),LABEL5(1)
(1X,A5,A5,'     ',F13.3,'     ',F7.3,'       ',A8,A5)
/COM,
/COM,----------------------------------------------------------------
/OUT
```

```
FINISH
*LIST,vmp09-t33-183,vrt
```

VM-P09-t52 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T52-181
/TITLE,VMP09-T52-181, SIMPLY SUPPORTED SOLID SQUARE PLATE
/COM,REFERENCE: NAFEMS FVB MANUAL TEST 52

/PREP7
ET,1,181,,,2
R,1,1.0
MP,EX,1,200E9
MP,NUXY,1,0.3
MP,DENS,1,8000.0
RECT,0,10,0,10
ESIZE,,20
AMESH, ALL
FINISH
/out,scratch
/SOLU
ANTYPE,MODAL
NSEL,,LOC,X,0.0,0.0001
D,ALL,UZ
NSEL,,LOC,Y,0.0,0.00001
D,ALL,UZ
NSEL,,LOC,X,10
D,ALL,UZ
NSEL,,LOC,Y,10
D,ALL,UZ
NSEL,ALL
MODOPT,LANB,10,
SOLVE
FINISH
/out
/POST1
*DIM,FREQ,ARRAY,10
*GET,FREQ(1,1),MODE,4,FREQ
*GET,FREQ(2,1),MODE,5,FREQ
*GET,FREQ(3,1),MODE,6,FREQ
*GET,FREQ(4,1),MODE,7,FREQ
*GET,FREQ(5,1),MODE,8,FREQ
*GET,FREQ(6,1),MODE,9,FREQ
*GET,FREQ(7,1),MODE,10,FREQ
R1=FREQ(1,1)/45.897
R2=FREQ(2,1)/109.44
R3=FREQ(3,1)/109.44
R4=FREQ(4,1)/167.59
R5=FREQ(5,1)/193.59
R6=FREQ(6,1)/206.19
R7=FREQ(7,1)/206.19

*DIM,VALUE,,7,2
*DIM,LABEL,CHAR,10
*DIM,RATIO,,7,2
LABEL(1) = 'FREQ 4','FREQ 5','FREQ 6','FREQ 7','FREQ 8','FREQ 9','FREQ 10'
*VFILL,VALUE(1,1),DATA,45.897,109.44,109.44,167.89,193.59,206.19,206.19
*VFILL,VALUE(1,2),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1),FREQ(7,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6,R7

/COM
/COM,-------------- VMP09-T52-181 RESULTS COMPARISON ---------------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL    |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),RATIO(1,1)
```

```
(1X,A8,'   ',F10.3,'  ',F15.3,'   ',1F8.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,5
*DIM,VALUE1,,5,3
*DIM,LABEL3,CHAR,5
LABEL1(1) = ' MODE',' MODE',' MODE',' MODE',' MODE'
LABEL3(1) = '4','5,6','7','8','9,10'
*VFILL,VALUE1(1,1),DATA,FREQ(1,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(7,1)
*VFILL,VALUE1(1,2),DATA,R1,R3,R4,R5,R7
*DIM,LABEL2,CHAR,5
*DIM,LABEL4,CHAR,5
LABEL2(1) = 'vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5'
LABEL4(1) = '2-181','2-181','2-181','2-181','2-181'

/OUT,vmp09-t52-181,vrt
/COM
/COM,------------------- VMP09-T52 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL1(1),LABEL3(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL4(1)
(1X,A5,A5,'      ',F13.3,'    ',F9.4,'        ',A8,A5)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmp09-t52-181,vrt
```

VM-P09-t52 185 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T52-185
/TITLE,VMP09-T52-185,SIMPLY SUPPORTED SOLID SQUARE PLATE
/COM,REFERENCE: NAFEMS FVB MANUAL TEST 52

/NOPR
/PREP7
BLOCK,0,10,0,10,0,1,
ET,1,185
MP,EX,1,200E9
MP,NUXY,1,0.3
MP,DENS,1,8000.0
MSHAPE,0,3D
MSHKEY,1
LESIZE,ALL,,,10,,,,,1
VMESH, ALL
FINISH

/SOLU
ANTYPE,MODAL
NSEL,,LOC,Z,0.049999,0.050011
NSEL,,LOC,X,0.0,0.0001
D,ALL,UZ
NSEL,,LOC,Z,0.049999,0.050011
NSEL,,LOC,Y,0.0,0.00001
D,ALL,UZ
NSEL,,LOC,Z,0.049999,0.050011
NSEL,,LOC,X,10
D,ALL,UZ
NSEL,,LOC,Z,0.049999,0.050011
NSEL,,LOC,Y,10
D,ALL,UZ
NSEL,ALL
MODOPT,LANB,10,
```

```
/OUT,SCRATCH
SOLVE
/OUT
FINISH
/POST1
*DIM,FREQ,ARRAY,10
*GET,FREQ(1,1),MODE,4,FREQ
*GET,FREQ(2,1),MODE,5,FREQ
*GET,FREQ(3,1),MODE,6,FREQ
*GET,FREQ(4,1),MODE,7,FREQ
*GET,FREQ(5,1),MODE,8,FREQ
*GET,FREQ(6,1),MODE,9,FREQ
*GET,FREQ(7,1),MODE,10,FREQ
R1=FREQ(1,1)/45.897
R2=FREQ(2,1)/109.44
R3=FREQ(3,1)/109.44
R4=FREQ(4,1)/167.89
R5=FREQ(5,1)/193.59
R6=FREQ(6,1)/206.19
R7=FREQ(7,1)/206.9

*DIM,VALUE,,7,2
*DIM,LABEL,CHAR,10
*DIM,RATIO,,7,1
LABEL(1) = 'FREQ 4','FREQ 5','FREQ 6','FREQ 7','FREQ 8','FREQ 9','FREQ 10'
*VFILL,VALUE(1,1),DATA,45.897,109.44,109.44,167.89,193.59,206.19,206.19
*VFILL,VALUE(1,2),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1),FREQ(7,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6,R7

/COM
/COM,-------------- VMP09-T52-185 RESULTS COMPARISON ---------------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F15.3,'   ',1F8.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,5
*DIM,VALUE1,,5,3
*DIM,LABEL3,CHAR,5
LABEL1(1) = ' MODE',' MODE',' MODE',' MODE',' MODE'
LABEL3(1) = '4','5,6','7','8','9,10'
*VFILL,VALUE1(1,1),DATA,FREQ(1,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(7,1)
*VFILL,VALUE1(1,2),DATA,R1,R3,R4,R5,R7
*DIM,LABEL2,CHAR,5
*DIM,LABEL4,CHAR,5
LABEL2(1) = 'vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5'
LABEL4(1) = '2-185','2-185','2-185','2-185','2-185'

/OUT,vmp09-t52-185,vrt
/COM
/COM,------------------- VMP09-T52 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID185
*VWRITE,LABEL1(1),LABEL3(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL4(1)
(1X,A5,A5,'      ',F13.3,'    ',F9.4,'        ',A8,A5)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmp09-t52-185,vrt
```

VM-P09-t52 186 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T52-186
/TITLE,VMP09-T52-186, SIMPLY-SUPPORTED SOLID SQUARE PLATE
/COM,   SELECTED BENCHMARKS FOR NATURAL FREQUENCY ANALYSIS
/COM,   JUNE 1987, TEST 52

/PREP7
N1=4
N2=1
ET,1,186
MP,EX,1,200E9
MP,NUXY,1,.3
MP,DENS,1,8000
K,1
K,2,10
K,3,10,10
K,4,,10
KGEN,2,1,4,1,,,1
L,1,5,N2
*REP,4,1,1
V,1,2,3,4,5,6,7,8
ESIZE,,N1
VMESH,1
NSEL,S,LOC,Y,0
NSEL,R,LOC,Z,0
D,ALL,UZ,0
NSEL,S,LOC,X,0
NSEL,R,LOC,Z,0
D,ALL,UZ,0
NSEL,S,LOC,Y,10
NSEL,R,LOC,Z,0
D,ALL,UZ,0
NSEL,S,LOC,X,10
NSEL,R,LOC,Z,0
D,ALL,UZ,0
NSEL,ALL
FINISH
/out,scratch
/SOLU
ANTYPE,MODAL
MODOPT,SUBSPACE,20
MXPAND,10
SOLVE
FINISH
/out
/POST1
*DIM,FREQ,ARRAY,10
*GET,FREQ(1,1),MODE,4,FREQ
*GET,FREQ(2,1),MODE,5,FREQ
*GET,FREQ(3,1),MODE,6,FREQ
*GET,FREQ(4,1),MODE,7,FREQ
*GET,FREQ(5,1),MODE,8,FREQ
*GET,FREQ(6,1),MODE,9,FREQ
*GET,FREQ(7,1),MODE,10,FREQ
R1=FREQ(1,1)/45.897
R2=FREQ(2,1)/109.44
R3=FREQ(3,1)/109.44
R4=FREQ(4,1)/167.89
R5=FREQ(5,1)/193.59
R6=FREQ(6,1)/206.19
R7=FREQ(7,1)/206.19
*DIM,VALUE,,7,2
*DIM,LABEL,CHAR,10
*DIM,RATIO,,7,1
LABEL(1) = 'FREQ 4','FREQ 5','FREQ 6','FREQ 7','FREQ 8','FREQ 9','FREQ 10'
*VFILL,VALUE(1,1),DATA,45.897,109.44,109.44,167.89,193.59,206.19,206.19
*VFILL,VALUE(1,2),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1),FREQ(7,1)
```

```
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6,R7
FINISH

/PREP7
ET,1,186
LUMPM,ON
FINISH
/out,scratch
/SOLU
SOLVE
FINISH
/out
/POST1
*DIM,FREQ1,ARRAY,10
*GET,FREQ1(1,1),MODE,4,FREQ
*GET,FREQ1(2,1),MODE,5,FREQ
*GET,FREQ1(3,1),MODE,6,FREQ
*GET,FREQ1(4,1),MODE,7,FREQ
*GET,FREQ1(5,1),MODE,8,FREQ
*GET,FREQ1(6,1),MODE,9,FREQ
*GET,FREQ1(7,1),MODE,10,FREQ
R8=FREQ1(1,1)/45.897
R9=FREQ1(2,1)/109.44
R10=FREQ1(3,1)/109.44
R11=FREQ1(4,1)/167.89
R12=FREQ1(5,1)/193.59
R13=FREQ1(6,1)/206.19
R14=FREQ1(7,1)/206.19
*DIM,VALUE1,,7,2
*DIM,LABEL1,CHAR,10
*DIM,RATIO1,,7,1
LABEL1(1) = 'FREQ 4','FREQ 5','FREQ 6','FREQ 7','FREQ 8','FREQ 9','FREQ 10'
*VFILL,VALUE1(1,1),DATA,45.897,109.44,109.44,167.89,193.59,206.19,206.19
*VFILL,VALUE1(1,2),DATA,FREQ1(1,1),FREQ1(2,1),FREQ1(3,1),FREQ1(4,1),FREQ1(5,1),FREQ1(6,1), FREQ1(7,1)
*VFILL,RATIO1(1,1),DATA,R8,R9,R10,R11,R12,R13,R14
/COM,
/COM,------------ VMP09-T52-186 RESULTS COMPARISON ----------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F15.3,'   ',1F8.3)
/COM
/COM,---------------- LUMPED MASS RESULTS --------------------
/COM
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),RATIO1(1,1)
(1X,A8,'   ',F10.3,'  ',F15.3,'   ',1F8.3)
FINISH

/POST26
*DIM,LABEL3,CHAR,5
*DIM,LABEL4,CHAR,5
*DIM,VALUE2,,5,3
LABEL3(1) = ' MODE',' MODE',' MODE',' MODE',' MODE'
LABEL4(1) = '4','5,6','7','8','9,10'
*VFILL,VALUE2(1,1),DATA,FREQ(1,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(7,1)
*VFILL,VALUE2(1,2),DATA,R1,R3,R4,R5,R7
*DIM,LABEL2,CHAR,5
*DIM,LABEL5,CHAR,5
LABEL2(1) = 'vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5'
LABEL5(1) = '2-186','2-186','2-186','2-186','2-186'

/OUT,vmp09-t52-186,vrt
/COM
/COM,------------------- VMP09-T52 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID186
*VWRITE,LABEL3(1),LABEL4(1),VALUE2(1,1),VALUE2(1,2),LABEL2(1),LABEL5(1)
```

```
(1X,A5,A5,'      ',F13.3,'    ',F9.4,'        ',A8,A5)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmp09-t52-186,vrt
```

VM-P09-t52 187 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T52-187
/TITLE,VMP09-T52-187, SIMPLY-SUPPORTED SOLID SQUARE PLATE
/COM,   SELECTED BENCHMARKS FOR NATURAL FREQUENCY ANALYSIS
/COM,   JUNE 1987, TEST 52

/PREP7
N1=4
N2=1
ET,1,187
MP,EX,1,200E9
MP,NUXY,1,.3
MP,DENS,1,8000
K,1
K,2,10
K,3,10,10
K,4,,10
KGEN,2,1,4,1,,,1
L,1,5,N2
*REP,4,1,1
V,1,2,3,4,5,6,7,8
ESIZE,,N1
VMESH,1
NSEL,S,LOC,Y,0
NSEL,R,LOC,Z,0
D,ALL,UZ,0
NSEL,S,LOC,X,0
NSEL,R,LOC,Z,0
D,ALL,UZ,0
NSEL,S,LOC,Y,10
NSEL,R,LOC,Z,0
D,ALL,UZ,0
NSEL,S,LOC,X,10
NSEL,R,LOC,Z,0
D,ALL,UZ,0
NSEL,ALL
FINISH
/out,scratch
/SOLVE
ANTYPE,MODAL
MODOPT,LANB,20
MXPAND,10
SOLVE
FINISH
/out
/POST1
*DIM,FREQ,ARRAY,10
*GET,FREQ(1,1),MODE,4,FREQ
*GET,FREQ(2,1),MODE,5,FREQ
*GET,FREQ(3,1),MODE,6,FREQ
*GET,FREQ(4,1),MODE,7,FREQ
*GET,FREQ(5,1),MODE,8,FREQ
*GET,FREQ(6,1),MODE,9,FREQ
*GET,FREQ(7,1),MODE,10,FREQ
R1=FREQ(1,1)/45.897
R2=FREQ(2,1)/109.44
R3=FREQ(3,1)/109.44
R4=FREQ(4,1)/167.89
```

```
R5=FREQ(5,1)/193.59
R6=FREQ(6,1)/206.19
R7=FREQ(7,1)/206.19
*DIM,VALUE,,7,2
*DIM,LABEL,CHAR,10
*DIM,RATIO,,7,1
LABEL(1) = 'FREQ 4','FREQ 5','FREQ 6','FREQ 7','FREQ 8','FREQ 9','FREQ 10'
*VFILL,VALUE(1,1),DATA,45.897,109.44,109.44,167.89,193.59,206.19,206.19
*VFILL,VALUE(1,2),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1),FREQ(7,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6,R7
FINISH

/PREP7
ET,1,187
LUMPM,ON
FINISH
/out,scratch
/SOLU
SOLVE
FINISH
/out
/POST1
*DIM,FREQ1,ARRAY,10
*GET,FREQ1(1,1),MODE,4,FREQ
*GET,FREQ1(2,1),MODE,5,FREQ
*GET,FREQ1(3,1),MODE,6,FREQ
*GET,FREQ1(4,1),MODE,7,FREQ
*GET,FREQ1(5,1),MODE,8,FREQ
*GET,FREQ1(6,1),MODE,9,FREQ
*GET,FREQ1(7,1),MODE,10,FREQ
R8=FREQ1(1,1)/45.897
R9=FREQ1(2,1)/109.44
R10=FREQ1(3,1)/109.44
R11=FREQ1(4,1)/167.89
R12=FREQ1(5,1)/193.59
R13=FREQ1(6,1)/206.19
R14=FREQ1(7,1)/206.19
*DIM,VALUE1,,7,2
*DIM,LABEL1,CHAR,10
*DIM,RATIO1,,7,1
LABEL1(1) = 'FREQ 4','FREQ 5','FREQ 6','FREQ 7','FREQ 8','FREQ 9','FREQ 10'
*VFILL,VALUE1(1,1),DATA,45.897,109.44,109.44,167.89,193.59,206.19,206.19
*VFILL,VALUE1(1,2),DATA,FREQ1(1,1),FREQ1(2,1),FREQ1(3,1),FREQ1(4,1),FREQ1(5,1),FREQ1(6,1), FREQ1(7,1)
*VFILL,RATIO1(1,1),DATA,R8,R9,R10,R11,R12,R13,R14
/COM,
/COM,------------ VMP09-T52-187 RESULTS COMPARISON ----------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F15.3,'   ',1F8.3)
/COM
/COM,---------------- LUMPED MASS RESULTS --------------------
/COM
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),RATIO1(1,1)
(1X,A8,'   ',F10.3,'  ',F15.3,'   ',1F8.3)
FINISH

/POST26
*DIM,LABEL3,CHAR,5
*DIM,VALUE2,,5,3
*DIM,LABEL4,CHAR,5
LABEL3(1) = ' MODE',' MODE',' MODE',' MODE',' MODE'
LABEL4(1) = '4','5,6','7','8','9,10'
*VFILL,VALUE2(1,1),DATA,FREQ(1,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(7,1),
*VFILL,VALUE2(1,2),DATA,R1,R3,R4,R5,R7
*DIM,LABEL2,CHAR,5
*DIM,LABEL5,CHAR,5
LABEL2(1) = 'vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5'
LABEL5(1) = '2-187','2-187','2-187','2-187','2-187'
```

```
/OUT,vmp09-t52-187,vrt
/COM
/COM,------------------- VMP09-T52 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID187
*VWRITE,LABEL3(1),LABEL4(1),VALUE2(1,1),VALUE2(1,2),LABEL2(1),LABEL5(1)
(1X,A5,A5,'      ',F13.3,'    ',F9.4,'        ',A8,A5)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmp09-t52-187,vrt
```

VM-P09-t52 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMP09-T52-281
/TITLE,VMP09-T52-281, SIMPLY SUPPORTED SOLID SQUARE PLATE
/COM,REFERENCE: NAFEMS FVB MANUAL TEST 52
/PREP7
ET,1,SHELL281
R,1,1.0
MP,EX,1,200E9
MP,NUXY,1,0.3
MP,DENS,1,8000.0
RECT,0,10,0,10
ESIZE,,20
AMESH, ALL
FINISH
/out,scratch
/SOLU
ANTYPE,MODAL
NSEL,,LOC,X,0.0,0.0001
D,ALL,UZ
NSEL,,LOC,Y,0.0,0.00001
D,ALL,UZ
NSEL,,LOC,X,10
D,ALL,UZ
NSEL,,LOC,Y,10
D,ALL,UZ
NSEL,ALL
MODOPT,LANB,10,
SOLVE
FINISH
/out
/POST1
*DIM,FREQ,ARRAY,10
*GET,FREQ(1,1),MODE,4,FREQ
*GET,FREQ(2,1),MODE,5,FREQ
*GET,FREQ(3,1),MODE,6,FREQ
*GET,FREQ(4,1),MODE,7,FREQ
*GET,FREQ(5,1),MODE,8,FREQ
*GET,FREQ(6,1),MODE,9,FREQ
*GET,FREQ(7,1),MODE,10,FREQ
R1=FREQ(1,1)/45.897
R2=FREQ(2,1)/109.44
R3=FREQ(3,1)/109.44
R4=FREQ(4,1)/167.59
R5=FREQ(5,1)/193.59
R6=FREQ(6,1)/206.19
R7=FREQ(7,1)/206.19
*DIM,VALUE,,7,2
*DIM,LABEL,CHAR,10
*DIM,RATIO,,7,2
```

```
LABEL(1) = 'FREQ 4','FREQ 5','FREQ 6','FREQ 7','FREQ 8','FREQ 9','FREQ 10'
*VFILL,VALUE(1,1),DATA,45.897,109.44,109.44,167.89,193.59,206.19,206.19
*VFILL,VALUE(1,2),DATA,FREQ(1,1),FREQ(2,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(6,1),FREQ(7,1)
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6,R7
/COM
/COM,-------------- VMP09-T52-281 RESULTS COMPARISON ---------------------
/COM,
/COM,         |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1),VALUE(1,1),VALUE(1,2),RATIO(1,1)
(1X,A8,'   ',F10.3,'  ',F15.3,'   ',1F8.3)
FINISH
/POST26
*DIM,LABEL1,CHAR,5
*DIM,VALUE1,,5,3
*DIM,LABEL3,CHAR,5
LABEL1(1) = ' MODE',' MODE',' MODE',' MODE',' MODE'
LABEL3(1) = '4','5,6','7','8','9,10'
*VFILL,VALUE1(1,1),DATA,FREQ(1,1),FREQ(3,1),FREQ(4,1),FREQ(5,1),FREQ(7,1)
*VFILL,VALUE1(1,2),DATA,R1,R3,R4,R5,R7
*DIM,LABEL2,CHAR,5
*DIM,LABEL4,CHAR,5
LABEL2(1) = 'vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5','vmp09-t5'
LABEL4(1) = '2-281','2-281','2-281','2-281','2-281'
/OUT,vmp09-t52-281,vrt
/COM
/COM,------------------- VMP09-T52 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),LABEL3(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL4(1)
(1X,A5,A5,'      ',F13.3,'    ',F9.4,'        ',A8,A5)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmp09-t52-281,vrt
```

VM-R020-t1a 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr020-t1a-183
/title,vmr020-t1a-183,Centre Cracked Plate in Tension
/com,
/com, Problem is taken from NAFEMS Publication
/com, "2D Test Cases in Linear Elastic Fracture Mechanics"
/com, Test case 1.1
/com,
/com, Reference: Rooke D P and Cartwright D J : Compendium
/com, of stress intensity factors, HMSO, London, England (1976)
/com,
/com, **********************************************************
/com, Stress Intensity Factor Calculation using Interaction
/com, Integral Approach

/prep7

E=207000                 ! youngs modulus
NU=0.3                   ! poissons ratio
sig=100                   ! surface load
pi=3.141593
a=10               ! crack length

et,1,plane183               ! plane 183 element
keyopt,1,3,2                ! plane strain
mp,ex,1,e
mp,nuxy,1,nu
```

```
k,1,-10,0
k,2,0,0
k,3,10,0
k,4,10,10
k,5,10,20
k,6,-10,20
k,7,-10,10

l,1,2
*rep,6,1,1
l,7,1
l,4,7
al,1,2,3,8,7
al,4,5,6,8
esize,1
kscon,2,1,1,4,0.75          !crack tip elements
amesh,1
esize,2
amesh,2
fini

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0
nsel,r,loc,x,0,10
d,all,uy,0
nsel,s,loc,x,-10
nsel,r,loc,y,0,20
d,all,ux,0
nsel,all
lsel,s,line,,5
sfl,all,press,-sig
lsel,all
nsel,s,loc,y,0
nsel,r,loc,x,0
cm,crack1,node              ! define the crack tip node component
nsel,all
cint,new,1
cint,type,sifs              ! Calculate Stress Intensity factor
cint,ctnc,crack1            ! crack ID
cint,ncon,4                 ! number of countours
cint,symm,on                ! symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
prcint,1                     ! Get the J1,J2,J3 values
*get,k1_1,cint,1,ctip,node(0,0,0),,1,dtype,k1
*get,k1_2,cint,1,ctip,node(0,0,0),,2,dtype,k1
*get,k1_3,cint,1,ctip,node(0,0,0),,3,dtype,k1
*get,k1_4,cint,1,ctip,node(0,0,0),,4,dtype,k1

k1=(k1_2+k1_3+k1_4)/3
*stat,k1

con1 = ((pi*a)**0.5)
k0=(sig*con1)
norm_sif=k1/k0
/out,
*status,norm_sif


*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
```

```
*VFILL,VALUE(1,1),DATA,1.325
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/1.325 )
SAVE,TABLE_1
FINI
/CLEAR,NOSTART

/com,*************************************************************
/com, Using J integral Calculation

/prep7

E=207000                 ! youngs modulus
NU=0.3                   ! poissons ratio
sig=100                   ! surface load
pi=3.141593
a=10               ! crack length

et,1,plane183               ! plane 183 element
keyopt,1,3,2                ! plane strain
mp,ex,1,e
mp,nuxy,1,nu

k,1,-10,0
k,2,0,0
k,3,10,0
k,4,10,10
k,5,10,20
k,6,-10,20
k,7,-10,10

l,1,2
*rep,6,1,1
l,7,1
l,4,7
al,1,2,3,8,7
al,4,5,6,8
esize,1
kscon,2,1,1,4,0.75  ! mesh crack tip elements
amesh,1
esize,2
amesh,2
fini

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0
nsel,r,loc,x,0,10
d,all,uy,0
nsel,s,loc,x,-10
nsel,r,loc,y,0,20
d,all,ux,0
nsel,all
lsel,s,line,,5
sfl,all,press,-sig
lsel,all
nsel,s,loc,y,0
nsel,r,loc,x,0
cm,crack1,node        ! define the crack tip node component
nsel,all
cint,new,1
cint,ctnc,crack1      ! crack ID
cint,ncon,4           ! number of countours
cint,symm,on          ! symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
fini
```

```
/out,scratch
/post1
prcint,1                     ! Get the J1,J2,J3 values
*get,j1,cint,1,ctip,node(0,0,0),,1,,
*get,j2,cint,1,ctip,node(0,0,0),,2,,
*get,j3,cint,1,ctip,node(0,0,0),,3,,
*get,j4,cint,1,ctip,node(0,0,0),,4,,
jc1 =(abs(j1)+abs(j2)+abs(j3)+abs(j4))/4
*stat,jc1
con1 = ((pi*a)**0.5)
con2 = E/(1-(nu*nu))
k1 = ((con2*jc1)**0.5)
k0=(sig*con1)
norm_sif=k1/k0
/out,
*status,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,1.325
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/1.325 )
SAVE,TABLE_2



/NOPR
/COM
/OUT,vmr020-t1a-183,vrt
/COM,------------------- vmr020-t1a-183 RESULTS COMPARISON ---------------------
/COM,
/COM,               |   TARGET   |   MECHANICAL APDL    |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING STRESS INTENSITY FACTOR CALCULATION
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
RESUME,TABLE_2
/COM,USING J-INTEGRAL APPROACH
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
/COM,-----------------------------------------------------------------------------

/OUT
FINISH
*list,vmr020-t1a-183,vrt
```

VM-R020-t1b 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr020-t1b-183
/title,vmr020-t1b-183,Centre Cracked Plate with Quadratic Thermal Distribution
/com,
/com, Problem is taken from NAFEMS Publication
/com, "2D Test Cases in Linear Elastic Fracture Mechanics"
/com, Test case 1.2
/com,
/com, Reference: Hellen T K and Cesari F : On the solution of
/com, the centre cracked plate with a quadratic thermal gradient
/com, Engineering Fracture Mechanics, Vol 12, pp 469-478
```

```
/com,
/com, ******************************************************
/com, Stress Intensity Factor Calculation using Interaction
/com, Integral Approach
/prep7

e=207000      !youngs modulus
nu=0.3       !poissons ratio
alp=1.35e-5      !coefficient of thermal expansion
k0=514.3      !critical stress intensity factor from nafems manual


et,1,plane183,,,0  !plane183 element

mp,ex,1,e
mp,nuxy,1,nu
mp,alpx,1,alp
mp,reft,1,0

k,1,10,0
k,2,100,0
k,3,100,50
k,4,100,250
k,5,0,250
k,6,0,50
k,7,0,0

l,1,2
*rep,6,1,1
l,7,1
l,6,3

al,1,2,8,6,7
al,3,4,5,8

esize,5
kscon,1,4,1,8,0.75  !mesh near crack tip
amesh,1
esize,10
amesh,2
finish


/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,x,10,100
nsel,r,loc,y,0
d,all,uy,0
nsel,all
nsel,s,loc,y,0,250
nsel,r,loc,x,0
d,all,ux,0
nsel,all

*get,nn,node,0,count  !quadratic thermal distribution
 *do,i,1,nn
  tt=0.01*nx(i)*nx(i)
  bf,i,temp,tt
 *enddo
allsel

nsel,s,loc,x,10
nsel,r,loc,y,0
cm,crack1,node

cint,new,1
cint,type,sifs      ! Calculate stress intensity factor
cint,ctnc,crack1 !crack ID
cint,ncon,4      !number of contours
cint,symm,on  !symmetry on
```

```
cint,norm,0,2
cint,list
allsel,all
solve
finish

/out,scratch
/post1
prcint,1,,k1

*get,k1_1,cint,1,ctip,node(10,0,0),,1,dtype,k1
*get,k1_2,cint,1,ctip,node(10,0,0),,2,dtype,k1
*get,k1_3,cint,1,ctip,node(10,0,0),,3,dtype,k1
*get,k1_4,cint,1,ctip,node(10,0,0),,4,dtype,k1

k1=(k1_2+k1_3+k1_4)/3
*stat,k1
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,1
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/1 )
SAVE,TABLE_1
FINI
/CLEAR,NOSTART

/com,************************************************************
/com, Using J integral Calculation


/prep7

e=207000      !youngs modulus
nu=0.3       !poissons ratio
alp=1.35e-5      !coefficient of thermal expansion
k0=514.3      !critical stress intensity factor from nafems manual


et,1,plane183,,,0  !plane183 element

mp,ex,1,e
mp,nuxy,1,nu
mp,alpx,1,alp
mp,reft,1,0

k,1,10,0
k,2,100,0
k,3,100,50
k,4,100,250
k,5,0,250
k,6,0,50
k,7,0,0

l,1,2
*rep,6,1,1
l,7,1
l,6,3

al,1,2,8,6,7
al,3,4,5,8

esize,5
kscon,1,4,1,8,0.75 !mesh near crack tip
amesh,1
esize,10
amesh,2
finish
```

```
/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,x,10,100
nsel,r,loc,y,0
d,all,uy,0
nsel,all
nsel,s,loc,y,0,250
nsel,r,loc,x,0
d,all,ux,0
nsel,all

*get,nn,node,0,count  !quadratic thermal distribution
 *do,i,1,nn
  tt=0.01*nx(i)*nx(i)
  bf,i,temp,tt
 *enddo
allsel

nsel,s,loc,x,10
nsel,r,loc,y,0
cm,crack1,node

cint,new,1
cint,ctnc,crack1 !crack ID
cint,ncon,4      !number of contours
cint,symm,on  !symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
finish

/out,scratch
/post1
prcint,1,,

*get,j1,cint,1,ctip,node(10,0,0),,1,,
*get,j2,cint,1,ctip,node(10,0,0),,2,,
*get,j3,cint,1,ctip,node(10,0,0),,3,,
*get,j4,cint,1,ctip,node(10,0,0),,4,,

j_avg=(abs(j1)+abs(j2)+abs(j3)+abs(j4))/4
con2 = e
k1 = ((con2*j_avg)**0.5)
*stat,k1
norm_sif=k1/k0
/out,
*stat,norm_sif


*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,1
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/1 )
SAVE,TABLE_2



/NOPR
/COM
/OUT,vmr020-t1b-183,vrt
/COM,------------------- vmr020-t1b-183 RESULTS COMPARISON ---------------------
/COM,
/COM,              |   TARGET   |   MECHANICAL APDL   |   RATIO
/COM,
RESUME,TABLE_1
```

```
/COM,USING STRESS INTENSITY FACTOR CALCULATION
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
RESUME,TABLE_2
/COM,USING J-INTEGRAL APPROACH
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
/COM,-------------------------------------------------------------------------------


/OUT
FINISH
*list,vmr020-t1b-183,vrt
```

VM-R020-t2a 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr020-t2a-183
/title,vmr020-t2a-183,Edge cracked plate with uniform tensile stress
/com,
/com, Problem is taken from NAFEMS Publication
/com, "2D Test Cases in Linear Elastic Fracture Mechanics"
/com, Test case 2.1
/com,
/com, Reference: Rooke D P and Cartwright D J : Compendium
/com, of stress intensity factors, HMSO, London, England (1976)
/com,
/com, **********************************************************
/com, Stress Intensity Factor Calculation using Interaction
/com, Integral Approach
/prep7

E=207000         ! youngs modulus
NU=0.3           ! poissons ratio
sig=100           ! surface load
pi=3.141593
a=10       !crack length

et,1,plane183       ! Plane183 element
keyopt,1,3,2        ! Plane strain element
mp,ex,1,e
mp,nuxy,1,nu

k,1,-10,,
k,2,,,
k,3,10,0
k,4,10,10
k,5,-10,10

l,1,2
*rep,4,1,1
l,5,1
al,1,2,3,4,5

esize,10
kscon,2,4,1,4,0.75   ! crack tip elements
amesh,1
finish

/solu
autots,on
```

```
nsubst,10
outres,all,all
nsel,s,loc,y,0
nsel,r,loc,x,0,10
d,all,uy,0
nsel,r,loc,x,10
d,all,ux,0
nsel,all
lsel,s,line,,4
sfl,all,press,-sig
lsel,all

nsel,s,loc,y,0
nsel,r,loc,x,0
cm,crack1,node         ! define the crack tip node component
nsel,all
cint,new,1
cint,type,sifs         ! calculate stress intensity factors
cint,ctnc,crack1       ! crack ID
cint,ncon,3            ! number of countours
cint,symm,on           ! symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
prcint,1,,k1
*get,k_1,cint,1,ctip,node(0,0,0),,1,dtype,k1
*get,k_2,cint,1,ctip,node(0,0,0),,2,dtype,k1
*get,k_3,cint,1,ctip,node(0,0,0),,3,dtype,k1
con1 = ((pi*a)**0.5)
k1=(k_1+k_2+k_3)/3
k0=(sig*con1)
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,3
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/3 )
SAVE,TABLE_1
FINI
/CLEAR,NOSTART

/com,************************************************************
/com, Using J integral Calculation

/prep7

E=207000         ! youngs modulus
NU=0.3           ! poissons ratio
sig=100           ! surface load
pi=3.141593
a=10       !crack length

et,1,plane183       ! Plane183 element
keyopt,1,3,2        ! Plane strain element
mp,ex,1,e
mp,nuxy,1,nu


k,1,-10,,
k,2,,,
k,3,10,0
k,4,10,10
k,5,-10,10
```

```
l,1,2
*rep,4,1,1
l,5,1
al,1,2,3,4,5


esize,10
kscon,2,4,1,4,0.75   ! crack tip elements
amesh,1

fini


/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0
nsel,r,loc,x,0,10
d,all,uy,0
nsel,r,loc,x,10
d,all,ux,0
nsel,all
lsel,s,line,,4
sfl,all,press,-sig
lsel,all

nsel,s,loc,y,0
nsel,r,loc,x,0
cm,crack1,node        ! define the crack tip node component
nsel,all
cint,new,1
cint,ctnc,crack1      ! crack ID
cint,ncon,3           ! number of countours
cint,symm,on          ! symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
prcint,1                     ! Get the J1,J2,J3 values
*get,j1,cint,1,ctip,node(0,0,0),,1,,
*get,j2,cint,1,ctip,node(0,0,0),,2,,
*get,j3,cint,1,ctip,node(0,0,0),,3,,
jc1 =(abs(j1)+abs(j2)+abs(j3))/3
*stat,jc1
con1 = ((pi*a)**0.5)
con2 = E/(1-(nu*nu))
K1 = ((con2*jc1)**0.5)
k0=(sig*con1)
norm_sif = K1/k0
/out,
*status,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,3
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/3 )
SAVE,TABLE_2

/NOPR
/COM
/OUT,vmr020-t2a-183,vrt
/COM,------------------- vmr020-t2a-183 RESULTS COMPARISON ---------------------
/COM,
/COM,              |   TARGET   |   MECHANICAL APDL   |   RATIO
```

```
/COM,
RESUME,TABLE_1
/COM,USING STRESS INTENSITY FACTOR CALCULATION
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
RESUME,TABLE_2
/COM,USING J-INTEGRAL APPROACH
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
/COM,--------------------------------------------------------------------------------

/OUT
FINISH
*list,vmr020-t2a-183,vrt
```

VM-R020-t2b 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr020-t2b-183
/title,vmr020-t2b-183,Edge cracked plate with uniform normal displacement
/com,
/com, Problem is taken from NAFEMS Publication
/com, "2D Test Cases in Linear Elastic Fracture Mechanics"
/com, Test case 2.2
/com,
/com, Reference: Rooke D P and Cartwright D J : Compendium
/com, of stress intensity factors, HMSO, London, England (1976)
/com,
/com, ***********************************************************
/com, Stress Intensity Factor Calculation using Interaction
/com, Integral Approach
/prep7

E=207000         ! youngs modulus
NU=0.3           ! poissons ratio
sigma=124.02
pi=3.141593
a=10       ! crack length

et,1,plane183,,,2  ! plane183 element, plane strain

mp,ex,1,e
mp,nuxy,1,nu

k,1,-10,,
k,2,,,
k,3,10,0
k,4,10,10
k,5,-10,10

l,1,2
*rep,4,1,1
l,5,1
al,1,2,3,4,5

esize,10
kscon,2,4,1,4,0.75   ! crack tip elements
amesh,1
fini

/solu
```

```
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0
nsel,r,loc,x,0,10
d,all,uy,0
nsel,r,loc,x,10
d,all,ux,0
nsel,all

nsel,s,loc,y,10
nsel,r,loc,x,-10,10
d,all,uy,0.01
nsel,all

nsel,s,loc,y,0
nsel,r,loc,x,0
cm,crack1,node        ! define the crack tip node component

cint,new,1
cint,type,sifs        ! calculate stress intensity factors
cint,ctnc,crack1      ! crack ID
cint,ncon,3           ! number of countours
cint,symm,on          ! symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
prcint,1,,k1
*get,k_1,cint,1,ctip,node(0,0,0),,1,dtype,k1
*get,k_2,cint,1,ctip,node(0,0,0),,2,dtype,k1
*get,k_3,cint,1,ctip,node(0,0,0),,3,dtype,k1
con1 = ((pi*a)**0.5)
k1=(k_2+k_3)/2
k0=(sigma*con1)
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,1.04
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/1.04 )
SAVE,TABLE_1
FINI
/CLEAR,NOSTART

/com,*************************************************************
/com, Using J integral Calculation

/prep7

E=207000         ! youngs modulus
NU=0.3           ! poissons ratio
sigma=124.02
pi=3.141593
a=10       ! crack length

et,1,plane183,,,2  ! plane183 element, plane strain

mp,ex,1,e
mp,nuxy,1,nu


k,1,-10,,
k,2,,,
```

```
k,3,10,0
k,4,10,10
k,5,-10,10

l,1,2
*rep,4,1,1
l,5,1
al,1,2,3,4,5


esize,10
kscon,2,4,1,4,0.75   ! crack tip elements
amesh,1
fini


/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0
nsel,r,loc,x,0,10
d,all,uy,0
nsel,r,loc,x,10
d,all,ux,0
nsel,all

nsel,s,loc,y,10
nsel,r,loc,x,-10,10
d,all,uy,0.01
nsel,all

nsel,s,loc,y,0
nsel,r,loc,x,0
cm,crack1,node        ! define the crack tip node component

cint,new,1
cint,ctnc,crack1      ! crack ID
cint,ncon,3           ! number of countours
cint,symm,on          ! symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
prcint,1                       ! Get the J1,J2,J3 values
*get,j1,cint,1,ctip,node(0,0,0),,1,,
*get,j2,cint,1,ctip,node(0,0,0),,2,,
*get,j3,cint,1,ctip,node(0,0,0),,3,,
jc1 =(abs(j1)+abs(j2)+abs(j3))/3
*stat,jc1
con1 = ((pi*a)**0.5)
con2 = E/(1-(nu*nu))
K1 = ((con2*jc1)**0.5)
k0=(sigma*con1)
norm_sif = K1/k0
/out,
*status,norm_sif


*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,1.04
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/1.04 )
SAVE,TABLE_2
/NOPR
/COM
```

```
/OUT,vmr020-t2b-183,vrt
/COM,------------------- vmr020-t2b-183 RESULTS COMPARISON ---------------------
/COM,
/COM,              |   TARGET   |   MECHANICAL APDL   |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING STRESS INTENSITY FACTOR CALCULATION
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
RESUME,TABLE_2
/COM,USING J-INTEGRAL APPROACH
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
/COM,-----------------------------------------------------------------------------
/OUT
FINISH
*list,vmr020-t2b-183,vrt
```

VM-R020-t3a 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr020-t3a-183
/title,vmr020-t3a-183,Angle crack plate embedded in a plate (Uniaxial tension)
/com,
/com, Problem is taken from NAFEMS Publication
/com, "2D Test Cases in Linear Elastic Fracture Mechanics"
/com, Test case 3.1, crack angle = 22.5
/com,
/com, Reference: Rooke D P and Cartwright D J : Compendium
/com, of stress intensity factors, HMSO, London, England (1976)
/com,
/com, **********************************************************
/com, Stress Intensity Factor Calculation using Interaction
/com, Integral Approach
/prep7

e=207000      !youngs modulus
nu=0.3       !poissons ratio
sig=100       !surface load
a=25       !length of the crack
pi=3.141593

et,1,plane183,,,2 !plane183 elements, plane strain

mp,ex,1,e
mp,nuxy,1,nu

k,1,,,
k,2,40.433,,
k,3,100,,
k,4,100,62.5
k,5,50,62.5
k,6,40.433,39.404
k,7,50,62.5
k,8,,62.5
k,9,,125
k,10,59.567,125
k,11,59.567,85.596
k,12,100,125

l,1,2
```

```
l,2,6
l,6,7
l,7,8
l,8,1

al,1,2,3,4,5

l,2,3
l,3,4
l,4,5
l,5,6

al,6,7,8,9,2

l,4,12
l,12,10
l,10,11
l,11,5

al,10,11,12,13,8

l,10,9
l,9,8
l,7,11

al,14,15,4,16,12

kscon,6,5,1,8,0.75 ! crack tip elements
kscon,11,5,1,8,0.75 ! crack tip elements

esize,4
amesh,1
amesh,2
amesh,3
amesh,4
cskp,11,0,6,5,9
cskp,12,0,11,5,3
csys,0

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0
nsel,r,loc,x,0,100
d,all,uy,0
nsel,r,loc,x,100
d,all,ux,0
nsel,all
lsel,s,line,,14
lsel,a,line,,11
sfl,all,press,-sig
lsel,all

nsel,s,loc,y,39.404
nsel,r,loc,x,40.433
cm,crack1,node      ! define the crack tip node component

nsel,s,loc,y,85.596
nsel,r,loc,x,59.567
cm,crack2,node      ! define the crack tip node component

cint,new,1
cint,type,sifs          ! calculate stress intensity factor
cint,ctnc,crack1       ! crack ID
cint,ncon,5           ! number of countours
cint,symm,off           ! symmetry off
cint,norm,12,2
cint,list
allsel,all

cint,new,2
```

```
cint,type,sifs          ! calculate stress intensity factor
cint,ctnc,crack2       ! crack ID
cint,ncon,5            ! number of countours
cint,symm,off          ! symmetry off
cint,norm,11,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
prcint,2,,k1
csys,0
rsys,0
*get,k1_1,cint,2,ctip,node(59.567,85.596,0),,1,dtype,k1
*get,k1_2,cint,2,ctip,node(59.567,85.596,0),,2,dtype,k1
*get,k1_3,cint,2,ctip,node(59.567,85.596,0),,3,dtype,k1
*get,k1_4,cint,2,ctip,node(59.567,85.596,0),,4,dtype,k1
*get,k1_5,cint,2,ctip,node(59.567,85.596,0),,5,dtype,k1

con1 = ((pi*a)**0.5)
k1=(k1_2+k1_3+k1_4+k1_5)/4
*stat,k1
k0=(sig*con1)
norm_k1=k1/k0
*stat,norm_k1

prcint,2,,k2
*get,k2_1,cint,2,ctip,node(59.567,85.596,0),,1,dtype,k2
*get,k2_2,cint,2,ctip,node(59.567,85.596,0),,2,dtype,k2
*get,k2_3,cint,2,ctip,node(59.567,85.596,0),,3,dtype,k2
*get,k2_4,cint,2,ctip,node(59.567,85.596,0),,4,dtype,k2
*get,k2_5,cint,2,ctip,node(59.567,85.596,0),,5,dtype,k2

con1 = ((pi*a)**0.5)
k2=(k2_2+k2_3+k2_4+k2_5)/4
k0=(sig*con1)
norm_k2=k2/k0
*stat,norm_k2
/out,

*DIM,LABEL,CHAR,2,5
*DIM,VALUE,,2,3
LABEL(1,1) = 'KI','KII'
*VFILL,VALUE(1,1),DATA,0.19,0.405
*VFILL,VALUE(1,2),DATA,norm_k1,norm_k2
*VFILL,VALUE(1,3),DATA,ABS(norm_k1/0.190 ),ABS(norm_k2/0.405 )
SAVE,TABLE_1


/NOPR
/COM
/OUT,vmr020-t3a-183,vrt
/COM,------------------- vmr020-t3a-183 RESULTS COMPARISON ---------------------
/COM,
/COM,              |   TARGET   |   MECHANICAL APDL   |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING STRESS INTENSITY FACTOR CALCULATION
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A4,A4'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,-----------------------------------------------------------------------------
/OUT
FINISH
*list,vmr020-t3a-183,vrt
```

VM-R020-t3b 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr020-t3b-183
/title,vmr020-t3b-183,Angle crack plate embedded in a plate (Uniaxial tension)
/com,
/com, Problem is taken from NAFEMS Publication
/com, "2D Test Cases in Linear Elastic Fracture Mechanics"
/com, Test case 3.2, crack angle = 67.5
/com,
/com, Reference: Rooke D P and Cartwright D J : Compendium
/com, of stress intensity factors, HMSO, London, England (1976)
/com,
/com, **********************************************************
/com, Stress Intensity Factor Calculation using Interaction
/com, Integral Approach
/prep7

e=207000         !youngs modulus
nu=0.3          !poissons ratio
sig=100          !surface load
a=25          !crack length
pi=3.141593

et,1,plane183,,,2 !plane183 elements, plane strain

mp,ex,1,e
mp,nuxy,1,nu

k,1,,,
k,2,50,,
k,3,100,,
k,4,100,72.069
k,5,73.0969,72.069
k,6,50,62.5
k,7,26.9031,52.933
k,8,,52.933
k,9,,125
k,10,50,125
k,11,50,62.5
k,12,100,125

l,1,2
l,2,6
l,6,7
l,7,8
l,8,1

al,1,2,3,4,5

l,2,3
l,3,4
l,4,5
l,5,6

al,6,7,8,9,2

l,4,12
l,12,10
l,10,11
l,11,5

al,10,11,12,13,8

l,10,9
l,9,8
l,7,11

al,14,15,4,16,12
```

```
kscon,5,4,1,8,0.75 !crack tip elements
kscon,7,4,1,8,0.75

esize,4
amesh,1
amesh,2
amesh,3
amesh,4
cskp,11,0,7,6,9
cskp,12,0,5,6,3
csys,0

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0
nsel,r,loc,x,0,100
d,all,uy,0
nsel,r,loc,x,100
d,all,ux,0
nsel,all
lsel,s,line,,14
lsel,a,line,,11
sfl,all,press,-sig
lsel,all

nsel,s,loc,y,52.933
nsel,r,loc,x,26.9031
cm,crack1,node      ! define the crack tip node component

nsel,s,loc,y,72.069
nsel,r,loc,x,73.0969
cm,crack2,node      ! define the crack tip node component

cint,new,1
cint,type,sifs          ! calculate stress intensity factors
cint,ctnc,crack1       ! crack ID
cint,ncon,6            ! number of countours
cint,symm,off           ! symmetry off
cint,norm,12,2
cint,list
allsel,all

cint,new,2
cint,type,sifs          ! calculate stress intensity factor
cint,ctnc,crack2       ! crack ID
cint,ncon,6            ! number of countours
cint,symm,off          ! symmetry off
cint,norm,11,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
csys,0
rsys,0
prcint,2,,k1
*get,k1_1,cint,2,ctip,node(73.0969,72.069,0),,1,dtype,k1
*get,k1_2,cint,2,ctip,node(73.0969,72.069,0),,2,dtype,k1
*get,k1_3,cint,2,ctip,node(73.0969,72.069,0),,3,dtype,k1
*get,k1_4,cint,2,ctip,node(73.0969,72.069,0),,4,dtype,k1
*get,k1_5,cint,2,ctip,node(73.0969,72.069,0),,5,dtype,k1
*get,k1_6,cint,2,ctip,node(73.0969,72.069,0),,6,dtype,k1
con1 = ((pi*a)**0.5)
k1=(k1_2+k1_3+k1_4+k1_5+k1_6)/5
k0=(sig*con1)
norm_k1=k1/k0
*stat,norm_k1
```

```
prcint,2,,k2
*get,k2_1,cint,2,ctip,node(73.0969,72.069,0),,1,dtype,k2
*get,k2_2,cint,2,ctip,node(73.0969,72.069,0),,2,dtype,k2
*get,k2_3,cint,2,ctip,node(73.0969,72.069,0),,3,dtype,k2
*get,k2_4,cint,2,ctip,node(73.0969,72.069,0),,4,dtype,k2
*get,k2_5,cint,2,ctip,node(73.0969,72.069,0),,5,dtype,k2
*get,k2_6,cint,2,ctip,node(73.0969,72.069,0),,6,dtype,k2
con1 = ((pi*a)**0.5)
k2=(k2_2+k2_3+k2_4+k2_5+k2_6)/5
k0=(sig*con1)
norm_k2=k2/k0
*stat,norm_k2

/out,

*DIM,LABEL,CHAR,2,5
*DIM,VALUE,,2,3
LABEL(1,1) = 'KI', 'KII'
*VFILL,VALUE(1,1),DATA,1.03,0.370
*VFILL,VALUE(1,2),DATA,norm_k1,norm_k2
*VFILL,VALUE(1,3),DATA,ABS(norm_k1/1.03 ),ABS(norm_k2/0.370 )
SAVE,TABLE_1


/NOPR
/COM
/OUT,vmr020-t3b-183,vrt
/COM,------------------- vmr020-t3b-183 RESULTS COMPARISON ---------------------
/COM,
/COM,              |   TARGET   |   MECHANICAL APDL   |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING STRESS INTENSITY FACTOR CALCULATION
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A4,A4'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,-----------------------------------------------------------------------------
/OUT
FINISH
*list,vmr020-t3b-183,vrt
```

VM-R020-t3c 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr020-t3c-183
/title,vmr020-t3c-183,Angle crack plate embedded in a plate (Uniaxial tension)
/com,
/com, Problem is taken from NAFEMS Publication
/com, "2D Test Cases in Linear Elastic Fracture Mechanics"
/com, Test case 3.3, crack angle = 90
/com,
/com, Reference: Rooke D P and Cartwright D J : Compendium
/com, of stress intensity factors, HMSO, London, England (1976)
/com,
/com, **********************************************************
/com, Stress Intensity Factor Calculation using Interaction
/com, Integral Approach
/prep7

e=207000          !youngs modulus
nu=0.3           !poissons ratio
sig=100           !suface load
pi=3.141593
a=25           !crack length

et,1,plane183,,,2     !plane183 elements, plane strain
```

```
mp,ex,1,e
mp,nuxy,1,nu

k,1,,,
k,2,50,,
k,3,100,,
k,4,100,62.5
k,5,75,62.5,
k,6,50,62.5
k,7,25,62.5
k,8,,62.5
k,9,,125
k,10,50,125
k,11,50,62.5
k,12,100,125

l,1,2
l,2,6
l,6,7
l,7,8
l,8,1

al,1,2,3,4,5

l,2,3
l,3,4
l,4,5
l,5,6

al,6,7,8,9,2

l,4,12
l,12,10
l,10,11
l,11,5

al,10,11,12,13,8

l,10,9
l,9,8
l,7,11

al,14,15,4,16,12

kscon,5,5,1,4,0.75 !crack tip elements
kscon,7,5,1,4,0.75

lsel,s,loc,y,0
lsel,a,loc,y,62.5
lsel,a,loc,y,125
lesize,all,,,5
lsel,all
lsel,s,loc,x,0
lsel,a,loc,x,50
lsel,a,loc,x,100
lesize,all,,,12.5
lsel,all

cskp,11,0,7,6,9
cskp,12,0,5,6,3
csys,0

amesh,1
amesh,2
amesh,3
amesh,4

/solu
autots,on
nsubst,10
outres,all,all
```

```
nsel,s,loc,y,0
nsel,r,loc,x,0,100
d,all,uy,0
nsel,r,loc,x,100
d,all,ux,0
nsel,all
lsel,s,line,,14
lsel,a,line,,11
sfl,all,press,-sig
lsel,all

nsel,s,loc,y,62.5
nsel,r,loc,x,25
cm,crack1,node      ! define the crack tip node component

nsel,s,loc,y,62.5
nsel,r,loc,x,75
cm,crack2,node      ! define the crack tip node component

cint,new,1
cint,type,sifs          ! calculate stress intensity factor
cint,ctnc,crack1       ! crack ID
cint,ncon,6           ! number of countours
cint,symm,off           ! symmetry off
cint,norm,12,2
cint,list
allsel,all

cint,new,2
cint,type,sifs          ! calculate stress intensity factor
cint,ctnc,crack2       ! crack ID
cint,ncon,6            ! number of countours
cint,symm,off          ! symmetry off
cint,norm,11,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
prcint,1,,k1
csys,0
rsys,0
*get,k1_1,cint,1,ctip,node(25,62.5,0),,1,dtype,k1
*get,k1_2,cint,1,ctip,node(25,62.5,0),,2,dtype,k1
*get,k1_3,cint,1,ctip,node(25,62.5,0),,3,dtype,k1
*get,k1_4,cint,1,ctip,node(25,62.5,0),,4,dtype,k1
*get,k1_5,cint,1,ctip,node(25,62.5,0),,5,dtype,k1
*get,k1_6,cint,1,ctip,38,,6,dtype,k1

con1 = ((pi*a)**0.5)
k1=(k1_1+k1_2+k1_3+k1_4+k1_5+k1_6)/6
k0=(sig*con1)
norm_sif=k1/k0
*stat,norm_sif

/out,
*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,1.2
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/1.2 )
SAVE,TABLE_1
FINI
/CLEAR,NOSTART


/com,*************************************************************
/com, Using J integral Calculation
```

```
/prep7

e=207000          !youngs modulus
nu=0.3           !poissons ratio
sig=100           !suface load
pi=3.141593
a=25           !crack length

et,1,plane183,,,2     !plane183 elements, plane strain

mp,ex,1,e
mp,nuxy,1,nu

k,1,,,
k,2,50,,
k,3,100,,
k,4,100,62.5
k,5,75,62.5,
k,6,50,62.5
k,7,25,62.5
k,8,,62.5
k,9,,125
k,10,50,125
k,11,50,62.5
k,12,100,125

l,1,2
l,2,6
l,6,7
l,7,8
l,8,1

al,1,2,3,4,5

l,2,3
l,3,4
l,4,5
l,5,6

al,6,7,8,9,2

l,4,12
l,12,10
l,10,11
l,11,5

al,10,11,12,13,8

l,10,9
l,9,8
l,7,11

al,14,15,4,16,12

kscon,5,5,1,4,0.75     !crack tip elemants
kscon,7,5,1,4,0.75

lsel,s,loc,y,0
lsel,a,loc,y,62.5
lsel,a,loc,y,125
lesize,all,,,5
lsel,all
lsel,s,loc,x,0
lsel,a,loc,x,50
lsel,a,loc,x,100
lesize,all,,,12.5
lsel,all

cskp,11,0,7,6,9
cskp,12,0,5,6,3
csys,0
```

```
amesh,1
amesh,2
amesh,3
amesh,4

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0
nsel,r,loc,x,0,100
d,all,uy,0
nsel,r,loc,x,100
d,all,ux,0
nsel,all
lsel,s,line,,14
lsel,a,line,,11
sfl,all,press,-sig
lsel,all

nsel,s,loc,y,62.5
nsel,r,loc,x,25
cm,crack1,node      ! define the crack tip node component

nsel,s,loc,y,62.5
nsel,r,loc,x,75
cm,crack2,node      ! define the crack tip node component

cint,new,1
cint,ctnc,crack1       ! crack ID
cint,ncon,6           ! number of countours
cint,symm,off           ! symmetry off
cint,norm,12,2
cint,list
allsel,all

cint,new,2
cint,ctnc,crack2       ! crack ID
cint,ncon,6            ! number of countours
cint,symm,off          ! symmetry off
cint,norm,11,2
cint,list
allsel,all
solve
fini


/out,scratch
/post1
prcint,1
csys,0
rsys,0
*get,j1,cint,1,ctip,node(25,62.5,0),,1,,
*get,j2,cint,1,ctip,node(25,62.5,0),,2,,
*get,j3,cint,1,ctip,node(25,62.5,0),,3,,
*get,j4,cint,1,ctip,node(25,62.5,0),,4,,
*get,j5,cint,1,ctip,node(25,62.5,0),,5,,
*get,j6,cint,1,ctip,node(25,62.5,0),,6,,

j_avg=(abs(j1)+abs(j2)+abs(j3)+abs(j4)+abs(j5)+abs(j6))/6
*stat,j_avg
con1 = ((pi*a)**0.5)
con2 = E/(1-(nu*nu))
k1 = ((con2*j_avg)**0.5)
k0=(sig*con1)
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
```

```
*VFILL,VALUE(1,1),DATA,1.2
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/1.2 )
SAVE,TABLE_2

/NOPR
/COM
/OUT,vmr020-t3c-183,vrt
/COM,------------------- vmr020-t3c-183 RESULTS COMPARISON ---------------------
/COM,
/COM,               |   TARGET   |   MECHANICAL APDL   |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING STRESS INTENSITY FACTOR CALCULATION
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
RESUME,TABLE_2
/COM,USING J-INTEGRAL APPROACH
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
/COM,-----------------------------------------------------------------------------

/OUT
FINISH
*list,vmr020-t3c-183,vrt
```

VM-R020-t4a 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr020-t4a-183
/title,vmr020-t4a-183,Crack at a hole in a plate (Uniaxial tension)
/com,
/com, Problem is taken from NAFEMS Publication
/com, "2D Test Cases in Linear Elastic Fracture Mechanics"
/com, Test case 4.1
/com,
/com, Reference: Rooke D P and Cartwright D J : Compendium
/com, of stress intensity factors, HMSO, London, England (1976)
/com,
/com, **********************************************************
/com, Stress Intensity Factor Calculation using Interaction
/com, Integral Approach
/prep7

e=207000         !youngs modulus
nu=0.3          !poissons ratio
sig=100          !surface load
a=3              !crack length
pi=3.141593

et,1,plane183,,,0   !plane183 elements

mp,ex,1,e
mp,nuxy,1,nu

k,1,3,0
k,2,10,0
k,3,10,20
k,4,0,20
k,5,0,2.5
k,6,2.5,0
```

```
k,7,10,5
k,8,0,5


l,1,2
l,2,7
l,7,3
l,3,4
l,4,8
l,8,5
csys,2
l,5,6
csys,0
l,6,1
l,7,8

al,1,2,9,6,7,8
al,3,4,5,9

esize,1
amesh,2

kscon,1,0.15,1,4,0.75 !crack tip elements
esize,1
amesh,1
finish

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,x,3,10
nsel,r,loc,y,0
d,all,uy,0
nsel,all
nsel,s,loc,y,2.5,20
nsel,r,loc,x,0
d,all,ux,0
nsel,all
sfl,4,press,-sig

nsel,s,loc,x,3
nsel,r,loc,y,0
cm,crack1,node  !define crack tip node component

cint,new,1
cint,type,sifs      ! calculate stress intensity factor
cint,ctnc,crack1 !crack ID
cint,ncon,4      !number of contours
cint,symm,on  !symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
finish

/out,scratch
/post1
prcint,1
*get,k1_1,cint,1,ctip,node(3,0,0),,1,dtype,k1
*get,k1_2,cint,1,ctip,node(3,0,0),,2,dtype,k1
*get,k1_3,cint,1,ctip,node(3,0,0),,3,dtype,k1

con1 = ((pi*a)**0.5)
k1=(k1_1+k1_2+k1_3)/3
k0=(sig*con1)
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
```

```
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,1.050
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/1.050 )
SAVE,TABLE_1
FINI
/CLEAR,NOSTART


/com,************************************************************
/com, Using J integral Calculation

/prep7

e=207000         !youngs modulus
nu=0.3          !poissons ratio
sig=100          !surface load
a=3              !crack length
pi=3.141593

et,1,plane183,,,0   !plane183 elements

mp,ex,1,e
mp,nuxy,1,nu

k,1,3,0
k,2,10,0
k,3,10,20
k,4,0,20
k,5,0,2.5
k,6,2.5,0
k,7,10,5
k,8,0,5


l,1,2
l,2,7
l,7,3
l,3,4
l,4,8
l,8,5
csys,2
l,5,6
csys,0
l,6,1
l,7,8

al,1,2,9,6,7,8
al,3,4,5,9

esize,1
amesh,2

kscon,1,0.15,1,4,0.75 !crack tip elements
esize,1
amesh,1
finish

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,x,3,10
nsel,r,loc,y,0
d,all,uy,0
nsel,all
nsel,s,loc,y,2.5,20
nsel,r,loc,x,0
d,all,ux,0
nsel,all
sfl,4,press,-sig
```

```
nsel,s,loc,x,3
nsel,r,loc,y,0
cm,crack1,node  !define crack tip node component

cint,new,1
cint,ctnc,crack1 !crack ID
cint,ncon,4  !number of contours
cint,symm,on  !symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
finish

/out,scratch
/post1
prcint,1
*get,j1,cint,1,ctip,node(3,0,0),,1,,,
*get,j2,cint,1,ctip,node(3,0,0),,2,,,
*get,j3,cint,1,ctip,node(3,0,0),,3,,,
*get,j4,cint,1,ctip,node(3,0,0),,4,,,
j_avg=(abs(j1)+abs(j2)+abs(j3)+abs(j4))/4
*stat,j_avg
con1 = ((pi*a)**0.5)
con2 = E
k1 = ((con2*j_avg)**0.5)
k0=(sig*con1)
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,1.050
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/1.050 )
SAVE,TABLE_2


/NOPR
/COM
/OUT,vmr020-t4a-183,vrt
/COM,------------------- vmr020-t4a-183 RESULTS COMPARISON ---------------------
/COM,
/COM,              |   TARGET   |   MECHANICAL APDL   |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING STRESS INTENSITY FACTOR CALCULATION
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
RESUME,TABLE_2
/COM,USING J-INTEGRAL APPROACH
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
/COM,-----------------------------------------------------------------------------

/OUT
FINISH
*list,vmr020-t4a-183,vrt
```

VM-R020-t4b 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr020-t4b-183
/title,vmr020-t4b-183,Crack at a hole in a plate (Uniaxial tension)
/com,
/com, Problem is taken from NAFEMS Publication
/com, "2D Test Cases in Linear Elastic Fracture Mechanics"
/com, Test case 4.2
/com,
/com, Reference: Rooke D P and Cartwright D J : Compendium
/com, of stress intensity factors, HMSO, London, England (1976)
/com,
/com, **********************************************************
/com, Stress Intensity Factor Calculation using Interaction
/com, Integral Approach
/prep7

e=207000     !youngs modulus
nu=0.3      !poissons ratio
sig=100      !surface load
a=3          !crack length
pi=3.141593

et,1,plane183,,,2    !plane183 elements

mp,ex,1,e
mp,nuxy,1,nu

k,1,3,0
k,2,10,0
k,3,10,20
k,4,0,20
k,5,0,2.5
k,6,2.5,0
k,7,10,5
k,8,0,5


l,1,2
l,2,7
l,7,3
l,3,4
l,4,8
l,8,5
csys,2
l,5,6
csys,0
l,6,1
l,7,8

al,1,2,9,6,7,8
al,3,4,5,9

esize,1
amesh,2

kscon,1,0.15,1,4,0.75 !crack tip elements
esize,1
amesh,1
finish

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,x,3,10
nsel,r,loc,y,0
d,all,uy,0
```

```
nsel,all
nsel,s,loc,y,2.5,20
nsel,r,loc,x,0
d,all,ux,0
nsel,all
sfl,4,press,-sig

nsel,s,loc,x,3
nsel,r,loc,y,0
cm,crack1,node  !define crack tip node component

cint,new,1
cint,type,sifs      ! Calculate stress intensity factor
cint,name,crack1 !crack ID
cint,ncon,4      !number of contours
cint,symm,on  !symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
finish

/out,scratch
/post1
prcint,1
*get,k1_1,cint,1,ctip,node(3,0,0),,1,dtype,k1
*get,k1_2,cint,1,ctip,node(3,0,0),,2,dtype,k1
*get,k1_3,cint,1,ctip,node(3,0,0),,3,dtype,k1

con1 = ((pi*a)**0.5)
k1=(k1_1+k1_2+k1_3)/3
k0=(sig*con1)
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,1.050
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/1.050 )
SAVE,TABLE_1
FINI
/CLEAR,NOSTART

/com,*****************************************************************************
/com,*** Using J-Integral Approach

/prep7

e=207000         !youngs modulus
nu=0.3          !poissons ratio
sig=100          !surface load
a=3              !crack length
pi=3.141593

et,1,plane183,,,2   !plane183 elements

mp,ex,1,e
mp,nuxy,1,nu

k,1,3,0
k,2,10,0
k,3,10,20
k,4,0,20
k,5,0,2.5
k,6,2.5,0
k,7,10,5
k,8,0,5
```

```
l,1,2
l,2,7
l,7,3
l,3,4
l,4,8
l,8,5
csys,2
l,5,6
csys,0
l,6,1
l,7,8

al,1,2,9,6,7,8
al,3,4,5,9

esize,1
amesh,2

kscon,1,0.15,1,4,0.75 !crack tip elements
esize,1
amesh,1
finish

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,x,3,10
nsel,r,loc,y,0
d,all,uy,0
nsel,all
nsel,s,loc,y,2.5,20
nsel,r,loc,x,0
d,all,ux,0
nsel,all
sfl,4,press,-sig

nsel,s,loc,x,3
nsel,r,loc,y,0
cm,crack1,node  !define crack tip node components

cint,new,1
cint,name,crack1 !crack ID
cint,ncon,4      !number of contours
cint,symm,on  !symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
finish

/out,scratch
/post1
prcint,1
*get,j1,cint,1,ctip,node(3,0,0),,1,,,
*get,j2,cint,1,ctip,node(3,0,0),,2,,,
*get,j3,cint,1,ctip,node(3,0,0),,3,,,
*get,j4,cint,1,ctip,node(3,0,0),,4,,,
j_avg=(abs(j1)+abs(j2)+abs(j3)+abs(j4))/4
*stat,j_avg
con1 = ((pi*a)**0.5)
con2 = E/(1-(nu*nu))
k1 = ((con2*j_avg)**0.5)
k0=(sig*con1)
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,1.050
```

```
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/1.050 )
SAVE,TABLE_2


/NOPR
/COM
/OUT,vmr020-t4b-183,vrt
/COM,------------------- vmr020-t4b-183 RESULTS COMPARISON ---------------------
/COM,
/COM,             |   TARGET   |   MECHANICAL APDL   |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING STRESS INTENSITY FACTOR CALCULATION
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
RESUME,TABLE_2
/COM,USING J-INTEGRAL APPROACH
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
/COM,
/COM,-----------------------------------------------------------------

/OUT
FINISH
*list,vmr020-t4b-183,vrt
```

VM-R020-t5a 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr020-t5a-183
/title,vmr020-t5a-183,Axisymmetric crack in a bar
/com,
/com, Problem is taken from NAFEMS Publication
/com, "2D Test Cases in Linear Elastic Fracture Mechanics"
/com, Test case 5.0
/com,
/com, Reference: Murakami Y: Stress intensity factor handbook
/com,            Pergamon Press (1987)
/com,
/com, **********************************************************
/com, Stress Intensity Factor Calculation using Interaction
/com, Integral Approach
/prep7

e=207000         !youngs modulus
nu=0.3          !poissons ratio
a=10          !crack length
b=10
sig=100          !sufrace load
r=20          !radius of the bar
pi=3.141593

et,1,plane183,,,1 !plane183 elements, axisymmetric

mp,ex,1,e
mp,nuxy,1,nu

k,1,10,0
k,2,0,0
k,3,0,10
```

```
k,4,0,30
k,5,20,30
k,6,20,10
k,7,20,0

l,1,2
*rep,6,1,1
l,7,1
l,3,6

al,1,2,8,6,7
al,3,4,5,8

esize,1
kscon,1,0.75,1,8,0.75 !crack tip elements
amesh,1
esize,2
amesh,2
allsel
cskp,12,0,3,6,2
csys,0
fini

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,x,0,10
nsel,r,loc,y,0
d,all,uy,0
nsel,all
nsel,s,loc,y,0,30
nsel,r,loc,x,0
d,all,ux,0
nsel,all

lsel,s,line,,4
sfl,all,press,-sig
lsel,all

nsel,s,loc,x,10
nsel,r,loc,y,0
cm,crack1,node  !define crack tip node components

cint,new,1
cint,type,sifs      ! calculate stress intensity factor
cint,ctnc,crack1 !crack ID
cint,ncon,5      !number of contours
cint,symm,on  !symmetry on
cint,norm,12,2
cint,list
allsel,all
solve
finish

/out,scratch
/post1
prcint,1,,k1
*get,k1_1,cint,1,ctip,node(10,0,0),,1,dtype,k1
*get,k1_2,cint,1,ctip,node(10,0,0),,2,dtype,k1
*get,k1_3,cint,1,ctip,node(10,0,0),,3,dtype,k1
*get,k1_4,cint,1,ctip,node(10,0,0),,4,dtype,k1
*get,k1_5,cint,1,ctip,node(10,0,0),,5,dtype,k1

con1 = ((pi*b)**0.5)
P=(sig*pi*r*r)
con2=(pi*b*b)
k1=(k1_2+k1_3+k1_4+k1_5)/4
*stat,k1
k0=P*con1/con2
*stat,k0
norm_sif=k1/k0
```

```
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,0.475
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/0.475 )
SAVE,TABLE_1
FINI
/CLEAR,NOSTART

/com,************************************************************
/com, Using J integral Calculation (plane strain formulation)

/prep7

e=207000         !youngs modulus
nu=0.3          !poissons ratio
a=10          !crack length
b=10
sig=100          !sufrace load
r=20          !radius of the bar
pi=3.141593

et,1,plane183,,,1 !plane183 elements, axisymmetric

mp,ex,1,e
mp,nuxy,1,nu

k,1,10,0
k,2,0,0
k,3,0,10
k,4,0,30
k,5,20,30
k,6,20,10
k,7,20,0

l,1,2
*rep,6,1,1
l,7,1
l,3,6

al,1,2,8,6,7
al,3,4,5,8

esize,1
kscon,1,0.75,1,8,0.75 !crack tip elements
amesh,1
esize,2
amesh,2
allsel
cskp,12,0,3,6,2
csys,0
fini

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,x,0,10
nsel,r,loc,y,0
d,all,uy,0
nsel,all
nsel,s,loc,y,0,30
nsel,r,loc,x,0
d,all,ux,0
nsel,all

lsel,s,line,,4
sfl,all,press,-sig
```

```
lsel,all

nsel,s,loc,x,10
nsel,r,loc,y,0
cm,crack1,node  !define crack tip node component

cint,new,1
cint,ctnc,crack1 !crack ID
cint,ncon,5      !number of contours
cint,symm,on  !symmetry on
cint,norm,12,2
cint,list
allsel,all
solve
finish

/out,scratch
/post1
prcint,1,,
*get,j_1,cint,1,ctip,node(10,0,0),,1,,
*get,j_2,cint,1,ctip,node(10,0,0),,2,,
*get,j_3,cint,1,ctip,node(10,0,0),,3,,
*get,j_4,cint,1,ctip,node(10,0,0),,4,,
*get,j_5,cint,1,ctip,node(10,0,0),,5,,

con1 = ((pi*b)**0.5)
P=(sig*pi*r*r)
con2=(pi*b*b)
j=(abs(j_1)+abs(j_2)+abs(j_3)+abs(j_4)+abs(j_5))/5
*stat,j
con3=e/(1-nu**2) !plane strain formulation
k1=(j*con3)**0.5
k0=P*con1/con2
*stat,k0
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,0.475
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/0.475 )
SAVE,TABLE_2
FINI
/CLEAR,NOSTART

/com,*************************************************************
/com, Using J integral Calculation (plane stress formulation)

/prep7

e=207000         !youngs modulus
nu=0.3          !poissons ratio
a=10          !crack length
b=10
sig=100          !sufrace load
r=20          !radius of the bar
pi=3.141593

et,1,plane183,,,1 !plane183 elements, axisymmetric

mp,ex,1,e
mp,nuxy,1,nu

k,1,10,0
k,2,0,0
k,3,0,10
k,4,0,30
k,5,20,30
k,6,20,10
```

```
k,7,20,0

l,1,2
*rep,6,1,1
l,7,1
l,3,6

al,1,2,8,6,7
al,3,4,5,8

esize,1
kscon,1,0.75,1,8,0.75 !crack tip elements
amesh,1
esize,2
amesh,2
allsel
cskp,12,0,3,6,2
csys,0
fini

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,x,0,10
nsel,r,loc,y,0
d,all,uy,0
nsel,all
nsel,s,loc,y,0,30
nsel,r,loc,x,0
d,all,ux,0
nsel,all

lsel,s,line,,4
sfl,all,press,-sig
lsel,all

nsel,s,loc,x,10
nsel,r,loc,y,0
cm,crack1,node  !define crack tip node components

cint,new,1
cint,ctnc,crack1 !crack ID
cint,ncon,5      !number of contours
cint,symm,on  !symmetry on
cint,norm,12,2
cint,list
allsel,all
solve
finish

/out,scratch
/post1
prcint,1,,
*get,j_1,cint,1,ctip,node(10,0,0),,1,,
*get,j_2,cint,1,ctip,node(10,0,0),,2,,
*get,j_3,cint,1,ctip,node(10,0,0),,3,,
*get,j_4,cint,1,ctip,node(10,0,0),,4,,
*get,j_5,cint,1,ctip,node(10,0,0),,5,,

con1 = ((pi*b)**0.5)
P=(sig*pi*r*r)
con2=(pi*b*b)
j=(abs(j_1)+abs(j_2)+abs(j_3)+abs(j_4)+abs(j_5))/5
*stat,j
con3=e   !plane stress formulation
k1=(j*con3)**0.5
k0=P*con1/con2
*stat,k0
norm_sif=k1/k0
/out,
*stat,norm_sif
```

```
*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,0.475
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/0.475 )
SAVE,TABLE_3


/NOPR
/COM
/OUT,vmr020-t5a-183,vrt
/COM,------------------- vmr020-t5a-183 RESULTS COMPARISON ---------------------
/COM,
/COM,               |   TARGET   |   MECHANICAL APDL   |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING STRESS INTENSITY FACTOR CALCULATION
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
RESUME,TABLE_2
/COM,USING J-INTEGRAL APPROACH - PLANE STRAIN FORMULATION
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
RESUME,TABLE_3
/COM,USING J-INTEGRAL APPROACH - PLANE STRESS FORMULATION
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,-----------------------------------------------------------------------------
/OUT
FINISH
*list,vmr020-t5a-183,vrt
```

VM-R020-t6a 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr020-t6a-183
/title,vmr020-t6a-183,Compact tension specimen
/com,
/com, Problem is taken from NAFEMS Publication
/com, "2D Test Cases in Linear Elastic Fracture Mechanics"
/com, Test case 6.0
/com,
/com, Reference: Murakami Y: Stress intensity factor handbook
/com,            Pergamon Press (1987)
/com,
/com, **********************************************************
/com, Stress Intensity Factor Calculation using Interaction
/com, Integral Approach
/prep7

e=207000         !youngs modulus
nu=.3          !poissons ratio
P=1000          !point load
t=1                 !thickness
w=50                !width
```

```
et,1,plane183,,,2 !plane183 elements, plane strain

mp,ex,1,e
mp,nuxy,1,nu


k,1,,
k,2,25,
k,3,25,6.875
k,4,25,13.75
k,5,25,30
k,6,-37.5,30
k,7,-37.5,13.75
k,8,-37.5,6.875
k,9,-25,6.875
k,10,-25,2
k,11,-18,2
k,12,-18,0
k,13,-25,13.75

l,1,2
*rep,11,1,1
l,12,1
l,9,3
l,7,13
l,13,4


al,1,2,13,9,10,11,12
al,3,15,14,7,8,13
al,4,5,6,14,15

esize,12.5
amesh,2
amesh,3

kscon,1,2,1,4,0.75 !crack tip elements
esize,12.5
amesh,1
fini

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0
nsel,r,loc,x,0,25
d,all,uy,0
nsel,r,loc,x,25
d,all,ux,0
nsel,all

fk,13,fy,P


nsel,s,loc,x,0
nsel,r,loc,y,0
cm,crack1,node  !define crack tip node components

cint,new,1
cint,type,sifs      ! calculate stress intensity factors
cint,name,crack1 !crack ID
cint,ncon,4      !number of contours
cint,symm,on  !symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
```

```
prcint,1
*get,k1_1,cint,1,ctip,node(0,0,0),,1,dtype,k1
*get,k1_2,cint,1,ctip,node(0,0,0),,2,dtype,k1
*get,k1_3,cint,1,ctip,node(0,0,0),,3,dtype,k1
*get,k1_4,cint,1,ctip,node(0,0,0),,4,dtype,k1

k1_avg=(k1_1+k1_2+k1_3+k1_4)/4
k0=P/(t*(w)**0.5)
norm_sif=k1_avg/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,9.659
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/9.659 )
SAVE,TABLE_1
FINI
/CLEAR,NOSTART

/com,************************************************************
/com, Using J integral Calculation

/prep7

e=207000         !youngs modulus
nu=.3          !poissons ratio
P=1000          !point load
t=1                 !thickness
w=50                !width

et,1,plane183,,,2 !plane183 elements, plane strain

mp,ex,1,e
mp,nuxy,1,nu

k,1,,
k,2,25,
k,3,25,6.875
k,4,25,13.75
k,5,25,30
k,6,-37.5,30
k,7,-37.5,13.75
k,8,-37.5,6.875
k,9,-25,6.875
k,10,-25,2
k,11,-18,2
k,12,-18,0
k,13,-25,13.75

l,1,2
*rep,11,1,1
l,12,1
l,9,3
l,7,13
l,13,4


al,1,2,13,9,10,11,12
al,3,15,14,7,8,13
al,4,5,6,14,15

esize,12.5
amesh,2
amesh,3

kscon,1,2,1,4,0.75 !crack tip elements
esize,12.5
amesh,1
fini
```

```
/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0
nsel,r,loc,x,0,25
d,all,uy,0
nsel,r,loc,x,25
d,all,ux,0
nsel,all

fk,13,fy,P


nsel,s,loc,x,0
nsel,r,loc,y,0
cm,crack1,node  !define crack tip node components

cint,new,1
cint,ctnc,crack1 !crack ID
cint,ncon,4      !number of contours
cint,symm,on  !symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
prcint,1
*get,j1,cint,1,ctip,node(0,0,0),,1,,
*get,j2,cint,1,ctip,node(0,0,0),,2,,
*get,j3,cint,1,ctip,node(0,0,0),,3,,
*get,j4,cint,1,ctip,node(0,0,0),,4,,

j_avg=(abs(j1)+abs(j2)+abs(j3)+abs(j4))/4
con2 = E/(1-(nu*nu))
k1 = ((con2*j_avg)**0.5)
k0=P/(t*(w)**0.5)
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,9.659
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/9.659 )
SAVE,TABLE_2


/NOPR
/COM
/OUT,vmr020-t6a-183,vrt
/COM,------------------- vmr020-t6a-183 RESULTS COMPARISON ---------------------
/COM,
/COM,              |   TARGET   |   MECHANICAL APDL   |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING STRESS INTENSITY FACTOR CALCULATION
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
RESUME,TABLE_2
/COM,USING J-INTEGRAL APPROACH
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
```

```
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
/COM,-------------------------------------------------------------------------------

/OUT
FINISH
*list,vmr020-t6a-183,vrt
```

VM-R020-t8a 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr020-t8a-183
/title,vmr020-t8a-183,V-notch crack plate: Uniform tensile stress
/com,
/com, Problem is taken from NAFEMS Publication
/com, "2D Test Cases in Linear Elastic Fracture Mechanics"
/com, Test case 8.1
/com,
/com, Reference: Murakami Y: Stress intensity factor handbook
/com,            Pergamon Press (1987)
/com,
/com, **********************************************************
/com, Stress Intensity Factor Calculation using Interaction
/com, Integral Approach
/prep7

e=207000000         !youngs modulus
nu=0.3          !poissons ratio
a=5              !length of the crack
sig=100          !surface load
pi=3.141593

et,1,plane183,,,2 !plane183 elements, plane strain

mp,ex,1,e
mp,nuxy,1,nu

k,1,25,0
k,2,30,0
k,3,100,0
k,4,250,0
k,5,250,100
k,6,250,250
k,7,0,250
k,8,0,100
k,9,0,25
k,10,100,100

l,1,2
*rep,8,1,1
l,9,1
l,3,10
l,8,10
l,10,5
al,1,2,10,11,8,9
al,3,4,12,10
al,5,6,7,11,12


esize,25
amesh,3
amesh,2
kscon,2,2,1,4,0.75 !crack tip elements
amesh,1
fini
```

```
/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0,250
nsel,r,loc,x,250
d,all,ux,0
nsel,all
nsel,s,loc,x,30,250
nsel,r,loc,y,0
d,all,uy,0
nsel,all

lsel,s,line,,6
sfl,all,press,-sig
lsel,all

nsel,s,loc,x,30
nsel,r,loc,y,0
cm,crack1,node  !define crack tip node components

cint,new,1
cint,type,sifs      ! calculate stress intensity factor
cint,ctnc,crack1 !crack ID
cint,ncon,4      !number of contours
cint,symm,on  !symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
prcint,1
*get,k1_1,cint,1,ctip,node(30,0,0),,1,dtype,k1
*get,k1_2,cint,1,ctip,node(30,0,0),,2,dtype,k1
*get,k1_3,cint,1,ctip,node(30,0,0),,3,dtype,k1
*get,k1_4,cint,1,ctip,node(30,0,0),,4,dtype,k1

con1 = ((pi*a)**0.5)
k1=(k1_1+k1_2+k1_3+k1_4)/4
k0=(sig*con1)
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,2.74
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/2.740 )
SAVE,TABLE_1
FINI
/CLEAR,NOSTART


/com,************************************************************
/com, Using J integral Calculation


/prep7

e=207000000         !youngs modulus
nu=0.3          !poissons ratio
a=5              !length of the crack
sig=100          !surface load
pi=3.141593

et,1,plane183,,,2 !plane183 elements, plane strain
```

```
mp,ex,1,e
mp,nuxy,1,nu

k,1,25,0
k,2,30,0
k,3,100,0
k,4,250,0
k,5,250,100
k,6,250,250
k,7,0,250
k,8,0,100
k,9,0,25
k,10,100,100

l,1,2
*rep,8,1,1
l,9,1
l,3,10
l,8,10
l,10,5
al,1,2,10,11,8,9
al,3,4,12,10
al,5,6,7,11,12


esize,25
amesh,3
amesh,2
kscon,2,2,1,4,0.75 !crack tip elements
amesh,1
fini

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0,250
nsel,r,loc,x,250
d,all,ux,0
nsel,all
nsel,s,loc,x,30,250
nsel,r,loc,y,0
d,all,uy,0
nsel,all

lsel,s,line,,6
sfl,all,press,-sig
lsel,all

nsel,s,loc,x,30
nsel,r,loc,y,0
cm,crack1,node  !define crack tip node components
nsel,all

cint,new,1
cint,ctnc,crack1 !crack ID
cint,ncon,4      !number of contours
cint,symm,on  !symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
prcint,1
*get,j1,cint,1,ctip,node(30,0,0),,1,,
*get,j2,cint,1,ctip,node(30,0,0),,2,,
*get,j3,cint,1,ctip,node(30,0,0),,3,,
*get,j4,cint,1,ctip,node(30,0,0),,4,,
j_avg=(abs(j1)+abs(j2)+abs(j3)+abs(j4))/4
```

```
con1 = ((pi*a)**0.5)
con2 = E/(1-(nu*nu))
k1 = ((con2*j_avg)**0.5)
k0=(sig*con1)
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,2.740
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/2.740 )
SAVE,TABLE_2

/NOPR
/COM
/OUT,vmr020-t8a-183,vrt
/COM,------------------- vmr020-t8a-183 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   MECHANICAL APDL   |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING STRESS INTENSITY FACTOR CALCULATION
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
RESUME,TABLE_2
/COM,USING J-INTEGRAL APPROACH
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F16.3)
/COM,
/COM,
/COM,
/COM,-----------------------------------------------------------------------------

/OUT
FINISH
*list,vmr020-t8a-183,vrt
```

VM-R020-t8b 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr020-t8b-183
/title,vmr020-t8b-183,V-notch crack plate: Uniform normal displacement
/com,
/com, Problem is taken from NAFEMS Publication
/com, "2D Test Cases in Linear Elastic Fracture Mechanics"
/com, Test case 8.2
/com,
/com, Reference: No rference available
/com,
/com,
/com, **********************************************************
/com, Stress Intensity Factor Calculation using Interaction
/com, Integral Approach
/prep7

e=207000000         !youngs modulus
nu=0.3          !poissons ratio
a=5              !crack length
sig=76700
pi=3.141593
```

```
et,1,plane183,,,2 !plane183 elements

mp,ex,1,e
mp,nuxy,1,nu

k,1,25,0
k,2,30,0
k,3,100,0
k,4,250,0
k,5,250,100
k,6,250,250
k,7,0,250
k,8,0,100
k,9,0,25
k,10,100,100

l,1,2
*rep,8,1,1
l,9,1
l,3,10
l,8,10
l,10,5
al,1,2,10,11,8,9
al,3,4,12,10
al,5,6,7,11,12


esize,25
amesh,3
amesh,2
kscon,2,1.4,1,4,0.75 !crack tip elements
amesh,1
fini

/solu
nlgeom,on
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0,250
nsel,r,loc,x,250
d,all,ux,0
nsel,all
nsel,s,loc,x,30,250
nsel,r,loc,y,0
d,all,uy,0
nsel,all
nsel,s,loc,x,0,250
nsel,r,loc,y,250
d,all,uy,0.1
nsel,all

nsel,s,loc,x,30
nsel,r,loc,y,0
cm,crack1,node  !define crack tip node component

cint,new,1
cint,type,sifs      !calculate stress intensity values
cint,name,crack1 !crack ID
cint,ncon,4      !number of contours
cint,symm,on  !symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
prcint,1,,k1
*get,k1_1,cint,1,ctip,node(30,0,0),,1,dtype,k1
*get,k1_2,cint,1,ctip,node(30,0,0),,2,dtype,k1
```

```
*get,k1_3,cint,1,ctip,node(30,0,0),,3,dtype,k1
*get,k1_4,cint,1,ctip,node(30,0,0),,4,dtype,k1

con1 = ((pi*a)**0.5)
k1=(k1_1+k1_2+k1_3+k1_4)/4
k0=(sig*con1)
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,3.226
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/3.226 )
SAVE,TABLE_1
FINI
/CLEAR,NOSTART

/com,*****************************************************************************************
/com, Using J Integral Approach

/prep7

e=207000000         !youngs modulus
nu=0.3          !poissons ratio
a=5              !crack length
sig=76700
pi=3.141593

et,1,plane183,,,2 !plane183 elements

mp,ex,1,e
mp,nuxy,1,nu

k,1,25,0
k,2,30,0
k,3,100,0
k,4,250,0
k,5,250,100
k,6,250,250
k,7,0,250
k,8,0,100
k,9,0,25
k,10,100,100

l,1,2
*rep,8,1,1
l,9,1
l,3,10
l,8,10
l,10,5
al,1,2,10,11,8,9
al,3,4,12,10
al,5,6,7,11,12


esize,25
amesh,3
amesh,2
kscon,2,1.25,1,4,0.75 !crack tip elements
amesh,1
fini

/solu
autots,on
nsubst,10
outres,all,all
nsel,s,loc,y,0,250
nsel,r,loc,x,250
d,all,ux,0
```

```
nsel,all
nsel,s,loc,x,30,250
nsel,r,loc,y,0
d,all,uy,0
nsel,all

nsel,s,loc,x,0,250
nsel,r,loc,y,250
d,all,uy,0.1
nsel,all

nsel,s,loc,x,30
nsel,r,loc,y,0
cm,crack1,node  !define crack tip node component

cint,new,1
cint,name,crack1 !crack ID
cint,ncon,4      !number of contours
cint,symm,on  !symmetry on
cint,norm,0,2
cint,list
allsel,all
solve
fini

/out,scratch
/post1
prcint,1
*get,j1,cint,1,ctip,node(30,0,0),,1,,
*get,j2,cint,1,ctip,node(30,0,0),,2,,
*get,j3,cint,1,ctip,node(30,0,0),,3,,
*get,j4,cint,1,ctip,node(30,0,0),,4,,
j_avg=(abs(j1)+abs(j2)+abs(j3)+abs(j4))/4
con1 = ((pi*a)**0.5)
con2 = E/(1-(nu*nu))
k1 = ((con2*j_avg)**0.5)
k0=(sig*con1)
norm_sif=k1/k0
/out,
*stat,norm_sif

*DIM,LABEL,CHAR,1,5
*DIM,VALUE,,1,3
LABEL(1,1) = 'KI'
*VFILL,VALUE(1,1),DATA,3.226
*VFILL,VALUE(1,2),DATA,norm_sif
*VFILL,VALUE(1,3),DATA,ABS(norm_sif/3.226 )
SAVE,TABLE_2

/NOPR
/COM
/OUT,vmr020-t8b-183,vrt
/COM,------------------- vmr020-t8b-183 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   TARGET   |  MECHANICAL APDL  |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING STRESS INTENSITY FACTOR CALCULATION
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F14.3)
/COM,
/COM,
/COM,
RESUME,TABLE_2
/COM,USING J-INTEGRAL APPROACH
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.3,'  ',F12.3,'   ',1F14.3)
/COM,
/COM,
/COM,
/COM,-----------------------------------------------------------------
```

```
/OUT
FINISH
*list,vmr020-t8b-183,vrt
```

VM-R027-3A 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr3a-181
/TITLE,vmr027-cr3a-181,2D PLANE STRESS-BIAXIAL LOAD SECONDARY CREEP
/COM, REFERENCE: TEST 3(A) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(SECONDARY CREEP)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
ET,1,181,,,
R,1,1,1,1,1,
E,1,2,3,4
E,4,3,5,6
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,
D,ALL,UY,
NSEL,ALL
D,ALL,ROTX
D,ALL,ROTY
D,4,UZ,0
FINISH

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
```

```
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
ESOL,4,1,,EPCR,EQV
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/YRANGE,-160,160
/COLOR,CURVE,RED,1
PLVAR,2
/NOERASE
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/YRANGE,-160,160
/COLOR,CURVE,BLUE,1
PLVAR,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/YRANGE,-160,160
/COLOR,CURVE,GREEN,1
PLVAR,4
/SHOW,CLOSE

/POST1
SET,1,1
*GET,SH1,NODE,3,EPCR,X
*GET,SH11,NODE,3,EPCR,Y
R1=1.00
R11=1.00
SET,2,1
*GET,SH2,NODE,3,EPCR,X
*GET,SH12,NODE,3,EPCR,Y
R2=SH2/0.0135
R12=SH12/(-0.0135)
SET,3,1
*GET,SH3,NODE,3,EPCR,X
*GET,SH13,NODE,3,EPCR,Y
```

```
R3=SH3/(0.135)
R13=SH13/(-0.135)
SET,4,1
*GET,SH4,NODE,3,EPCR,X
*GET,SH14,NODE,3,EPCR,Y
R4=SH4/0.675
R14=SH14/(-0.675)
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,X
*GET,SH15,NODE,3,EPCR,Y
R5=SH5/(1.35)
R15=SH15/(-1.35)
SET,,,,,,,9
*GET,SH6,NODE,3,EPCR,X
*GET,SH16,NODE,3,EPCR,Y
R6=SH6/6.75
R16=SH16/(-6.75)
SET,,,,,,,14
*GET,SH7,NODE,3,EPCR,X
*GET,SH17,NODE,3,EPCR,Y
R7=SH7/13.5
R17=SH17/(-13.5)
SET,,,,,,,54
*GET,SH8,NODE,3,EPCR,X
*GET,SH18,NODE,3,EPCR,Y
R8=SH8/67.5
R18=SH18/(-67.5)
SET,,,,,,,104
*GET,SH9,NODE,3,EPCR,X
*GET,SH19,NODE,3,EPCR,Y
R9=SH9/135.0
R19=SH19/(-135.0)
*DIM,VALUE,,9,6
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,0.0,0.0135,0.135,0.675,1.35,6.75,13.5,67.5,135.0
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
*VFILL,VALUE(1,4),DATA,0.0,-0.0135,-0.135,-0.675,-1.35,-6.75,-13.5,-67.5,-135.0
*VFILL,VALUE(1,5),DATA,SH11,SH12,SH13,SH14,SH15,SH16,SH17,SH18,SH19
*VFILL,VALUE(1,6),DATA,R11,R12,R13,R14,R15,R16,R17,R18,R19
/COM
/COM
/COM,-------------------- vmr027-cr3a-181 RESULTS COMPARISON ----------------------
/COM,
/COM,|   TIME   | TARGETX |   Mechanical APDL  |   RATIO  |  TARGETY |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3), VALUE(1,4),VALUE(1,5),VALUE(1,6)
(1X,A8,'   ',F8.3,'   ',F8.3,'   ',1F16.3,'   ',F13.3,'   ',F8.3,'   ',F13.3)
FINISH


/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR6X ',' ECR6Y '
*VFILL,VALUE1(1,1),DATA,SH9,SH19
*VFILL,VALUE1(1,2),DATA,R9,R19
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr027-','cr3a-181'

/OUT,vmr027-cr3a-181,vrt
/COM
/COM,------------------- vmr027-cr3a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8)
```

```
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr3a-181,vrt
```

VM-R027-3A 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr3a-182
/TITLE,vmr027-cr3a-182,2D PLANE STRESS-BIAXIAL LOAD SECONDARY CREEP
/COM, REFERENCE: TEST 3(A) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(SECONDARY CREEP)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
ET,1,182
KEYOPT,1,1,1
KEYOPT,1,3,0
E,1,2,3,4
E,4,3,5,6
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,
D,ALL,UY,
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
```

```
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
ESOL,4,1,,EPCR,EQV
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/YRANGE,-160,160
/COLOR,CURVE,RED,1
PLVAR,2
/NOERASE
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/YRANGE,-160,160
/COLOR,CURVE,BLUE,1
PLVAR,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/YRANGE,-160,160
/COLOR,CURVE,GREEN,1
PLVAR,4
/SHOW,CLOSE

/POST1
SET,1,1
*GET,SH1,NODE,3,EPCR,X
*GET,SH11,NODE,3,EPCR,Y
R1=1.00
R11=1.00
SET,2,1
*GET,SH2,NODE,3,EPCR,X
*GET,SH12,NODE,3,EPCR,Y
R2=SH2/0.0135
R12=SH12/(-0.0135)
SET,3,1
*GET,SH3,NODE,3,EPCR,X
*GET,SH13,NODE,3,EPCR,Y
R3=SH3/(0.135)
```

```
R13=SH13/(-0.135)
SET,4,1
*GET,SH4,NODE,3,EPCR,X
*GET,SH14,NODE,3,EPCR,Y
R4=SH4/0.675
R14=SH14/(-0.675)
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,X
*GET,SH15,NODE,3,EPCR,Y
R5=SH5/(1.35)
R15=SH15/(-1.35)
SET,,,,,,,9
*GET,SH6,NODE,3,EPCR,X
*GET,SH16,NODE,3,EPCR,Y
R6=SH6/6.75
R16=SH16/(-6.75)
SET,,,,,,,14
*GET,SH7,NODE,3,EPCR,X
*GET,SH17,NODE,3,EPCR,Y
R7=SH7/13.5
R17=SH17/(-13.5)
SET,,,,,,,54
*GET,SH8,NODE,3,EPCR,X
*GET,SH18,NODE,3,EPCR,Y
R8=SH8/67.5
R18=SH18/(-67.5)
SET,,,,,,,104
*GET,SH9,NODE,3,EPCR,X
*GET,SH19,NODE,3,EPCR,Y
R9=SH9/135.0
R19=SH19/(-135.0)
*DIM,VALUE,,9,6
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,0.0,0.0135,0.135,0.675,1.35,6.75,13.5,67.5,135.0
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
*VFILL,VALUE(1,4),DATA,0.0,-0.0135,-0.135,-0.675,-1.35,-6.75,-13.5,-67.5,-135.0
*VFILL,VALUE(1,5),DATA,SH11,SH12,SH13,SH14,SH15,SH16,SH17,SH18,SH19
*VFILL,VALUE(1,6),DATA,R11,R12,R13,R14,R15,R16,R17,R18,R19
/COM
/COM
/COM,-------------------- vmr027-cr3a-182 RESULTS COMPARISON ----------------------
/COM,
/COM,|   TIME    | TARGETX |   Mechanical APDL   |   RATIO   |  TARGETY |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3), VALUE(1,4),VALUE(1,5),VALUE(1,6)
(1X,A8,'   ',F8.3,'   ',F12.3,'   ',1F14.3,'   ',F10.3,'   ',F8.3,'   ',F13.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR6X ',' ECR6Y '
*VFILL,VALUE1(1,1),DATA,SH9,SH19
*VFILL,VALUE1(1,2),DATA,R9,R19
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr027-','cr3a-182'

/OUT,vmr027-cr3a-182,vrt
/COM
/COM,------------------- vmr027-cr3a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-------------------------------------------------------------------
```

```
/OUT

FINISH
*LIST,vmr027-cr3a-182,vrt
```

VM-R027-3A 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr3a-183
/TITLE,vmr027-cr3a-183, 2D PLANE STRESS-BIAXIAL LOAD SECONDARY CREEP
/COM, REFERENCE: TEST 3(A) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(SECONDARY CREEP)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
SAVE
/PREP7
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183
KEYOPT,1,3,0
E,1,2,3,4,5,6,7,8
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,
D,ALL,UY,
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
```

```
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
ESOL,4,1,,EPCR,EQV
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/YRANGE,-160,160
/COLOR,CURVE,RED,1
PLVAR,2
/NOERASE
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/YRANGE,-160,160
/COLOR,CURVE,BLUE,1
PLVAR,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/YRANGE,-160,160
/COLOR,CURVE,GREEN,1
PLVAR,4
/SHOW,CLOSE

/POST1
SET,1,1
*GET,SH1,NODE,3,EPCR,X
*GET,SH11,NODE,3,EPCR,Y
R1=1.00
R11=1.00
SET,2,1
*GET,SH2,NODE,3,EPCR,X
*GET,SH12,NODE,3,EPCR,Y
R2=SH2/0.0135
R12=SH12/(-0.0135)
SET,3,1
*GET,SH3,NODE,3,EPCR,X
*GET,SH13,NODE,3,EPCR,Y
R3=SH3/(0.135)
R13=SH13/(-0.135)
```

```
SET,4,1
*GET,SH4,NODE,3,EPCR,X
*GET,SH14,NODE,3,EPCR,Y
R4=SH4/0.675
R14=SH14/(-0.675)
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,X
*GET,SH15,NODE,3,EPCR,Y
R5=SH5/(1.35)
R15=SH15/(-1.35)
SET,,,,,,,9
*GET,SH6,NODE,3,EPCR,X
*GET,SH16,NODE,3,EPCR,Y
R6=SH6/6.75
R16=SH16/(-6.75)
SET,,,,,,,14
*GET,SH7,NODE,3,EPCR,X
*GET,SH17,NODE,3,EPCR,Y
R7=SH7/13.5
R17=SH17/(-13.5)
SET,,,,,,,54
*GET,SH8,NODE,3,EPCR,X
*GET,SH18,NODE,3,EPCR,Y
R8=SH8/67.5
R18=SH18/(-67.5)
SET,,,,,,,104
*GET,SH9,NODE,3,EPCR,X
*GET,SH19,NODE,3,EPCR,Y
R9=SH9/135.0
R19=SH19/(-135.0)
*DIM,VALUE,,9,6
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,0.0,0.0135,0.135,0.675,1.35,6.75,13.5,67.5,135.0
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
*VFILL,VALUE(1,4),DATA,0.0,-0.0135,-0.135,-0.675,-1.35,-6.75,-13.5,-67.5,-135.0
*VFILL,VALUE(1,5),DATA,SH11,SH12,SH13,SH14,SH15,SH16,SH17,SH18,SH19
*VFILL,VALUE(1,6),DATA,R11,R12,R13,R14,R15,R16,R17,R18,R19
/COM
/COM
/COM,-------------------- vmr027-cr3a-183 RESULTS COMPARISON ----------------------
/COM,
/COM,|   TIME   | TARGETX |   Mechanical APDL  |   RATIO  |  TARGETY |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3), VALUE(1,4),VALUE(1,5),VALUE(1,6)
(1X,A8,'   ',F8.3,'   ',F12.3,'   ',1F14.3,'   ',F10.3,'   ',F8.3,'   ',F13.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR6X ',' ECR6Y '
*VFILL,VALUE1(1,1),DATA,SH9,SH19
*VFILL,VALUE1(1,2),DATA,R9,R19
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr027-','cr3a-183'

/OUT,vmr027-cr3a-183,vrt
/COM
/COM,------------------- vmr027-cr3a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT
```

```
FINISH
*LIST,vmr027-cr3a-183,vrt
```

VM-R027-3A 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr3a-281
/TITLE,vmr027-cr3a-281,2D PLANE STRESS-BIAXIAL LOAD SECONDARY CREEP
/COM, REFERENCE: TEST 3(A) FROM NAFEMS R0027.
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(SECONDARY CREEP)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
N,7,50,0
N,8,100,25
N,9,50,50
N,10,0,25
N,11,100,75
N,12,50,100
N,13,0,75
ET,1,SHELL281,,,
R,1,1,1,1,1,
E,1,2,3,4,7,8,9,10
E,4,3,5,6,9,11,12,13
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,
D,ALL,UY,
NSEL,ALL
D,ALL,UZ
D,ALL,ROTX
D,ALL,ROTY
/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL
/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
```

```
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH
/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
ESOL,4,1,,EPCR,EQV
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/YRANGE,-160,160
/COLOR,CURVE,RED,1
PLVAR,2
/NOERASE
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/YRANGE,-160,160
/COLOR,CURVE,BLUE,1
PLVAR,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/YRANGE,-160,160
/COLOR,CURVE,GREEN,1
PLVAR,4
/SHOW,CLOSE
/POST1
SET,1,1
*GET,SH1,NODE,3,EPCR,X
*GET,SH11,NODE,3,EPCR,Y
R1=1.00
R11=1.00
SET,2,1
*GET,SH2,NODE,3,EPCR,X
*GET,SH12,NODE,3,EPCR,Y
R2=SH2/0.0135
R12=SH12/(-0.0135)
SET,3,1
*GET,SH3,NODE,3,EPCR,X
*GET,SH13,NODE,3,EPCR,Y
```

```
R3=SH3/(0.135)
R13=SH13/(-0.135)
SET,4,1
*GET,SH4,NODE,3,EPCR,X
*GET,SH14,NODE,3,EPCR,Y
R4=SH4/0.675
R14=SH14/(-0.675)
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,X
*GET,SH15,NODE,3,EPCR,Y
R5=SH5/(1.35)
R15=SH15/(-1.35)
SET,,,,,,,9
*GET,SH6,NODE,3,EPCR,X
*GET,SH16,NODE,3,EPCR,Y
R6=SH6/6.75
R16=SH16/(-6.75)
SET,,,,,,,14
*GET,SH7,NODE,3,EPCR,X
*GET,SH17,NODE,3,EPCR,Y
R7=SH7/13.5
R17=SH17/(-13.5)
SET,,,,,,,54
*GET,SH8,NODE,3,EPCR,X
*GET,SH18,NODE,3,EPCR,Y
R8=SH8/67.5
R18=SH18/(-67.5)
SET,,,,,,,104
*GET,SH9,NODE,3,EPCR,X
*GET,SH19,NODE,3,EPCR,Y
R9=SH9/135.0
R19=SH19/(-135.0)
*DIM,VALUE,,9,6
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,0.0,0.0135,0.135,0.675,1.35,6.75,13.5,67.5,135.0
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
*VFILL,VALUE(1,4),DATA,0.0,-0.0135,-0.135,-0.675,-1.35,-6.75,-13.5,-67.5,-135.0
*VFILL,VALUE(1,5),DATA,SH11,SH12,SH13,SH14,SH15,SH16,SH17,SH18,SH19
*VFILL,VALUE(1,6),DATA,R11,R12,R13,R14,R15,R16,R17,R18,R19
/COM
/COM
/COM,-------------------- vmr027-cr3a-281 RESULTS COMPARISON ----------------------
/COM,
/COM,|   TIME   | TARGETX |   Mechanical APDL   |   RATIO  |  TARGETY |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3), VALUE(1,4),VALUE(1,5),VALUE(1,6)
(1X,A8,'   ',F8.3,'   ',F8.3,'   ',1F13.3,'   ',F13.3,'   ',F8.3,'   ',F13.3)
FINISH
/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR6X ',' ECR6Y '
*VFILL,VALUE1(1,1),DATA,SH9,SH19
*VFILL,VALUE1(1,2),DATA,R9,R19
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr027-','cr3a-281'
/OUT,vmr027-cr3a-281,vrt
/COM
/COM,----------------- vmr027-cr3a RESULTS COMPARISON -------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
```

```
FINISH
*LIST,vmr027-cr3a-281,vrt
```

VM-R027-3B 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr3b-181
/TITLE,vmr027-cr3b-181,2D PLANE STRESS-BIAXIAL DISPLACEMENT SECONDARY CREEP
/COM, REFERENCE: TEST 3(B) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(SECONDARY CREEP)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
ET,1,181,,,
R,1,1,1,1,1,
E,1,2,3,4
E,4,3,5,6
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,
D,ALL,UY,
NSEL,ALL
D,ALL,ROTX
D,ALL,ROTY
D,2,UZ,0
FINISH
/SOLU
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,ALL
NSEL,S,LOC,Y,100
D,ALL,UY,-0.1
NSEL,ALL
RATE,ON,ON
TIME,1E-8
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,0.1
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,1.0
/OUTPUT,SCRATCH
SOLVE
```

```
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,5.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,10.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,50.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,5,5,5
TIME,100.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,500.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,100,100,100
TIME,1000
/OUTPUT,SCRATCH
SOLVE
/OUT

/POST26
ESOL,2,1,,S,X
PLVAR,2
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/XRANGE,0,1000
/YRANGE,0,40
FINISH

/POST1
SET,1
*GET,SH1,NODE,3,S,X
R1=SH1/153.85
SET,2
*GET,SH2,NODE,3,S,X
R2=SH2/76.29
SET,3
*GET,SH3,NODE,3,S,X
R3=SH3/43.42
SET,4
*GET,SH4,NODE,3,S,X
R4=SH4/29.11
SET,5
*GET,SH5,NODE,3,S,X
R5=SH5/24.45
SET,6
*GET,SH6,NODE,3,S,X
R6=SH6/16.33
SET,7
*GET,SH7,NODE,3,S,X
R7=SH7/13.78
SET,8
*GET,SH8,NODE,3,S,X
R8=SH8/9.20
```

```
SET,9
*GET,SH9,NODE,3,S,X
R9=SH9/7.73
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,153.85,76.29,43.42,29.11,24.45,16.33,13.78,9.20,7.73
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/COM
/COM
/COM,----------- vmr027-cr3b-181 RESULTS COMPARISON -------------
/COM,
/COM, vmr027-cr3b-181.jpeg RESULTS SHOULD MATCH R0027 NAFEMS MANUAL
/COM, GRAPH RESULTS OF TEST 3(B).
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR6X ',' ECR6Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr027-','cr3b-181'

/OUT,vmr027-cr3b-181,vrt
/COM
/COM,------------------- vmr027-cr3b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr3b-181,vrt
```

VM-R027-3B 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr3b-182
/TITLE,vmr027-cr3b-182, 2D PLANE STRESS-BIAXIAL DISPLACEMENT SECONDARY CREEP
/COM, REFERENCE: TEST 3(B) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(SECONDARY CREEP)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,6
```

```
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
ET,1,182
KEYOPT,1,1,1
KEYOPT,1,3,0
E,1,2,3,4
E,4,3,5,6
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,
D,ALL,UY,
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,ALL
NSEL,S,LOC,Y,100
D,ALL,UY,-0.1
NSEL,ALL
RATE,ON,ON
TIME,1E-8
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,0.1
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,1.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,5.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,10.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,50.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,5,5,5
TIME,100.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,500.0
/OUTPUT,SCRATCH
SOLVE
```

```
/OUT
RATE,ON,ON
NSUBST,100,100,100
TIME,1000
/OUTPUT,SCRATCH
SOLVE
/OUT

/POST26
ESOL,2,1,,S,X
PLVAR,2
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/XRANGE,0,1000
/YRANGE,0,40
FINISH

/POST1
SET,1
*GET,SH1,NODE,3,S,X
R1=SH1/153.85
SET,2
*GET,SH2,NODE,3,S,X
R2=SH2/76.29
SET,3
*GET,SH3,NODE,3,S,X
R3=SH3/43.42
SET,4
*GET,SH4,NODE,3,S,X
R4=SH4/29.11
SET,5
*GET,SH5,NODE,3,S,X
R5=SH5/24.45
SET,6
*GET,SH6,NODE,3,S,X
R6=SH6/16.33
SET,7
*GET,SH7,NODE,3,S,X
R7=SH7/13.78
SET,8
*GET,SH8,NODE,3,S,X
R8=SH8/9.20
SET,9
*GET,SH9,NODE,3,S,X
R9=SH9/7.73
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,153.85,76.29,43.42,29.11,24.45,16.33,13.78,9.20,7.73
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/COM
/COM
/COM,----------- vmr027-cr3b-182 RESULTS COMPARISON -------------
/COM,
/COM, vmr027-cr3b-182.jpeg RESULTS SHOULD MATCH R0027 NAFEMS MANUAL
/COM, GRAPH RESULTS OF TEST 3(B).
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR6X ',' ECR6Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr027-','cr3b-182'
```

```
/OUT,vmr027-cr3b-182,vrt
/COM
/COM,------------------- vmr027-cr3b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr3b-182,vrt
```

VM-R027-3B 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr3b-183
/TITLE,vmr027-cr3b-183,2D PLANE STRESS-BIAXIAL DISPLACEMENT SECONDARY CREEP
/COM, REFERENCE: TEST 3(B) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(SECONDARY CREEP)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183
KEYOPT,1,3,0
E,1,2,3,4,5,6,7,8
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,
D,ALL,UY,
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,ALL
NSEL,S,LOC,Y,100
D,ALL,UY,-0.1
NSEL,ALL
RATE,ON,ON
TIME,1E-8
/OUTPUT,SCRATCH
SOLVE
```

```
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,0.1
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,1.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,5.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,10.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,50.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,5,5,5
TIME,100.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,500.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,100,100,100
TIME,1000
/OUTPUT,SCRATCH
SOLVE
/OUT

/POST26
ESOL,2,1,,S,X
PLVAR,2
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/XRANGE,0,1000
/YRANGE,0,40
FINISH

/POST1
SET,1
*GET,SH1,NODE,3,S,X
R1=SH1/153.85
SET,2
*GET,SH2,NODE,3,S,X
R2=SH2/76.29
SET,3
*GET,SH3,NODE,3,S,X
R3=SH3/43.42
SET,4
*GET,SH4,NODE,3,S,X
R4=SH4/29.11
```

```
SET,5
*GET,SH5,NODE,3,S,X
R5=SH5/24.45
SET,6
*GET,SH6,NODE,3,S,X
R6=SH6/16.33
SET,7
*GET,SH7,NODE,3,S,X
R7=SH7/13.78
SET,8
*GET,SH8,NODE,3,S,X
R8=SH8/9.20
SET,9
*GET,SH9,NODE,3,S,X
R9=SH9/7.73
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,153.85,76.29,43.42,29.11,24.45,16.33,13.78,9.20,7.73
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/COM
/COM
/COM,----------- vmr027-cr3b-183 RESULTS COMPARISON -------------
/COM,
/COM, vmr027-cr3b-183.jpeg RESULTS SHOULD MATCH R0027 NAFEMS MANUAL
/COM, GRAPH RESULTS OF TEST 3(B).
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'    ',F8.3,'    ',F13.3,'    ',1F13.3,'    ')
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR6X ',' ECR6Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr027-','cr3b-183'

/OUT,vmr027-cr3b-183,vrt
/COM
/COM,------------------- vmr027-cr3b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL    |    RATIO   |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr3b-183,vrt
```

VM-R027-3B 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr3b-281
/TITLE,vmr027-cr3b-281,2D PLANE STRESS-BIAXIAL DISPLACEMENT SECONDARY CREEP
/COM, REFERENCE: TEST 3(B) FROM NAFEMS R0027.
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(SECONDARY CREEP)***
*SET,C1,3.125E-14
```

```
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
N,7,50,0
N,8,100,25
N,9,50,50
N,10,0,25
N,11,100,75
N,12,50,100
N,13,0,75
ET,1,SHELL281,,,
R,1,1,1,1,1,
E,1,2,3,4,7,8,9,10
E,4,3,5,6,9,11,12,13
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,
D,ALL,UY,
NSEL,ALL
D,ALL,ROTX
D,ALL,ROTY
D,9,UZ,0
FINISH
/SOLU
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,ALL
NSEL,S,LOC,Y,100
D,ALL,UY,-0.1
NSEL,ALL
RATE,ON,ON
TIME,1E-8
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,0.1
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,1.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,5.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,10.0
```

```
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,50.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,5,5,5
TIME,100.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,10,10,10
TIME,500.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,100,100,100
TIME,1000
/OUTPUT,SCRATCH
SOLVE
/OUT
/POST26
ESOL,2,1,,S,X
PLVAR,2
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/XRANGE,0,1000
/YRANGE,0,40
FINISH
/POST1
SET,1
*GET,SH1,NODE,3,S,X
R1=SH1/153.85
SET,2
*GET,SH2,NODE,3,S,X
R2=SH2/76.29
SET,3
*GET,SH3,NODE,3,S,X
R3=SH3/43.42
SET,4
*GET,SH4,NODE,3,S,X
R4=SH4/29.11
SET,5
*GET,SH5,NODE,3,S,X
R5=SH5/24.45
SET,6
*GET,SH6,NODE,3,S,X
R6=SH6/16.33
SET,7
*GET,SH7,NODE,3,S,X
R7=SH7/13.78
SET,8
*GET,SH8,NODE,3,S,X
R8=SH8/9.20
SET,9
*GET,SH9,NODE,3,S,X
R9=SH9/7.73
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,153.85,76.29,43.42,29.11,24.45,16.33,13.78,9.20,7.73
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/COM
/COM
/COM,----------- vmr027-cr3b-281 RESULTS COMPARISON -------------
```

```
/COM,
/COM, vmr027-cr3b-281.jpeg RESULTS SHOULD MATCH R0027 NAFEMS MANUAL
/COM, GRAPH RESULTS OF TEST 3(B).
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
FINISH
/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR6X ',' ECR6Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr027-','cr3b-281'
/OUT,vmr027-cr3b-281,vrt
/COM
/COM,------------------- vmr027-cr3b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr027-cr3b-281,vrt
/OUT,SCRATCH
```

VM-R027-4C 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr4c-181
/TITLE,vmr027-cr4c-181,2D PLANE STRESS-SHEAR LOADING SECONDARY CREEP
/COM,THE COMPARISON IS MADE GRAPHICALLY AND QUANTITATIVELY WITH
/COM,THE RESULTS OF THE TEST4(C) FROM THE NAFEMS R0027 REPORT.

/PREP7
TAU=100.0
L=100
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
ET,1,181,,,
```

```
R,1,1,1,1,1,
E,1,5,9,8
E,5,2,6,9
E,9,6,3,7
E,8,9,7,4
NSEL,S,LOC,X,
NSEL,R,LOC,Y,
D,ALL,UX,
D,ALL,UY,
NSEL,ALL
NSEL,S,LOC,X,
NSEL,R,LOC,Y,100
D,ALL,UX,
NSEL,ALL
D,7,UZ,0
D,5,ROTX,0
D,5,ROTY,0
FINISH

/SOLU
F,1,FX,-L*TAU/4
F,5,FX,-L*TAU/2
F,2,FX,-L*TAU/4
F,2,FY,L*TAU/4
F,6,FY,L*TAU/2
F,3,FY,L*TAU/4
F,3,FX,L*TAU/4
F,7,FX,L*TAU/2
F,4,FX,L*TAU/4
F,4,FY,-L*TAU/4
F,8,FY,-L*TAU/2
F,1,FY,-L*TAU/4
RATE, ON
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,0.10,0.0999,0.10
TIME, 0.10
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,1.0,0.999,1.0
TIME, 1.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,5.0,4.999,5.0
TIME, 5.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,10.0,9.999,10.0
TIME, 10.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
```

```
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,5
/GROPT,DIVY,9
/XRANGE,0,1000
/YRANGE,0,9
ESOL,2,1,,EPCR,XY
PLVAR,2
PRVAR,2

/POST1
SET,1,1
*GET,SH1,NODE,3,EPCR,XY
R1=1
SET,2,1
*GET,SH2,NODE,3,EPCR,XY
R2=SH2/0.000844
SET,3,1
*GET,SH3,NODE,3,EPCR,XY
R3=SH3/0.0084375
SET,4,1
*GET,SH4,NODE,3,EPCR,XY
R4=SH4/0.042188
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,XY
R5=SH5/0.084375
SET,,,,,,,9
*GET,SH6,NODE,3,EPCR,XY
R6=SH6/0.421875
SET,,,,,,,14
*GET,SH7,NODE,3,EPCR,XY
R7=SH7/0.84375
SET,,,,,,,54
*GET,SH8,NODE,3,EPCR,XY
R8=SH8/4.21875
SET,,,,,,,104
*GET,SH9,NODE,3,EPCR,XY
R9=SH9/8.4375
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,13
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,0.0, 0.000844, 0.0084375,0.042188,0.084375,0.421875,0.84375,4.21875,8.4375
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/COM
/COM,--------- vmr027-cr4c-181 RESULTS COMPARISON-----------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.5,'   ',F13.5,'   ',1F13.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
```

```
LABEL1(1) = ' ECR2X ',' ECR2Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr027-','cr4c-181'

/OUT,vmr027-cr4c-181,vrt
/COM
/COM,------------------- vmr027-cr4c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr4c-181,vrt
```

VM-R027-4C 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr4c-182
/TITLE,vmr027-cr4c-182,2D PLANE STRESS-SHEAR LOADING SECONDARY CREEP
/COM,THE COMPARISON IS MADE GRAPHICALLY AND QUANTITATIVELY WITH
/COM,THE RESULTS OF THE TEST4(C) FROM THE NAFEMS R0027 REPORT.

/PREP7
TAU=100.0
L=100
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
ET,1,182
KEYOPT,1,1,1
KEYOPT,1,3,0
E,1,5,9,8
E,5,2,6,9
E,9,6,3,7
E,8,9,7,4
NSEL,S,LOC,X,
NSEL,R,LOC,Y,
D,ALL,UX,
D,ALL,UY,
NSEL,ALL
```

```
NSEL,S,LOC,X,
NSEL,R,LOC,Y,100
D,ALL,UX,
NSEL,ALL

/SOLU
F,1,FX,-L*TAU/4
F,5,FX,-L*TAU/2
F,2,FX,-L*TAU/4
F,2,FY,L*TAU/4
F,6,FY,L*TAU/2
F,3,FY,L*TAU/4
F,3,FX,L*TAU/4
F,7,FX,L*TAU/2
F,4,FX,L*TAU/4
F,4,FY,-L*TAU/4
F,8,FY,-L*TAU/2
F,1,FY,-L*TAU/4
RATE, ON
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,0.10,0.0999,0.10
TIME, 0.10
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,1.0,0.999,1.0
TIME, 1.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,5.0,4.999,5.0
TIME, 5.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,10.0,9.999,10.0
TIME, 10.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
```

```
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,5
/GROPT,DIVY,9
/XRANGE,0,1000
/YRANGE,0,9
ESOL,2,1,,EPCR,XY
PLVAR,2
PRVAR,2
FINISH

/POST1
SET,1,1
*GET,SH1,NODE,3,EPCR,XY
R1=1
SET,2,1
*GET,SH2,NODE,3,EPCR,XY
R2=SH2/0.000844
SET,3,1
*GET,SH3,NODE,3,EPCR,XY
R3=SH3/0.0084375
SET,4,1
*GET,SH4,NODE,3,EPCR,XY
R4=SH4/0.042188
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,XY
R5=SH5/0.084375
SET,,,,,,,9
*GET,SH6,NODE,3,EPCR,XY
R6=SH6/0.421875
SET,,,,,,,14
*GET,SH7,NODE,3,EPCR,XY
R7=SH7/0.84375
SET,,,,,,,54
*GET,SH8,NODE,3,EPCR,XY
R8=SH8/4.21875
SET,,,,,,,104
*GET,SH9,NODE,3,EPCR,XY
R9=SH9/8.4375
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,13
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,0.0, 0.000844, 0.0084375,0.042188,0.084375,0.421875,0.84375,4.21875,8.4375
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/COM
/COM,--------- vmr027-cr4c-182 RESULTS COMPARISON-----------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.5,'   ',F11.5,'   ',1F14.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR2X ',' ECR2Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr027-','cr4c-182'

/OUT,vmr027-cr4c-182,vrt
/COM
/COM,------------------- vmr027-cr4c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
```

```
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F8.3,'      ',F16.4,'     ',A7,A8)
/COM,
/COM,-------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr4c-182,vrt
```

VM-R027-4C 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr4c-183
/TITLE,vmr027-cr4c-183,2D PLANE STRESS-SHEAR LOADING SECONDARY CREEP
/COM,THE COMPARISON IS MADE GRAPHICALLY AND QUANTITATIVELY WITH THE
/COM,RESULTS OF THE TEST4(C) FROM THE NAFEMS R0027 REPORT.

/PREP7
TAU=100.0
L=100
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183
KEYOPT,1,3,0
E,1,2,3,4,5,6,7,8
NSEL,S,LOC,X,
NSEL,R,LOC,Y,
D,ALL,UX,
D,ALL,UY,
NSEL,ALL
NSEL,S,LOC,X,
NSEL,R,LOC,Y,100
D,ALL,UX,
D,ALL,UY
NSEL,ALL
FINISH

/SOLU
F,1,FX,-L*TAU/6
F,5,FX,-L*TAU*2/3
F,2,FX,-L*TAU/6
F,2,FY,L*TAU/6
F,6,FY,L*TAU*2/3
F,3,FY,L*TAU/6
F,3,FX,L*TAU/6
F,7,FX,L*TAU*2/3
F,4,FX,L*TAU/6
F,4,FY,-L*TAU/6
```

```
F,8,FY,-L*TAU*2/3
F,1,FY,-L*TAU/6
RATE, ON
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,0.10,0.0999,0.10
TIME, 0.10
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,1.0,0.999,1.0
TIME, 1.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,5.0,4.999,5.0
TIME, 5.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,10.0,9.999,10.0
TIME, 10.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,5
/GROPT,DIVY,9
/XRANGE,0,1000
/YRANGE,0,9
ESOL,2,1,,EPCR,XY
PLVAR,2
PRVAR,2
FINISH

/POST1
SET,1,1
*GET,SH1,NODE,3,EPCR,XY
```

```
R1=1.000
SET,2,1
*GET,SH2,NODE,3,EPCR,XY
R2=SH2/0.000844
SET,3,1
*GET,SH3,NODE,3,EPCR,XY
R3=SH3/0.0084375
SET,4,1
*GET,SH4,NODE,3,EPCR,XY
R4=SH4/0.042188
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,XY
R5=SH5/0.084375
SET,,,,,,,9
*GET,SH6,NODE,3,EPCR,XY
R6=SH6/0.421875
SET,,,,,,,14
*GET,SH7,NODE,3,EPCR,XY
R7=SH7/0.84375
SET,,,,,,,54
*GET,SH8,NODE,3,EPCR,XY
R8=SH8/4.21875
SET,,,,,,,104
*GET,SH9,NODE,3,EPCR,XY
R9=SH9/8.4375
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,13
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,0.0, 0.000844, 0.0084375,0.042188,0.084375,0.421875,0.84375,4.21875,8.4375
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/COM
/COM,--------- vmr027-cr4c-183 RESULTS COMPARISON-----------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.5,'   ',F12.5,'   ',1F12.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR2X ',' ECR2Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr027-','cr4c-183'

/OUT,vmr027-cr4c-183,vrt
/COM
/COM,------------------- vmr027-cr4c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL    |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F12.3,'      ',F12.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr027-cr4c-183,vrt
```

VM-R027-4C 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr4c-281
```

```
/TITLE,vmr027-cr4c-281,2D PLANE STRESS-SHEAR LOADING SECONDARY CREEP
/COM,THE COMPARISON IS MADE GRAPHICALLY AND QUANTITATIVELY WITH THE
/COM,RESULTS OF THE TEST4(C) FROM THE NAFEMS R0027 REPORT.
/PREP7
TAU=100.0
L=100
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,281
R,1,1,1,1,1
E,1,2,3,4,5,6,7,8
NSEL,S,LOC,X,
NSEL,R,LOC,Y,
D,ALL,ALL
NSEL,ALL
NSEL,S,LOC,X,
NSEL,R,LOC,Y,100
D,ALL,UX
D,ALL,UY
D,ALL,UZ
NSEL,ALL
FINISH
/SOLU
F,1,FX,-L*TAU/6
F,5,FX,-L*TAU*2/3
F,2,FX,-L*TAU/6
F,2,FY,L*TAU/6
F,6,FY,L*TAU*2/3
F,3,FY,L*TAU/6
F,3,FX,L*TAU/6
F,7,FX,L*TAU*2/3
F,4,FX,L*TAU/6
F,4,FY,-L*TAU/6
F,8,FY,-L*TAU*2/3
F,1,FY,-L*TAU/6
RATE, ON
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,0.10,0.0999,0.10
TIME, 0.10
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,1.0,0.999,1.0
TIME, 1.0
```

```
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,5.0,4.999,5.0
TIME, 5.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,10.0,9.999,10.0
TIME, 10.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH
/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,5
/GROPT,DIVY,9
/XRANGE,0,1000
/YRANGE,0,9
ESOL,2,1,,EPCR,XY
PLVAR,2
PRVAR,2
FINISH
/POST1
SET,1,1
*GET,SH1,NODE,3,EPCR,XY
R1=1.000
SET,2,1
*GET,SH2,NODE,3,EPCR,XY
R2=SH2/0.000844
SET,3,1
*GET,SH3,NODE,3,EPCR,XY
R3=SH3/0.0084375
SET,4,1
*GET,SH4,NODE,3,EPCR,XY
R4=SH4/0.042188
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,XY
R5=SH5/0.084375
SET,,,,,,,9
*GET,SH6,NODE,3,EPCR,XY
R6=SH6/0.421875
SET,,,,,,,14
*GET,SH7,NODE,3,EPCR,XY
R7=SH7/0.84375
SET,,,,,,,54
*GET,SH8,NODE,3,EPCR,XY
```

```
R8=SH8/4.21875
SET,,,,,,,104
*GET,SH9,NODE,3,EPCR,XY
R9=SH9/8.4375
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,13
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,0.0, 0.000844, 0.0084375,0.042188,0.084375,0.421875,0.84375,4.21875,8.4375
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/COM
/COM,--------- vmr027-cr4c-281 RESULTS COMPARISON-----------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.5,'   ',F12.5,'   ',1F12.3)
FINISH
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR2X ',' ECR2Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr027-','cr4c-281'
/OUT,vmr027-cr4c-281,vrt
/COM
/COM,------------------- vmr027-cr4c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE281
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F12.3,'      ',F12.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
*LIST,vmr027-cr4c-281,vrt
```

VM-R027-5B 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr5b-182
/TITLE,vmr027-cr5b-182,2D PLANE STRAIN-BIAXIAL DISPLACEMENT SECONDARY CREEP
/COM, REFERENCE: TEST 5(B) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS !***
*SET,C1,3.125E-14
*SET,C2,5.0
*SET,C3,0.0
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
SAVE
N,1
N,2,100
N,3,100,100
N,4,0,100
ET,1,182,1,,2
E,1,2,3,4
```

```
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,S,LOC,Y,100
D,ALL,UY,0.05
NSEL,ALL
FINI

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
ESOL,2,1,,S,X
ESOL,3,1,,S,Y
ESOL,4,1,,S,Z
PRVAR,2,3,4
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/YRANGE,250,330
PLVAR,2
/POST1
SET,1,1
*GET,SH13,NODE,3,S,X
R13=SH13/326.92
SET,2,1
```

```
*GET,SH23,NODE,3,S,X
R23=SH23/314.79
SET,3,1
*GET,SH33,NODE,3,S,X
R33=SH33/292.41
SET,4,1
*GET,SH43,NODE,3,S,X
R43=SH43/278.97
SET,,,,,,,5
*GET,SH53,NODE,3,S,X
R53=SH53/274.41
SET,,,,,,,9
*GET,SH63,NODE,3,S,X
R63=SH63/266.34
SET,,,,,,,14
*GET,SH73,NODE,3,S,X
R73=SH73/263.76
SET,,,,,,,54
*GET,SH83,NODE,3,S,X
R83=SH83/259.21
SET,,,,,,,104
*GET,SH93,NODE,3,S,X
R93=SH93/257.74
*DIM,VALUE3,,9,3
*DIM,LABEL3,CHAR,10
LABEL3(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE3(1,1),DATA,326.92,314.79,292.41,278.97,274.41,266.34,263.76,259.21,257.74
*VFILL,VALUE3(1,2),DATA,SH13,SH23,SH33,SH43,SH53,SH63,SH73,SH83,SH93
*VFILL,VALUE3(1,3),DATA,R13,R23,R33,R43,R53,R63,R73,R83,R93
/COM
/COM
/COM,--------- vmr027-cr5b-182 RESULTS COMPARISON-----------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL3(1), VALUE3(1,1), VALUE3(1,2), VALUE3(1,3)
(1X,A8,'   ',F8.3,'   ',F12.3,'   ',1F12.3)
/SHOW,CLOSE
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR6X ',' ECR6Y '
*VFILL,VALUE1(1,1),DATA,SH93
*VFILL,VALUE1(1,2),DATA,R93
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr027-','cr5b-182'

/OUT,vmr027-cr5b-182,vrt
/COM
/COM,------------------- vmr027-cr5b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO   |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F12.3,'      ',F12.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr5b-182,vrt
```

VM-R027-5B 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
```

```
/VERIFY,vmr027-cr5b-183
/TITLE,vmr027-cr5b-183, 2D PLANE STRAIN-BIAXIAL DISPLACEMENT SECONDARY CREEP
/COM, REFERENCE: TEST 5(B) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS !***
*SET,C1,3.125E-14
*SET,C2,5.0
*SET,C3,0.0
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
SAVE
N,1
N,2,100
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183,,,2
E,1,2,3,4,5,6,7,8
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,S,LOC,Y,100
D,ALL,UY,0.05
NSEL,ALL
FINISH

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
```

```
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
ESOL,2,1,,S,X
ESOL,3,1,,S,Y
ESOL,4,1,,S,Z
PRVAR,2,3,4
/AXLAB,Y,STRESS
/AXLAB,X,TIME
/YRANGE,250,330
PLVAR,2

/POST1
SET,1,1
*GET,SH12,NODE,3,S,X
R12=SH12/326.92
SET,2,1
*GET,SH22,NODE,3,S,X
R22=SH22/314.79
SET,3,1
*GET,SH32,NODE,3,S,X
R32=SH32/292.41
SET,4,1
*GET,SH42,NODE,3,S,X
R42=SH42/278.97
SET,,,,,,,5
*GET,SH52,NODE,3,S,X
R52=SH52/274.41
SET,,,,,,,9
*GET,SH62,NODE,3,S,X
R62=SH62/266.34
SET,,,,,,,14
*GET,SH72,NODE,3,S,X
R72=SH72/263.76
SET,,,,,,,54
*GET,SH82,NODE,3,S,X
R82=SH82/259.21
SET,,,,,,,104
*GET,SH92,NODE,3,S,X
R92=SH92/257.74
*DIM,VALUE2,,9,3
*DIM,LABEL2,CHAR,10
LABEL2(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE2(1,1),DATA,326.92,314.79,292.41,278.97,274.41,266.34,263.76,259.21,257.74
*VFILL,VALUE2(1,2),DATA,SH12,SH22,SH32,SH42,SH52,SH62,SH72,SH82,SH92
*VFILL,VALUE2(1,3),DATA,R12,R22,R32,R42,R52,R62,R72,R82,R92
/COM
/COM
/COM,--------- vmr027-cr5b-183 RESULTS COMPARISON-----------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL  |    RATIO
/COM,
*VWRITE,LABEL2(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'   ',F12.3,'   ',1F12.3)
/SHOW,CLOSE
FINISH

/POST26
```

```
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR6X ',' ECR6Y '
*VFILL,VALUE1(1,1),DATA,SH92
*VFILL,VALUE1(1,2),DATA,R92
*DIM,LABEL3,CHAR,2
LABEL3(1) = 'vmr027-','cr5b-183'

/OUT,vmr027-cr5b-183,vrt
/COM
/COM,------------------- vmr027-cr5b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL3(1),LABEL3(2)
(1X,A8,'      ',F12.3,'      ',F12.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr5b-183,vrt
```

VM-R027-6B 185 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr6b-185
/TITLE,vmr027-cr6b-185,3D TRIAXIAL DISPLACEMENT SECONDARY CREEP
/COM, REFRENCE: TEST 6(B) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS !***
*SET,C1,3.125E-14
*SET,C2,5.0
*SET,C3,0.0
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,0.2000E+06
MP,EY,1,0.2000E+06
MP,EZ,1,0.2000E+06
MP,GXY,1,0.7692E+05
MP,GYZ,1,0.7692E+05
MP,GXZ,1,0.7692E+05
MP,NUXY,1,0.3000E+00
MP,NUYZ,1,0.3000E+00
MP,NUXZ,1,0.3000E+00
MP,DENS,1,0.0000E+00
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
SAVE
ET,1,SOLID185
KEYOPT,1,1,0
KEYOPT,1,2,1
KEYOPT,1,4,0
KEYOPT,1,5,0
KEYOPT,1,6,0
BLOCK,0,100,0,100,0,100,
ESIZE,50,0,
VMESH,ALL
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
```

```
D,ALL,UY
NSEL,S,LOC,Z,100
D,ALL,UZ
NSEL,S,LOC,X,100
D,ALL,UX,0.3
NSEL,S,LOC,Y,100
D,ALL,UY,0.2
NSEL,S,LOC,Z
D,ALL,UZ,-0.1
NSEL,ALL

*DO,I,1,2,1
*IF,I,EQ,2,THEN
/PREP7
TB,HILL,1
TBDATA,1, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0
*ENDIF

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

*IF,I,EQ,1,THEN
/POST26
ESOL,2,1,,S,X
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/COLOR,CURVE,RED,1
/YRANGE,1000,1160
PLVAR,2
```

```
PRVAR,2
FINISH

/POST1
SET,1,1
*GET,SH1,NODE,1,S,X
R1=SH1/1153.85
SET,2,1
*GET,SH2,NODE,1,S,X
R2=SH2/1076.29
SET,3,1
*GET,SH3,NODE,1,S,X
R3=SH3/1043.42
SET,4,1
*GET,SH4,NODE,1,S,X
R4=SH4/1029.11
SET,,,,,,,5
*GET,SH5,NODE,1,S,X
R5=SH5/1024.45
SET,,,,,,,9
*GET,SH6,NODE,1,S,X
R6=SH6/1016.33
SET,,,,,,,14
*GET,SH7,NODE,1,S,X
R7=SH7/1013.78
SET,,,,,,,54
*GET,SH8,NODE,1,S,X
R8=SH8/1009.20
SET,,,,,,,104
*GET,SH9,NODE,1,S,X
R9=SH9/1007.73
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,1153.85,1076.29,1043.42,1029.11,1024.45,1016.33,1013.78,1009.20,1007.73
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
*ENDIF
*IF,I,EQ,2,THEN
/COM,
/COM,  ANISOTROPIC CREEP MODELED AS ISOTROPIC
/COM,

/POST26
ESOL,3,1,,S,X
PRVAR,3
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/YRANGE,1000,1160
/COLOR,CURVE,BLUE,1
PLVAR,3

/POST1
SET,1,1
*GET,SH12,NODE,1,S,X
R12=SH12/1153.85
SET,2,1
*GET,SH13,NODE,1,S,X
R13=SH13/1076.29
SET,3,1
*GET,SH14,NODE,1,S,X
R14=SH14/1043.42
SET,4,1
*GET,SH15,NODE,1,S,X
R15=SH15/1029.11
SET,,,,,,,5
*GET,SH16,NODE,1,S,X
R16=SH16/1024.45
SET,,,,,,,9
*GET,SH17,NODE,1,S,X
R17=SH17/1016.33
SET,,,,,,,14
```

```
*GET,SH18,NODE,1,S,X
R18=SH18/1013.78
SET,,,,,,,54
*GET,SH19,NODE,1,S,X
R19=SH19/1009.20
SET,,,,,,,104
*GET,SH20,NODE,1,S,X
R20=SH20/1007.73
*DIM,VALUE2,,9,3
*DIM,LABEL2,CHAR,10
LABEL2(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE2(1,1),DATA,1153.85,1076.29,1043.42,1029.11,1024.45,1016.33,1013.78,1009.20,1007.73
*VFILL,VALUE2(1,2),DATA,SH12,SH13,SH14,SH15,SH16,SH17,SH18,SH19,SH20
*VFILL,VALUE2(1,3),DATA,R12,R13,R14,R15,R16,R17,R18,R19,R20
*ENDIF
*ENDDO
/COM
/COM
/COM,--------- vmr027-cr6b-185 ISOTROPIC RESULTS COMPARISON-----------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F12.3,'   ',1F12.3)
/COM
/COM
/COM,--------- vmr027-cr6b-185 ANISOTROPIC RESULTS COMPARISON-----------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL2(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'   ',F12.3,'   ',1F12.3)
FINISH


/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ISOCRX ',' ANICRX '
*VFILL,VALUE1(1,1),DATA,SH9,SH20
*VFILL,VALUE1(1,2),DATA,R9,R20
*DIM,LABEL3,CHAR,2
LABEL3(1) = 'vmr027-','cr6b-185'

/OUT,vmr027-cr6b-185,vrt
/COM
/COM,------------------- vmr027-cr6b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID185
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL3(1),LABEL3(2)
(1X,A8,'      ',F12.3,'      ',F12.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL3(1),LABEL3(2)
(1X,A8,'      ',F12.3,'      ',F12.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr6b-185,vrt
```

VM-R027-6B 186 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr6b-186
/TITLE,vmr027-cr6b-186,3D TRIXIAL DISPLACEMENT SECONDARY CREEP
/COM, REFRENCE: TEST 6(B) FROM NAFEMS R0027.
```

```
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS !***
*SET,C1,3.125E-14
*SET,C2,5.0
*SET,C3,0.0
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,0.2000E+06
MP,EY,1,0.2000E+06
MP,EZ,1,0.2000E+06
MP,GXY,1,0.7692E+05
MP,GYZ,1,0.7692E+05
MP,GXZ,1,0.7692E+05
MP,NUXY,1,0.3000E+00
MP,NUYZ,1,0.3000E+00
MP,NUXZ,1,0.3000E+00
MP,DENS,1,0.0000E+00
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
SAVE
ET,1,SOLID186
KEYOPT,1,5,0
KEYOPT,1,6,0
KEYOPT,1,11,0
BLOCK,0,100,0,100,0,100,
ESIZE,100,0,
VMESH,ALL
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Z,100
D,ALL,UZ
NSEL,S,LOC,X,100
D,ALL,UX,0.3
NSEL,S,LOC,Y,100
D,ALL,UY,0.2
NSEL,S,LOC,Z
D,ALL,UZ,-0.1
NSEL,ALL

*DO,I,1,2,1
*IF,I,EQ,2,THEN
/PREP7
TB,HILL,1
TBDATA,1, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0
*ENDIF

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
```

```
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

*IF,I,EQ,1,THEN
/POST26
ESOL,2,1,,S,X
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/COLOR,CURVE,RED,1
/YRANGE,1000,1160
PLVAR,2
PRVAR,2
FINISH

/POST1
SET,1,1
*GET,SH1,NODE,1,S,X
R1=SH1/1153.85
SET,2,1
*GET,SH2,NODE,1,S,X
R2=SH2/1076.29
SET,3,1
*GET,SH3,NODE,1,S,X
R3=SH3/1043.42
SET,4,1
*GET,SH4,NODE,1,S,X
R4=SH4/1029.11
SET,,,,,,,5
*GET,SH5,NODE,1,S,X
R5=SH5/1024.45
SET,,,,,,,9
*GET,SH6,NODE,1,S,X
R6=SH6/1016.33
SET,,,,,,,14
*GET,SH7,NODE,1,S,X
R7=SH7/1013.78
SET,,,,,,,54
*GET,SH8,NODE,1,S,X
R8=SH8/1009.20
SET,,,,,,,104
*GET,SH9,NODE,1,S,X
R9=SH9/1007.73
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,1153.85,1076.29,1043.42,1029.11,1024.45,1016.33,1013.78,1009.20,1007.73
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
```

```
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
*ENDIF

*IF,I,EQ,2,THEN
/COM,
/COM,  ANISOTROPIC CREEP MODELED AS ISOTROPIC
/COM,

/POST26
ESOL,3,1,,S,X
PRVAR,3
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/COLOR,CURVE,BLUE,1
/YRANGE,1000,1160
PLVAR,3

/POST1
SET,1,1
*GET,SH12,NODE,1,S,X
R12=SH12/1153.85
SET,2,1
*GET,SH13,NODE,1,S,X
R13=SH13/1076.29
SET,3,1
*GET,SH14,NODE,1,S,X
R14=SH14/1043.42
SET,4,1
*GET,SH15,NODE,1,S,X
R15=SH15/1029.11
SET,,,,,,,5
*GET,SH16,NODE,1,S,X
R16=SH16/1024.45
SET,,,,,,,9
*GET,SH17,NODE,1,S,X
R17=SH17/1016.33
SET,,,,,,,14
*GET,SH18,NODE,1,S,X
R18=SH18/1013.78
SET,,,,,,,54
*GET,SH19,NODE,1,S,X
R19=SH19/1009.20
SET,,,,,,,104
*GET,SH20,NODE,1,S,X
R20=SH20/1007.73
*DIM,VALUE2,,9,3
*DIM,LABEL2,CHAR,10
LABEL2(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE2(1,1),DATA,1153.85,1076.29,1043.42,1029.11,1024.45,1016.33,1013.78,1009.20,1007.73
*VFILL,VALUE2(1,2),DATA,SH12,SH13,SH14,SH15,SH16,SH17,SH18,SH19,SH20
*VFILL,VALUE2(1,3),DATA,R12,R13,R14,R15,R16,R17,R18,R19,R20
*ENDIF
*ENDDO
/COM
/COM,--------- vmr027-cr6b-186 ISOTROPIC RESULTS COMPARISON-----------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F12.3,'   ',1F12.3)
/COM,
/COM,
/COM,--------- vmr027-cr6b-186 ANISOTROPIC RESULTS COMPARISON-----------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL2(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'   ',F12.3,'   ',1F12.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,2
```

```
*DIM,VALUE1,,2,3
LABEL1(1) = ' ISOCRX ',' ANICRX '
*VFILL,VALUE1(1,1),DATA,SH9,SH20
*VFILL,VALUE1(1,2),DATA,R9,R20
*DIM,LABEL3,CHAR,2
LABEL3(1) = 'vmr027-','cr6b-186'

/OUT,vmr027-cr6b-186,vrt
/COM
/COM,------------------- vmr027-cr6b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID186
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL3(1),LABEL3(2)
(1X,A8,'      ',F12.3,'      ',F12.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL3(1),LABEL3(2)
(1X,A8,'      ',F12.3,'      ',F12.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr6b-186,vrt
```

VM-R027-6B 187 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr6b-187
/TITLE,vmr027-cr6b-187,3D TRIAXIAL DISPLACEMENT SECONDARY CREEP
/COM, REFRENCE: TEST 6(B) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS !***
*SET,C1,3.125E-14
*SET,C2,5.0
*SET,C3,0.0
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,0.2000E+06
MP,EY,1,0.2000E+06
MP,EZ,1,0.2000E+06
MP,GXY,1,0.7692E+05
MP,GYZ,1,0.7692E+05
MP,GXZ,1,0.7692E+05
MP,NUXY,1,0.3000E+00
MP,NUYZ,1,0.3000E+00
MP,NUXZ,1,0.3000E+00
MP,DENS,1,0.0000E+00
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
SAVE
ET,1,SOLID187
BLOCK,0,100,0,100,0,100,
ESIZE,100,0,
VMESH,ALL
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Z,100
D,ALL,UZ
NSEL,S,LOC,X,100
```

```
D,ALL,UX,0.3
NSEL,S,LOC,Y,100
D,ALL,UY,0.2
NSEL,S,LOC,Z
D,ALL,UZ,-0.1
NSEL,ALL

*DO,I,1,2,1

*IF,I,EQ,2,THEN
/PREP7
TB,HILL,1
TBDATA,1, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0
*ENDIF

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

*IF,I,EQ,1,THEN
/POST26
ESOL,2,1,,S,X
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/COLOR,CURVE,RED,1
/YRANGE,1000,1160
PLVAR,2
PRVAR,2
FINISH
```

```
/POST1
SET,1,1
*GET,SH1,NODE,1,S,X
R1=SH1/1153.85
SET,2,1
*GET,SH2,NODE,1,S,X
R2=SH2/1076.29
SET,3,1
*GET,SH3,NODE,1,S,X
R3=SH3/1043.42
SET,4,1
*GET,SH4,NODE,1,S,X
R4=SH4/1029.11
SET,,,,,,,5
*GET,SH5,NODE,1,S,X
R5=SH5/1024.45
SET,,,,,,,9
*GET,SH6,NODE,1,S,X
R6=SH6/1016.33
SET,,,,,,,14
*GET,SH7,NODE,1,S,X
R7=SH7/1013.78
SET,,,,,,,54
*GET,SH8,NODE,1,S,X
R8=SH8/1009.20
SET,,,,,,,104
*GET,SH9,NODE,1,S,X
R9=SH9/1007.73
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,1153.85,1076.29,1043.42,1029.11,1024.45,1016.33,1013.78,1009.20,1007.73
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
*ENDIF

*IF,I,EQ,2,THEN
/COM,
/COM,  ANISOTROPIC CREEP MODELED AS ISOTROPIC
/COM,

/POST26
ESOL,3,1,,S,X
PRVAR,3
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/COLOR,CURVE,BLUE,1
/YRANGE,1000,1160
PLVAR,3

/POST1
SET,1,1
*GET,SH12,NODE,1,S,X
R12=SH12/1153.85
SET,2,1
*GET,SH13,NODE,1,S,X
R13=SH13/1076.29
SET,3,1
*GET,SH14,NODE,1,S,X
R14=SH14/1043.42
SET,4,1
*GET,SH15,NODE,1,S,X
R15=SH15/1029.11
SET,,,,,,,5
*GET,SH16,NODE,1,S,X
R16=SH16/1024.45
SET,,,,,,,9
*GET,SH17,NODE,1,S,X
R17=SH17/1016.33
SET,,,,,,,14
*GET,SH18,NODE,1,S,X
R18=SH18/1013.78
```

```
SET,,,,,,,54
*GET,SH19,NODE,1,S,X
R19=SH19/1009.20
SET,,,,,,,104
*GET,SH20,NODE,1,S,X
R20=SH20/1007.73
*DIM,VALUE2,,9,3
*DIM,LABEL2,CHAR,10
LABEL2(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE2(1,1),DATA,1153.85,1076.29,1043.42,1029.11,1024.45,1016.33,1013.78,1009.20,1007.73
*VFILL,VALUE2(1,2),DATA,SH12,SH13,SH14,SH15,SH16,SH17,SH18,SH19,SH20
*VFILL,VALUE2(1,3),DATA,R12,R13,R14,R15,R16,R17,R18,R19,R20
*ENDIF
*ENDDO
/COM
/COM,--------- vmr027-cr6b-187 ISOTROPIC RESULTS COMPARISON-----------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F12.3,'   ',1F12.3)
/COM,
/COM,
/COM,--------- vmr027-cr6b-187 ANISOTROPIC RESULTS COMPARISON-----------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL2(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'   ',F12.3,'   ',1F12.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ISOCRX ',' ANICRX '
*VFILL,VALUE1(1,1),DATA,SH9,SH20
*VFILL,VALUE1(1,2),DATA,R9,R20
*DIM,LABEL3,CHAR,2
LABEL3(1) = 'vmr027-','cr6b-187'

/OUT,vmr027-cr6b-187,vrt
/COM
/COM,------------------- vmr027-cr6b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID187
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL3(1),LABEL3(2)
(1X,A8,'      ',F12.3,'      ',F12.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL3(1),LABEL3(2)
(1X,A8,'      ',F12.3,'      ',F12.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr6b-187,vrt
```

VM-R027-10A 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr10a-181
/TITLE,vmr027-cr10a-181,2D PLANE STRESS-BIAXIAL LOAD PRIMARY CREEP
/COM, REFERENCE: TEST 10(A) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (PRIMARY CREEP)!***
*SET,C1,1.5625E-14
```

```
*SET,C2,5.0
*SET,C3,-0.5
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
ET,1,181,,,
R,1,1,1,1,1,
E,1,2,3,4
E,4,3,5,6
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL
D,ALL,UZ
D,ALL,ROTZ
FINISH

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
```

```
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
ESOL,4,1,,EPCR,EQV
PRVAR,2,3,4
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
PLVAR,2,3,4

/POST1
SET,1,1
*GET,SH1,NODE,3,EPCR,X
R1=1.0
SET,2,1
*GET,SH2,NODE,3,EPCR,X
R2=SH2/0.0427
SET,3,1
*GET,SH3,NODE,3,EPCR,X
R3=SH3/0.135
SET,4,1
*GET,SH4,NODE,3,EPCR,X
R4=SH4/0.3019
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,X
R5=SH5/0.4269
SET,,,,,,,9
*GET,SH6,NODE,3,EPCR,X
R6=SH6/0.9546
SET,,,,,,,14
*GET,SH7,NODE,3,EPCR,X
R7=SH7/1.35
SET,,,,,,,54
*GET,SH8,NODE,3,EPCR,X
R8=SH8/3.019
SET,,,,,,,104
*GET,SH9,NODE,3,EPCR,X
R9=SH9/4.2691
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,0.0000,0.0427,0.1350,0.3019,0.4269,0.9546,1.3500,3.0190,4.2691
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9

/POST1
SET,1,1
*GET,SH11,NODE,3,EPCR,EQV
R11=1.0
SET,2,1
*GET,SH21,NODE,3,EPCR,EQV
R21=SH21/(0.0493)
SET,3,1
*GET,SH31,NODE,3,EPCR,EQV
R31=SH31/(0.1559)
SET,4,1
*GET,SH41,NODE,3,EPCR,EQV
R41=SH41/(0.3486)
```

```
SET,,,,,,,5
*GET,SH51,NODE,3,EPCR,EQV
R51=SH51/(0.4930)
SET,,,,,,,9
*GET,SH61,NODE,3,EPCR,EQV
R61=SH61/(1.1024)
SET,,,,,,,14
*GET,SH71,NODE,3,EPCR,EQV
R71=SH71/(1.5590)
SET,,,,,,,54
*GET,SH81,NODE,3,EPCR,EQV
R81=SH81/(3.4861)
SET,,,,,,,104
*GET,SH91,NODE,3,EPCR,EQV
R91=SH91/(4.9300)
*DIM,VALUE1,,9,3
*DIM,LABEL1,CHAR,10
LABEL1(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE1(1,1),DATA,0.0000,0.0493,0.1559,0.3486,0.4930,1.1024,1.5590,3.4861,4.9300
*VFILL,VALUE1(1,2),DATA,SH11,SH21,SH31,SH41,SH51,SH61,SH71,SH81,SH91
*VFILL,VALUE1(1,3),DATA,R11,R21,R31,R41,R51,R61,R71,R81,R91
/COM
/COM
/COM,------------ vmr027-cr10a-181 RESULTS COMPARISON ---------------
/COM,
/COM, vmr027-cr10a-181.jpeg RESULTS SHOULD MATCH R0027 NAFEMS MANUAL
/COM, GRAPH AND NUMERICAL RESULTS IN TEST 10(A).
/COM,
/COM,--------- CREEP STRAIN RESULTS IN X DIRECTION ----------
/COM,
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F5.3)
/COM
/COM,----------- CREEP EFFECTIVE STRAIN RESULTS -------------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL1(1), VALUE1(1,1), VALUE1(1,2), VALUE1(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F5.3)
FINISH

/POST26
*DIM,LABEL3,CHAR,2
*DIM,VALUE2,,2,3
LABEL3(1) = ' ECR6X ',' EFFCR '
*VFILL,VALUE2(1,1),DATA,SH9,SH91
*VFILL,VALUE2(1,2),DATA,R9,R91
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr10a-18','1'

/OUT,vmr027-cr10a-181,vrt
/COM
/COM,------------------- vmr027-cr10a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL3(1),VALUE2(1,1),VALUE2(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
*VWRITE,LABEL3(2),VALUE2(2,1),VALUE2(2,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr10a-181,vrt
```

VM-R027-10A 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr10a-182
/TITLE,vmr027-cr10a-182,2D PLANE STRESS-BIAXIAL LOAD PRIMARY CREEP
/COM, REFERENCE: TEST 10(A) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (PRIMARY CREEP)!***
*SET,C1,1.5625E-14
*SET,C2,5.0
*SET,C3,-0.5
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
ET,1,182
KEYOPT,1,1,1
KEYOPT,1,3,0
E,1,5,9,8
E,5,2,6,9
E,9,6,3,7
E,8,9,7,4
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
OUTPR,ALL,LAST
/OUT,SCRATCH
SOLVE
/OUT,
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
```

```
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
ESOL,4,1,,EPCR,EQV
PRVAR,2,3,4
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
PLVAR,2,3,4

/POST1
SET,1,1
*GET,SH1,NODE,3,EPCR,X
R1=1.0
SET,2,1
*GET,SH2,NODE,3,EPCR,X
R2=SH2/0.0427
SET,3,1
*GET,SH3,NODE,3,EPCR,X
R3=SH3/0.135
SET,4,1
*GET,SH4,NODE,3,EPCR,X
R4=SH4/0.3019
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,X
R5=SH5/0.4269
SET,,,,,,,9
*GET,SH6,NODE,3,EPCR,X
R6=SH6/0.9546
SET,,,,,,,14
*GET,SH7,NODE,3,EPCR,X
R7=SH7/1.35
SET,,,,,,,54
*GET,SH8,NODE,3,EPCR,X
R8=SH8/3.019
SET,,,,,,,104
*GET,SH9,NODE,3,EPCR,X
R9=SH9/4.2691
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
```

```
*VFILL,VALUE(1,1),DATA,0.0000,0.0427,0.1350,0.3019,0.4269,0.9546,1.3500,3.0190,4.2691
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9

/POST1
SET,1,1
*GET,SH11,NODE,3,EPCR,EQV
R11=1.0
SET,2,1
*GET,SH21,NODE,3,EPCR,EQV
R21=SH21/(0.0493)
SET,3,1
*GET,SH31,NODE,3,EPCR,EQV
R31=SH31/(0.1559)
SET,4,1
*GET,SH41,NODE,3,EPCR,EQV
R41=SH41/(0.3486)
SET,,,,,,,5
*GET,SH51,NODE,3,EPCR,EQV
R51=SH51/(0.4930)
SET,,,,,,,9
*GET,SH61,NODE,3,EPCR,EQV
R61=SH61/(1.1024)
SET,,,,,,,14
*GET,SH71,NODE,3,EPCR,EQV
R71=SH71/(1.5590)
SET,,,,,,,54
*GET,SH81,NODE,3,EPCR,EQV
R81=SH81/(3.4861)
SET,,,,,,,104
*GET,SH91,NODE,3,EPCR,EQV
R91=SH91/(4.9300)
*DIM,VALUE1,,9,3
*DIM,LABEL1,CHAR,10
LABEL1(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE1(1,1),DATA,0.0000,0.0493,0.1559,0.3486,0.4930,1.1024,1.5590,3.4861,4.9300
*VFILL,VALUE1(1,2),DATA,SH11,SH21,SH31,SH41,SH51,SH61,SH71,SH81,SH91
*VFILL,VALUE1(1,3),DATA,R11,R21,R31,R41,R51,R61,R71,R81,R91
/COM
/COM
/COM,------------ vmr027-cr10a-182 RESULTS COMPARISON ---------------
/COM,
/COM, vmr027-cr10a-182.jpeg RESULTS SHOULD MATCH R0027 NAFEMS MANUAL
/COM, GRAPH AND NUMERICAL RESULTS IN TEST 10(A).
/COM,
/COM,--------- CREEP STRAIN RESULTS IN X DIRECTION ----------
/COM,
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F5.3)
/COM
/COM,----------- CREEP EFFECTIVE STRAIN RESULTS -------------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL1(1), VALUE1(1,1), VALUE1(1,2), VALUE1(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F5.3)
FINISH

/POST26
*DIM,LABEL3,CHAR,2
*DIM,VALUE2,,2,3
LABEL3(1) = ' ECR6X ',' EFFCR '
*VFILL,VALUE2(1,1),DATA,SH9,SH91
*VFILL,VALUE2(1,2),DATA,R9,R91
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr10a-18','2'

/OUT,vmr027-cr10a-182,vrt
/COM
```

```
/COM,------------------- vmr027-cr10a RESULTS COMPARISON ---------------------
/COM,
/COM,             |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL3(1),VALUE2(1,1),VALUE2(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
*VWRITE,LABEL3(2),VALUE2(2,1),VALUE2(2,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr10a-182,vrt
```

VM-R027-10A 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr10a-183
/TITLE,vmr027-cr10a-183,2D PLANE STRESS-BIAXIAL LOAD PRIMARY CREEP
/COM, REFERENCE: TEST 10(A) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (PRIMARY CREEP)!***
*SET,C1,1.5625E-14
*SET,C2,5.0
*SET,C3,-0.5
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183
KEYOPT,1,3,0
E,1,2,3,4,5,6,7,8
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
```

```
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
ESOL,4,1,,EPCR,EQV
PRVAR,2,3,4
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
PLVAR,2,3,4

/POST1
SET,1,1
*GET,SH1,NODE,3,EPCR,X
R1=1.0
SET,2,1
*GET,SH2,NODE,3,EPCR,X
R2=SH2/0.0427
SET,3,1
*GET,SH3,NODE,3,EPCR,X
R3=SH3/0.135
SET,4,1
*GET,SH4,NODE,3,EPCR,X
R4=SH4/0.3019
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,X
R5=SH5/0.4269
SET,,,,,,,9
*GET,SH6,NODE,3,EPCR,X
R6=SH6/0.9546
SET,,,,,,,14
```

```
*GET,SH7,NODE,3,EPCR,X
R7=SH7/1.35
SET,,,,,,,54
*GET,SH8,NODE,3,EPCR,X
R8=SH8/3.019
SET,,,,,,,104
*GET,SH9,NODE,3,EPCR,X
R9=SH9/4.2691
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,0.0000,0.0427,0.1350,0.3019,0.4269,0.9546,1.3500,3.0190,4.2691
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9

/POST1
SET,1,1
*GET,SH11,NODE,3,EPCR,EQV
R11=1.0
SET,2,1
*GET,SH21,NODE,3,EPCR,EQV
R21=SH21/(0.0493)
SET,3,1
*GET,SH31,NODE,3,EPCR,EQV
R31=SH31/(0.1559)
SET,4,1
*GET,SH41,NODE,3,EPCR,EQV
R41=SH41/(0.3486)
SET,,,,,,,5
*GET,SH51,NODE,3,EPCR,EQV
R51=SH51/(0.4930)
SET,,,,,,,9
*GET,SH61,NODE,3,EPCR,EQV
R61=SH61/(1.1024)
SET,,,,,,,14
*GET,SH71,NODE,3,EPCR,EQV
R71=SH71/(1.5590)
SET,,,,,,,54
*GET,SH81,NODE,3,EPCR,EQV
R81=SH81/(3.4861)
SET,,,,,,,104
*GET,SH91,NODE,3,EPCR,EQV
R91=SH91/(4.9300)
*DIM,VALUE1,,9,3
*DIM,LABEL1,CHAR,10
LABEL1(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE1(1,1),DATA,0.0000,0.0493,0.1559,0.3486,0.4930,1.1024,1.5590,3.4861,4.9300
*VFILL,VALUE1(1,2),DATA,SH11,SH21,SH31,SH41,SH51,SH61,SH71,SH81,SH91
*VFILL,VALUE1(1,3),DATA,R11,R21,R31,R41,R51,R61,R71,R81,R91
/COM
/COM
/COM,------------ vmr027-cr10a-183 RESULTS COMPARISON ---------------
/COM,
/COM, vmr027-cr10a-183.jpeg RESULTS SHOULD MATCH R0027 NAFEMS MANUAL
/COM, GRAPH AND NUMERICAL RESULTS IN TEST 10(A).
/COM,
/COM,--------- CREEP STRAIN RESULTS IN X DIRECTION ----------
/COM,
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F5.3)
/COM
/COM,----------- CREEP EFFECTIVE STRAIN RESULTS -------------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL1(1), VALUE1(1,1), VALUE1(1,2), VALUE1(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F5.3)
FINISH
```

```
/POST26
*DIM,LABEL3,CHAR,2
*DIM,VALUE2,,2,3
LABEL3(1) = ' ECR6X ',' EFFCR '
*VFILL,VALUE2(1,1),DATA,SH9,SH91
*VFILL,VALUE2(1,2),DATA,R9,R91
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr10a-18','3'

/OUT,vmr027-cr10a-183,vrt
/COM
/COM,------------------- vmr027-cr10a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL3(1),VALUE2(1,1),VALUE2(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
*VWRITE,LABEL3(2),VALUE2(2,1),VALUE2(2,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr10a-183,vrt
```

VM-R027-10A 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr10a-281
/TITLE,vmr027-cr10a-281,2D PLANE STRESS-BIAXIAL LOAD PRIMARY CREEP
/COM, REFERENCE: TEST 10(A) FROM NAFEMS R0027.
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (PRIMARY CREEP)!***
*SET,C1,1.5625E-14
*SET,C2,5.0
*SET,C3,-0.5
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
N,7,50,0
N,8,100,25
N,9,50,50
N,10,0,25
N,11,100,75
N,12,50,100
N,13,0,75
ET,1,SHELL281,,,
R,1,1,1,1,1,
E,1,2,3,4,7,8,9,10
E,4,3,5,6,9,11,12,13
NSEL,ALL
NSEL,S,LOC,X
```

```
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL
D,ALL,UZ
D,ALL,ROTZ
FINISH
/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH
/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
ESOL,4,1,,EPCR,EQV
PRVAR,2,3,4
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
PLVAR,2,3,4
/POST1
SET,1,1
*GET,SH1,NODE,3,EPCR,X
R1=1.0
SET,2,1
```

```
*GET,SH2,NODE,3,EPCR,X
R2=SH2/0.0427
SET,3,1
*GET,SH3,NODE,3,EPCR,X
R3=SH3/0.135
SET,4,1
*GET,SH4,NODE,3,EPCR,X
R4=SH4/0.3019
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,X
R5=SH5/0.4269
SET,,,,,,,9
*GET,SH6,NODE,3,EPCR,X
R6=SH6/0.9546
SET,,,,,,,14
*GET,SH7,NODE,3,EPCR,X
R7=SH7/1.35
SET,,,,,,,54
*GET,SH8,NODE,3,EPCR,X
R8=SH8/3.019
SET,,,,,,,104
*GET,SH9,NODE,3,EPCR,X
R9=SH9/4.2691
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,0.0000,0.0427,0.1350,0.3019,0.4269,0.9546,1.3500,3.0190,4.2691
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/POST1
SET,1,1
*GET,SH11,NODE,3,EPCR,EQV
R11=1.0
SET,2,1
*GET,SH21,NODE,3,EPCR,EQV
R21=SH21/(0.0493)
SET,3,1
*GET,SH31,NODE,3,EPCR,EQV
R31=SH31/(0.1559)
SET,4,1
*GET,SH41,NODE,3,EPCR,EQV
R41=SH41/(0.3486)
SET,,,,,,,5
*GET,SH51,NODE,3,EPCR,EQV
R51=SH51/(0.4930)
SET,,,,,,,9
*GET,SH61,NODE,3,EPCR,EQV
R61=SH61/(1.1024)
SET,,,,,,,14
*GET,SH71,NODE,3,EPCR,EQV
R71=SH71/(1.5590)
SET,,,,,,,54
*GET,SH81,NODE,3,EPCR,EQV
R81=SH81/(3.4861)
SET,,,,,,,104
*GET,SH91,NODE,3,EPCR,EQV
R91=SH91/(4.9300)
*DIM,VALUE1,,9,3
*DIM,LABEL1,CHAR,10
LABEL1(1) = '0','0.1', '1.0', '5.0', '10.0', '50.0','100.0','500.0','1000.0'
*VFILL,VALUE1(1,1),DATA,0.0000,0.0493,0.1559,0.3486,0.4930,1.1024,1.5590,3.4861,4.9300
*VFILL,VALUE1(1,2),DATA,SH11,SH21,SH31,SH41,SH51,SH61,SH71,SH81,SH91
*VFILL,VALUE1(1,3),DATA,R11,R21,R31,R41,R51,R61,R71,R81,R91
/COM
/COM
/COM,------------ vmr027-cr10a-281 RESULTS COMPARISON ---------------
/COM,
/COM, vmr027-cr10a-281.jpeg RESULTS SHOULD MATCH R0027 NAFEMS MANUAL
/COM, GRAPH AND NUMERICAL RESULTS IN TEST 10(A).
/COM,
/COM,--------- CREEP STRAIN RESULTS IN X DIRECTION ----------
/COM,
```

```
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F5.3)
/COM
/COM,----------- CREEP EFFECTIVE STRAIN RESULTS -------------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL   |   RATIO
/COM,
*VWRITE,LABEL1(1), VALUE1(1,1), VALUE1(1,2), VALUE1(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F5.3)
FINISH
/POST26
*DIM,LABEL3,CHAR,2
*DIM,VALUE2,,2,3
LABEL3(1) = ' ECR6X ',' EFFCR '
*VFILL,VALUE2(1,1),DATA,SH9,SH91
*VFILL,VALUE2(1,2),DATA,R9,R91
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr10a-28','1'
/OUT,vmr027-cr10a-281,vrt
/COM
/COM,------------------- vmr027-cr10a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL3(1),VALUE2(1,1),VALUE2(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
*VWRITE,LABEL3(2),VALUE2(2,1),VALUE2(2,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr027-cr10a-281,vrt
```

VM-R027-10B 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr10b-181
/TITLE,vmr027-cr10b-181,2D PLANE STRESS-BIAXIAL DISPLACEMENT PRIMARY CREEP
/COM, REFERENCE: TEST 10(B) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (TIME HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5.0
*SET,C3,-0.5
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (STRAIN HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3
```

```
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
ET,1,181,,,
R,1,1,1,1,1,
E,1,5,9,8
E,5,2,6,9
E,9,6,3,7
E,8,9,7,4
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,ALL
NSEL,S,LOC,Y,100
D,ALL,UY,-0.1
NSEL,ALL
D,9,UZ,0
D,9,ROTY,0
D,5,ROTX,0
FINISH
*DO,I,1,2

/PREP7
*IF,I,EQ,1,THEN
/COM,
/COM, TIME HARDENING CASE
/COM,
MAT,1
*ELSEIF,I,EQ,2,THEN
/COM,
/COM, STRAIN HARDENING CASE
/COM,
MPCHG,2,ALL
*ENDIF

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
```

```
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
*IF,I,EQ,1,THEN
ESOL,2,1,,S,X,TIMEHARD
PRVAR,2
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/YRANGE,0,160
/COLOR,CURVE,RED,1
PLVAR,2
/NOERASE

/POST1
SET,1,1
*GET,SH1,NODE,3,S,X
R1=SH1/153.85
SET,,,,,,,9
*GET,SH6,NODE,3,S,X
R6=SH6/26.69
SET,,,,,,,14
*GET,SH7,NODE,3,S,X
R7=SH7/24.45
SET,,,,,,,54
*GET,SH8,NODE,3,S,X
R8=SH8/20.00
SET,,,,,,,104
*GET,SH9,NODE,3,S,X
R9=SH9/18.34
*DIM,VALUE,,5,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,153.85,26.69,24.45,20.00,18.34
*VFILL,VALUE(1,2),DATA,SH1,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R6,R7,R8,R9
/COM
/COM
/COM,----------- vmr027-cr10b-181 TIME HARDENING RESULTS COMPARISON ------------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
FINISH

*ELSEIF,I,EQ,2,THEN
/POST26
ESOL,3,1,,S,X,STRAINHA
PRVAR,3
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/YRANGE,0,160
/COLOR,CURVE,BLUE,1
```

```
PLVAR,3

/POST1
SET,1,1
*GET,S1,NODE,3,S,X
R11=S1/153.85
SET,,,,,,,9
*GET,S6,NODE,3,S,X
R66=S6/35.96
SET,,,,,,,14
*GET,S7,NODE,3,S,X
R77=S7/33.46
SET,,,,,,,54
*GET,S8,NODE,3,S,X
R88=S8/28.06
SET,,,,,,,104
*GET,S9,NODE,3,S,X
R99=S9/26.10
*DIM,VALUE2,,5,6
LABEL(1) = '0','50.0','100.0','500.0','1000.0'
*VFILL,VALUE2(1,1),DATA,153.85,35.96,33.46,28.06,26.10
*VFILL,VALUE2(1,2),DATA,S1,S6,S7,S8,S9
*VFILL,VALUE2(1,3),DATA,R11,R66,R77,R88,R99
/COM
/COM
/COM,------------ vmr027-cr10b-181 STRAIN HARDENING RESULTS COMPARISON -------------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL  |   RATIO  |
/COM,
*VWRITE,LABEL(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
FINISH
*ENDIF
*ENDDO
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' S6 ',' S7 '
*VFILL,VALUE1(1,1),DATA,SH9,S9
*VFILL,VALUE1(1,2),DATA,R9,R99
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr10b-18','1'

/OUT,vmr027-cr10b-181,vrt
/COM
/COM,------------------- vmr027-cr10b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,---------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr10b-181,vrt
```

VM-R027-10B 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr10b-182
/TITLE,vmr027-cr10b-182,2D PLANE STRESS-BIAXIAL DISPLACEMENT PRIMARY CREEP
```

```
/COM, REFERENCE: TEST 10(B) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (TIME HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5.0
*SET,C3,-0.5
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (STRAIN HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
ET,1,182
KEYOPT,1,1,1
KEYOPT,1,3,0
E,1,5,9,8
E,5,2,6,9
E,9,6,3,7
E,8,9,7,4
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,ALL
NSEL,S,LOC,Y,100
D,ALL,UY,-0.1
NSEL,ALL

*DO,I,1,2

/PREP7
*IF,I,EQ,1,THEN
/COM,
/COM, TIME HARDENING CASE
/COM,
MAT,1
*ELSEIF,I,EQ,2,THEN
/COM,
/COM, STRAIN HARDENING CASE
/COM,
MPCHG,2,ALL
*ENDIF

/SOLU
RATE, OFF
```

```
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
*IF,I,EQ,1,THEN
ESOL,2,1,,S,X,TIMEHARD
PRVAR,2
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/YRANGE,0,160
/COLOR,CURVE,RED,1
PLVAR,2
/NOERASE

/POST1
SET,1,1
*GET,SH1,NODE,3,S,X
R1=SH1/153.85
SET,,,,,,,9
*GET,SH6,NODE,3,S,X
R6=SH6/26.69
SET,,,,,,,14
*GET,SH7,NODE,3,S,X
R7=SH7/24.45
SET,,,,,,,54
*GET,SH8,NODE,3,S,X
R8=SH8/20.00
SET,,,,,,,104
*GET,SH9,NODE,3,S,X
R9=SH9/18.34
*DIM,VALUE,,5,3
```

```
*DIM,LABEL,CHAR,10
LABEL(1) = '0','50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,153.85,26.69,24.45,20.00,18.34
*VFILL,VALUE(1,2),DATA,SH1,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R6,R7,R8,R9
/COM
/COM
/COM,----------- vmr027-cr10b-182 TIME HARDENING RESULTS COMPARISON -------------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
FINISH

*ELSEIF,I,EQ,2,THEN
/POST26
ESOL,3,1,,S,X,STRAINHA
PRVAR,3
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/YRANGE,0,160
/COLOR,CURVE,BLUE,1
PLVAR,3

/POST1
SET,1,1
*GET,S1,NODE,3,S,X
R11=S1/153.85
SET,,,,,,,9
*GET,S6,NODE,3,S,X
R66=S6/35.96
SET,,,,,,,14
*GET,S7,NODE,3,S,X
R77=S7/33.46
SET,,,,,,,54
*GET,S8,NODE,3,S,X
R88=S8/28.06
SET,,,,,,,104
*GET,S9,NODE,3,S,X
R99=S9/26.10
*DIM,VALUE2,,5,6
LABEL(1) = '0','50.0','100.0','500.0','1000.0'
*VFILL,VALUE2(1,1),DATA,153.85,35.96,33.46,28.06,26.10
*VFILL,VALUE2(1,2),DATA,S1,S6,S7,S8,S9
*VFILL,VALUE2(1,3),DATA,R11,R66,R77,R88,R99
/COM
/COM
/COM,--------- vmr027-cr10b-182 STRAIN HARDENING RESULTS COMPARISON ----------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO  |
/COM,
*VWRITE,LABEL(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
FINISH
*ENDIF
*ENDDO
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' S6 ',' S7 '
*VFILL,VALUE1(1,1),DATA,SH9,S9
*VFILL,VALUE1(1,2),DATA,R9,R99
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr10b-18','2'

/OUT,vmr027-cr10b-182,vrt
/COM
/COM,------------------- vmr027-cr10b RESULTS COMPARISON ---------------------
/COM,
```

```
/COM,             |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr10b-182,vrt
```

VM-R027-10B 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr10b-183
/TITLE,vmr027-cr10b-183,2D PLANE STRESS-BIAXIAL DISPLACEMENT PRIMARY CREEP
/COM, REFERENCE: TEST 10(B) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (TIME HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5.0
*SET,C3,-0.5
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (STRAIN HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183
KEYOPT,1,3,0
E,1,2,3,4,5,6,7,8
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,ALL
NSEL,S,LOC,Y,100
D,ALL,UY,-0.1
NSEL,ALL
```

```
*DO,I,1,2

/PREP7
*IF,I,EQ,1,THEN
/COM,
/COM, TIME HARDENING CASE
/COM,
MAT,1
*ELSEIF,I,EQ,2,THEN
/COM,
/COM, STRAIN HARDENING CASE
/COM,
MPCHG,2,ALL
*ENDIF

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
*IF,I,EQ,1,THEN
ESOL,2,1,,S,X,TIMEHARD
PRVAR,2
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/YRANGE,0,160
/COLOR,CURVE,RED,1
PLVAR,2
/NOERASE
```

```
/POST1
SET,1,1
*GET,SH1,NODE,3,S,X
R1=SH1/153.85
SET,,,,,,,9
*GET,SH6,NODE,3,S,X
R6=SH6/26.69
SET,,,,,,,14
*GET,SH7,NODE,3,S,X
R7=SH7/24.45
SET,,,,,,,54
*GET,SH8,NODE,3,S,X
R8=SH8/20.00
SET,,,,,,,104
*GET,SH9,NODE,3,S,X
R9=SH9/18.34
*DIM,VALUE,,5,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,153.85,26.69,24.45,20.00,18.34
*VFILL,VALUE(1,2),DATA,SH1,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R6,R7,R8,R9
/COM
/COM
/COM,--------- vmr027-cr10b-183 TIME HARDENING RESULTS COMPARISON ------------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
FINISH

*ELSEIF,I,EQ,2,THEN
/POST26
ESOL,3,1,,S,X,STRAINHA
PRVAR,3
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/YRANGE,0,160
/COLOR,CURVE,BLUE,1
PLVAR,3

/POST1
SET,1,1
*GET,S1,NODE,3,S,X
R11=S1/153.85
SET,,,,,,,9
*GET,S6,NODE,3,S,X
R66=S6/35.96
SET,,,,,,,14
*GET,S7,NODE,3,S,X
R77=S7/33.46
SET,,,,,,,54
*GET,S8,NODE,3,S,X
R88=S8/28.06
SET,,,,,,,104
*GET,S9,NODE,3,S,X
R99=S9/26.10
*DIM,VALUE2,,5,6
LABEL(1) = '0','50.0','100.0','500.0','1000.0'
*VFILL,VALUE2(1,1),DATA,153.85,35.96,33.46,28.06,26.10
*VFILL,VALUE2(1,2),DATA,S1,S6,S7,S8,S9
*VFILL,VALUE2(1,3),DATA,R11,R66,R77,R88,R99
/COM
/COM
/COM,-------- vmr027-cr10b-183 STRAIN HARDENING RESULTS COMPARISON ---------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO  |
/COM,
*VWRITE,LABEL(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
```

```
FINISH
*ENDIF
*ENDDO
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' S6 ',' S7 '
*VFILL,VALUE1(1,1),DATA,SH9,S9
*VFILL,VALUE1(1,2),DATA,R9,R99
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr10b-18','3'

/OUT,vmr027-cr10b-183,vrt
/COM
/COM,------------------- vmr027-cr10b RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr10b-183,vrt
```

VM-R027-10B 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr10b-281
/TITLE,vmr027-cr10b-281,2D PLANE STRESS-BIAXIAL DISPLACEMENT PRIMARY CREEP
/COM, REFERENCE: TEST 10(B) FROM NAFEMS R0027.
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (TIME HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5.0
*SET,C3,-0.5
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (STRAIN HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
```

```
N,7,50,100
N,8,0,50
N,9,50,50
N,10,25,0,0
N,11,75,0,0
N,12,0,25,0
N,13,50,25,0
N,14,100,25,0
N,15,25,50,0
N,16,75,50,0
N,17,0,75,0
N,18,50,75,0
N,19,100,75,0
N,20,25,100,0
N,21,75,100,0
ET,1,SHELL281,,,
R,1,1,1,1,1,
E,1,5,9,8,10,13,15,12
E,5,2,6,9,11,14,16,13
E,9,6,3,7,16,19,21,18
E,8,9,7,4,15,18,20,17
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,ALL
NSEL,S,LOC,Y,100
D,ALL,UY,-0.1
NSEL,ALL
D,13,UZ,0
D,13,ROTY,0
D,13,ROTX,0
FINISH
*DO,I,1,2
/PREP7
*IF,I,EQ,1,THEN
/COM,
/COM, TIME HARDENING CASE
/COM,
MAT,1
*ELSEIF,I,EQ,2,THEN
/COM,
/COM, STRAIN HARDENING CASE
/COM,
MPCHG,2,ALL
*ENDIF
/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
```

```
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
OUTRES,ALL,LAST
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH
/POST26
*IF,I,EQ,1,THEN
ESOL,2,1,,S,X,TIMEHARD
PRVAR,2
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/YRANGE,0,160
/COLOR,CURVE,RED,1
PLVAR,2
/NOERASE
/POST1
SET,1,1
*GET,SH1,NODE,3,S,X
R1=SH1/153.85
SET,,,,,,,9
*GET,SH6,NODE,3,S,X
R6=SH6/26.69
SET,,,,,,,14
*GET,SH7,NODE,3,S,X
R7=SH7/24.45
SET,,,,,,,54
*GET,SH8,NODE,3,S,X
R8=SH8/20.00
SET,,,,,,,104
*GET,SH9,NODE,3,S,X
R9=SH9/18.34
*DIM,VALUE,,5,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,153.85,26.69,24.45,20.00,18.34
*VFILL,VALUE(1,2),DATA,SH1,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R6,R7,R8,R9
/COM
/COM
/COM,----------- vmr027-cr10b-281 TIME HARDENING RESULTS COMPARISON ------------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
FINISH
*ELSEIF,I,EQ,2,THEN
/POST26
ESOL,3,1,,S,X,STRAINHA
PRVAR,3
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/YRANGE,0,160
/COLOR,CURVE,BLUE,1
```

```
PLVAR,3
/POST1
SET,1,1
*GET,S1,NODE,3,S,X
R11=S1/153.85
SET,,,,,,,9
*GET,S6,NODE,3,S,X
R66=S6/35.96
SET,,,,,,,14
*GET,S7,NODE,3,S,X
R77=S7/33.46
SET,,,,,,,54
*GET,S8,NODE,3,S,X
R88=S8/28.06
SET,,,,,,,104
*GET,S9,NODE,3,S,X
R99=S9/26.10
*DIM,VALUE2,,5,6
LABEL(1) = '0','50.0','100.0','500.0','1000.0'
*VFILL,VALUE2(1,1),DATA,153.85,35.96,33.46,28.06,26.10
*VFILL,VALUE2(1,2),DATA,S1,S6,S7,S8,S9
*VFILL,VALUE2(1,3),DATA,R11,R66,R77,R88,R99
/COM
/COM
/COM,------------ vmr027-cr10b-281 STRAIN HARDENING RESULTS COMPARISON -------------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL   |   RATIO   |
/COM,
*VWRITE,LABEL(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'    ',F13.3,'    ',1F13.3,'   ')
FINISH
*ENDIF
*ENDDO
FINISH
/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' S6 ',' S7 '
*VFILL,VALUE1(1,1),DATA,SH9,S9
*VFILL,VALUE1(1,2),DATA,R9,R99
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr10b-28','1'
/OUT,vmr027-cr10b-281,vrt
/COM
/COM,------------------- vmr027-cr10b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL    |   RATIO   |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'       ',F9.4,'      ',A7,A8,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'       ',F9.4,'      ',A7,A8,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr027-cr10b-281,vrt
```

VM-R027-10C 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr10c-181
/TITLE,vmr027-cr10c-181,2D PLANE STRESS-BIAXIAL STEPPED LOAD PRIMARY CREEP
/COM, REFERENCE: TEST 10(C) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
```

```
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(STRAIN HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** ELASTIC CONSTANT
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
ET,1,181,,,
R,1,1,1,1,1,
E,1,5,9,8
E,5,2,6,9
E,9,6,3,7
E,8,9,7,4
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,
D,ALL,UY,
NSEL,ALL
D,ALL,UZ
D,ALL,ROTX
D,ALL,ROTY

*DO,I,1,2
*STATUS,I

/PREP7
*IF,I,EQ,1,THEN
MAT,1
*ELSEIF,I,EQ,2,THEN
MPCHG,2,ALL
*ENDIF
FINI

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL

RATE,ON,ON
TIME,1E-8
/OUTPUT,SCRATCH
SOLVE
/OUT
```

```
RATE,ON,ON
NSUBST,20,20,20
TIME,1.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,20,20,20
TIME,10.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,20,20,20
TIME,50.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,50,50,50
TIME,100.0
/OUTPUT,SCRATCH
SOLVE
/OUT

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-250
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,250
NSEL,ALL
RATE,ON,ON
NSUBST,50,50,50
TIME,110.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,50,50,50
TIME,120.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,50,50,50
TIME,150.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
NSUBST,50,50,50
TIME,200
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST1
*IF,I,EQ,1,THEN
SET,,,,,,,1
*GET,S1,NODE,1,EPCR,X
R1=1.00
SET,,,,,,,2
*GET,S2,NODE,1,EPCR,X
R2=S2/0.135
SET,,,,,,,3
*GET,S3,NODE,1,EPCR,X
R3=S3/0.4269
SET,,,,,,,4
*GET,S4,NODE,1,EPCR,X
R4=S4/0.9546
```

```
SET,,,,,,,5
*GET,S5,NODE,1,EPCR,X
R5=S5/1.35
SET,,,,,,,6
*GET,S6,NODE,1,EPCR,X
R6=S6/1.5511
SET,,,,,,,7
*GET,S7,NODE,1,EPCR,X
R7=S7/1.7433
SET,,,,,,,8
*GET,S8,NODE,1,EPCR,X
R8=S8/2.276
SET,,,,,,,9
*GET,S9,NODE,1,EPCR,X
R9=S9/3.0565
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','1.0', '10.0', '50.0', '100.0', '110.0','120.0','150.0','200.0'
*VFILL,VALUE(1,1),DATA,0.0000,0.1350,0.4269,0.9546,1.3500,1.5511,1.7433,2.2760,3.0565
*VFILL,VALUE(1,2),DATA,S1,S2,S3,S4,S5,S6,S7,S8,S9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9

*ELSEIF,I,EQ,2,THEN
SET,,,,,,,1
*GET,SH1,NODE,1,EPCR,X
R10=1.00
SET,,,,,,,2
*GET,SH2,NODE,1,EPCR,X
R11=SH2/0.135
SET,,,,,,,3
*GET,SH3,NODE,1,EPCR,X
R12=SH3/0.4269
SET,,,,,,,4
*GET,SH4,NODE,1,EPCR,X
R13=SH4/0.9546
SET,,,,,,,5
*GET,SH5,NODE,1,EPCR,X
R14=SH5/1.35
SET,,,,,,,6
*GET,SH6,NODE,1,EPCR,X
R15=SH6/1.8762
SET,,,,,,,7
*GET,SH7,NODE,1,EPCR,X
R16=SH7/2.2842
SET,,,,,,,8
*GET,SH8,NODE,1,EPCR,X
R17=SH8/3.2108
SET,,,,,,,9
*GET,SH9,NODE,1,EPCR,X
R18=SH9/4.3354
*DIM,VALUE2,,9,3
*DIM,LABEL2,CHAR,10
LABEL2(1) = '0','1.0', '10.0', '50.0', '100.0', '110.0','120.0','150.0','200.0'
*VFILL,VALUE2(1,1),DATA,0.0000,0.1350,0.4269,0.9546,1.3500,1.8762,2.2842,3.2108,4.3354
*VFILL,VALUE2(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE2(1,3),DATA,R10,R11,R12,R13,R14,R15,R16,R17,R18
*ENDIF

/POST26
*IF,I,EQ,1,THEN
ESOL,2,1,,EPCR,X,TIMEHARD
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/XRANGE,0,200
/YRANGE,0,5
/COLOR,CURVE,BLUE,1
PLVAR,2
/NOERASE
*ELSEIF,I,EQ,2,THEN
ESOL,3,1,,EPCR,X,STRAINHA
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
```

```
/COLOR,CURVE,RED,1
/XRANGE,0,200
/YRANGE,0,5
PLVAR,3
*ENDIF
*ENDDO

/COM
/COM
/COM,----------- vmr027-cr10c-181 TIME HARDENING RESULTS COMPARISON -------------
/COM,
/COM, vmr027-cr10c-181.jpeg RESULTS SHOULD MATCH R0027 NAFEMS MANUAL
/COM, GRAPH RESULTS OF TEST 10(C).
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
/COM,
/COM,
/COM,----------- vmr027-cr10c-181 STRAIN HARDENING RESULTS COMPARISON -------------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL2(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' S2 ',' S7 '
*VFILL,VALUE1(1,1),DATA,S9,SH9
*VFILL,VALUE1(1,2),DATA,R9,R18
*DIM,LABEL3,CHAR,3
LABEL3(1) = 'vmr027-','cr10c-18','1'

/OUT,vmr027-cr10c-181,vrt
/COM
/COM,------------------- vmr027-cr10c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL3(1),LABEL3(2),LABEL3(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL3(1),LABEL3(2),LABEL3(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,---------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr10c-181,vrt
```

VM-R027-10C 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr10c-182
/TITLE,vmr027-cr10c-182,2D PLANE STRESS-BIAXIAL STEPPED LOAD PRIMARY CREEP
/COM, REFERENCE: TEST 10(C) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
```

```
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(STRAIN HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** ELASTIC CONSTANT
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
ET,1,182
KEYOPT,1,1,1
KEYOPT,1,3,0
E,1,5,9,8
E,5,2,6,9
E,9,6,3,7
E,8,9,7,4
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,
D,ALL,UY,
NSEL,ALL

*DO,I,1,2
*STATUS,I

/PREP7
*IF,I,EQ,1,THEN
MAT,1
*ELSEIF,I,EQ,2,THEN
MPCHG,2,ALL
*ENDIF
FINI

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL

RATE,ON,ON
TIME,1E-8
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,20,20,20
TIME,1.0
/OUTPUT,SCRATCH
SOLVE
/OUT
```

```
RATE,ON,ON
NSUBST,20,20,20
TIME,10.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,20,20,20
TIME,50.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,50,50,50
TIME,100.0
/OUTPUT,SCRATCH
SOLVE
/OUT

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-250
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,250
NSEL,ALL
RATE,ON,ON
NSUBST,50,50,50
TIME,110.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,50,50,50
TIME,120.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,50,50,50
TIME,150.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
NSUBST,50,50,50
TIME,200
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST1
*IF,I,EQ,1,THEN
SET,,,,,,,1
*GET,S1,NODE,1,EPCR,X
R1=1.00
SET,,,,,,,2
*GET,S2,NODE,1,EPCR,X
R2=S2/0.135
SET,,,,,,,3
*GET,S3,NODE,1,EPCR,X
R3=S3/0.4269
SET,,,,,,,4
*GET,S4,NODE,1,EPCR,X
R4=S4/0.9546
SET,,,,,,,5
*GET,S5,NODE,1,EPCR,X
R5=S5/1.35
SET,,,,,,,6
*GET,S6,NODE,1,EPCR,X
R6=S6/1.5511
```

```
SET,,,,,,,7
*GET,S7,NODE,1,EPCR,X
R7=S7/1.7433
SET,,,,,,,8
*GET,S8,NODE,1,EPCR,X
R8=S8/2.276
SET,,,,,,,9
*GET,S9,NODE,1,EPCR,X
R9=S9/3.0565
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','1.0', '10.0', '50.0', '100.0', '110.0','120.0','150.0','200.0'
*VFILL,VALUE(1,1),DATA,0.0000,0.1350,0.4269,0.9546,1.3500,1.5511,1.7433,2.2760,3.0565
*VFILL,VALUE(1,2),DATA,S1,S2,S3,S4,S5,S6,S7,S8,S9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9

*ELSEIF,I,EQ,2,THEN
SET,,,,,,,1
*GET,SH1,NODE,1,EPCR,X
R10=1.00
SET,,,,,,,2
*GET,SH2,NODE,1,EPCR,X
R11=SH2/0.135
SET,,,,,,,3
*GET,SH3,NODE,1,EPCR,X
R12=SH3/0.4269
SET,,,,,,,4
*GET,SH4,NODE,1,EPCR,X
R13=SH4/0.9546
SET,,,,,,,5
*GET,SH5,NODE,1,EPCR,X
R14=SH5/1.35
SET,,,,,,,6
*GET,SH6,NODE,1,EPCR,X
R15=SH6/1.8762
SET,,,,,,,7
*GET,SH7,NODE,1,EPCR,X
R16=SH7/2.2842
SET,,,,,,,8
*GET,SH8,NODE,1,EPCR,X
R17=SH8/3.2108
SET,,,,,,,9
*GET,SH9,NODE,1,EPCR,X
R18=SH9/4.3354
*DIM,VALUE2,,9,3
*DIM,LABEL2,CHAR,10
LABEL2(1) = '0','1.0', '10.0', '50.0', '100.0', '110.0','120.0','150.0','200.0'
*VFILL,VALUE2(1,1),DATA,0.0000,0.1350,0.4269,0.9546,1.3500,1.8762,2.2842,3.2108,4.3354
*VFILL,VALUE2(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE2(1,3),DATA,R10,R11,R12,R13,R14,R15,R16,R17,R18
*ENDIF

/POST26
*IF,I,EQ,1,THEN
ESOL,2,1,,EPCR,X,TIMEHARD
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/XRANGE,0,200
/YRANGE,0,5
/COLOR,CURVE,BLUE,1
PLVAR,2
/NOERASE
*ELSEIF,I,EQ,2,THEN
ESOL,3,1,,EPCR,X,STRAINHA
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/COLOR,CURVE,RED,1
/XRANGE,0,200
/YRANGE,0,5
PLVAR,3
*ENDIF
*ENDDO
```

```
/COM
/COM
/COM,----------- vmr027-cr10c-182 TIME HARDENING RESULTS COMPARISON -------------
/COM,
/COM, vmr027-cr10c-182.jpeg RESULTS SHOULD MATCH R0027 NAFEMS MANUAL
/COM, GRAPH RESULTS OF TEST 10(C).
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
/COM,
/COM,
/COM,----------- vmr027-cr10c-182 STRAIN HARDENING RESULTS COMPARISON -------------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL2(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' S2 ',' S7 '
*VFILL,VALUE1(1,1),DATA,S9,SH9
*VFILL,VALUE1(1,2),DATA,R9,R18
*DIM,LABEL3,CHAR,3
LABEL3(1) = 'vmr027-','cr10c-18','2'

/OUT,vmr027-cr10c-182,vrt
/COM
/COM,------------------- vmr027-cr10c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL3(1),LABEL3(2),LABEL3(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL3(1),LABEL3(2),LABEL3(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,--------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr10c-182,vrt
```

VM-R027-10C 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr10c-183
/TITLE,vmr027-cr10c-183,2D PLANE STRESS-BIAXIAL STEPPED LOAD PRIMARY CREEP
/COM, REFERENCE: TEST 10(C) FROM NAFEMS R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
```

```
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(STRAIN HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** ELASTIC CONSTANT
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183
KEYOPT,1,3,0
E,1,2,3,4,5,6,7,8
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,
D,ALL,UY,
NSEL,ALL

*DO,I,1,2
*STATUS,I

/PREP7
*IF,I,EQ,1,THEN
MAT,1
*ELSEIF,I,EQ,2,THEN
MPCHG,2,ALL
*ENDIF
FINI

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL

RATE,ON,ON
TIME,1E-8
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,20,20,20
TIME,1.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,20,20,20
TIME,10.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,20,20,20
TIME,50.0
/OUTPUT,SCRATCH
SOLVE
```

```
/OUT
RATE,ON,ON
NSUBST,50,50,50
TIME,100.0
/OUTPUT,SCRATCH
SOLVE
/OUT

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-250
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,250
NSEL,ALL
RATE,ON,ON
NSUBST,50,50,50
TIME,110.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,50,50,50
TIME,120.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,50,50,50
TIME,150.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
NSUBST,50,50,50
TIME,200
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST1
*IF,I,EQ,1,THEN
SET,,,,,,,1
*GET,S1,NODE,1,EPCR,X
R1=1.00
SET,,,,,,,2
*GET,S2,NODE,1,EPCR,X
R2=S2/0.135
SET,,,,,,,3
*GET,S3,NODE,1,EPCR,X
R3=S3/0.4269
SET,,,,,,,4
*GET,S4,NODE,1,EPCR,X
R4=S4/0.9546
SET,,,,,,,5
*GET,S5,NODE,1,EPCR,X
R5=S5/1.35
SET,,,,,,,6
*GET,S6,NODE,1,EPCR,X
R6=S6/1.5511
SET,,,,,,,7
*GET,S7,NODE,1,EPCR,X
R7=S7/1.7433
SET,,,,,,,8
*GET,S8,NODE,1,EPCR,X
R8=S8/2.276
SET,,,,,,,9
*GET,S9,NODE,1,EPCR,X
R9=S9/3.0565
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
```

```
LABEL(1) = '0','1.0', '10.0', '50.0', '100.0', '110.0','120.0','150.0','200.0'
*VFILL,VALUE(1,1),DATA,0.0000,0.1350,0.4269,0.9546,1.3500,1.5511,1.7433,2.2760,3.0565
*VFILL,VALUE(1,2),DATA,S1,S2,S3,S4,S5,S6,S7,S8,S9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9

*ELSEIF,I,EQ,2,THEN
SET,,,,,,,1
*GET,SH1,NODE,1,EPCR,X
R10=1.00
SET,,,,,,,2
*GET,SH2,NODE,1,EPCR,X
R11=SH2/0.135
SET,,,,,,,3
*GET,SH3,NODE,1,EPCR,X
R12=SH3/0.4269
SET,,,,,,,4
*GET,SH4,NODE,1,EPCR,X
R13=SH4/0.9546
SET,,,,,,,5
*GET,SH5,NODE,1,EPCR,X
R14=SH5/1.35
SET,,,,,,,6
*GET,SH6,NODE,1,EPCR,X
R15=SH6/1.8762
SET,,,,,,,7
*GET,SH7,NODE,1,EPCR,X
R16=SH7/2.2842
SET,,,,,,,8
*GET,SH8,NODE,1,EPCR,X
R17=SH8/3.2108
SET,,,,,,,9
*GET,SH9,NODE,1,EPCR,X
R18=SH9/4.3354
*DIM,VALUE2,,9,3
*DIM,LABEL2,CHAR,10
LABEL2(1) = '0','1.0', '10.0', '50.0', '100.0', '110.0','120.0','150.0','200.0'
*VFILL,VALUE2(1,1),DATA,0.0000,0.1350,0.4269,0.9546,1.3500,1.8762,2.2842,3.2108,4.3354
*VFILL,VALUE2(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE2(1,3),DATA,R10,R11,R12,R13,R14,R15,R16,R17,R18
*ENDIF

/POST26
*IF,I,EQ,1,THEN
ESOL,2,1,,EPCR,X,TIMEHARD
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/XRANGE,0,200
/YRANGE,0,5
/COLOR,CURVE,BLUE,1
PLVAR,2
/NOERASE
*ELSEIF,I,EQ,2,THEN
ESOL,3,1,,EPCR,X,STRAINHA
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/COLOR,CURVE,RED,1
/XRANGE,0,200
/YRANGE,0,5
PLVAR,3
*ENDIF
*ENDDO

/COM
/COM
/COM,----------- vmr027-cr10c-183 TIME HARDENING RESULTS COMPARISON -------------
/COM,
/COM, vmr027-cr10c-183.jpeg RESULTS SHOULD MATCH R0027 NAFEMS MANUAL
/COM, GRAPH RESULTS OF TEST 10(C).
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
```

```
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
/COM,
/COM,
/COM,----------- vmr027-cr10c-183 STRAIN HARDENING RESULTS COMPARISON -------------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL2(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' S2 ',' S7 '
*VFILL,VALUE1(1,1),DATA,S9,SH9
*VFILL,VALUE1(1,2),DATA,R9,R18
*DIM,LABEL3,CHAR,3
LABEL3(1) = 'vmr027-','cr10c-18','3'

/OUT,vmr027-cr10c-183,vrt
/COM
/COM,------------------- vmr027-cr10c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL3(1),LABEL3(2),LABEL3(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL3(1),LABEL3(2),LABEL3(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr10c-183,vrt
```

VM-R027-10C 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr10c-281
/TITLE,vmr027-cr10c-281,2D PLANE STRESS-BIAXIAL STEPPED LOAD PRIMARY CREEP
/COM, REFERENCE: TEST 10(C) FROM NAFEMS R0027.
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(STRAIN HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** ELASTIC CONSTANT
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
```

```
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
N,10,25,0,0
N,11,75,0,0
N,12,0,25,0
N,13,50,25,0
N,14,100,25,0
N,15,25,50,0
N,16,75,50,0
N,17,0,75,0
N,18,50,75,0
N,19,100,75,0
N,20,25,100,0
N,21,75,100,0
ET,1,SHELL281,,,
R,1,1,1,1,1,
E,1,5,9,8,10,13,15,12
E,5,2,6,9,11,14,16,13
E,9,6,3,7,16,19,21,18
E,8,9,7,4,15,18,20,17
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,
D,ALL,UY,
NSEL,ALL
D,ALL,UZ
D,ALL,ROTX
D,ALL,ROTY
*DO,I,1,2
*STATUS,I
/PREP7
*IF,I,EQ,1,THEN
MAT,1
*ELSEIF,I,EQ,2,THEN
MPCHG,2,ALL
*ENDIF
FINI
/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,200
NSEL,ALL
RATE,ON,ON
TIME,1E-8
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,20,20,20
TIME,1.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,20,20,20
TIME,10.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,20,20,20
```

```
TIME,50.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,50,50,50
TIME,100.0
/OUTPUT,SCRATCH
SOLVE
/OUT
/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-250
NSEL,ALL
NSEL,S,LOC,Y,100
SF,ALL,PRES,250
NSEL,ALL
RATE,ON,ON
NSUBST,50,50,50
TIME,110.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,50,50,50
TIME,120.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
NSUBST,50,50,50
TIME,150.0
/OUTPUT,SCRATCH
SOLVE
/OUT
RATE, ON, ON
NSUBST,50,50,50
TIME,200
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH
/POST1
*IF,I,EQ,1,THEN
SET,,,,,,,1
*GET,S1,NODE,1,EPCR,X
R1=1.00
SET,,,,,,,2
*GET,S2,NODE,1,EPCR,X
R2=S2/0.135
SET,,,,,,,3
*GET,S3,NODE,1,EPCR,X
R3=S3/0.4269
SET,,,,,,,4
*GET,S4,NODE,1,EPCR,X
R4=S4/0.9546
SET,,,,,,,5
*GET,S5,NODE,1,EPCR,X
R5=S5/1.35
SET,,,,,,,6
*GET,S6,NODE,1,EPCR,X
R6=S6/1.5511
SET,,,,,,,7
*GET,S7,NODE,1,EPCR,X
R7=S7/1.7433
SET,,,,,,,8
*GET,S8,NODE,1,EPCR,X
R8=S8/2.276
SET,,,,,,,9
*GET,S9,NODE,1,EPCR,X
R9=S9/3.0565
*DIM,VALUE,,9,3
```

```
*DIM,LABEL,CHAR,10
LABEL(1) = '0','1.0', '10.0', '50.0', '100.0', '110.0','120.0','150.0','200.0'
*VFILL,VALUE(1,1),DATA,0.0000,0.1350,0.4269,0.9546,1.3500,1.5511,1.7433,2.2760,3.0565
*VFILL,VALUE(1,2),DATA,S1,S2,S3,S4,S5,S6,S7,S8,S9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
*ELSEIF,I,EQ,2,THEN
SET,,,,,,,1
*GET,SH1,NODE,1,EPCR,X
R10=1.00
SET,,,,,,,2
*GET,SH2,NODE,1,EPCR,X
R11=SH2/0.135
SET,,,,,,,3
*GET,SH3,NODE,1,EPCR,X
R12=SH3/0.4269
SET,,,,,,,4
*GET,SH4,NODE,1,EPCR,X
R13=SH4/0.9546
SET,,,,,,,5
*GET,SH5,NODE,1,EPCR,X
R14=SH5/1.35
SET,,,,,,,6
*GET,SH6,NODE,1,EPCR,X
R15=SH6/1.8762
SET,,,,,,,7
*GET,SH7,NODE,1,EPCR,X
R16=SH7/2.2842
SET,,,,,,,8
*GET,SH8,NODE,1,EPCR,X
R17=SH8/3.2108
SET,,,,,,,9
*GET,SH9,NODE,1,EPCR,X
R18=SH9/4.3354
*DIM,VALUE2,,9,3
*DIM,LABEL2,CHAR,10
LABEL2(1) = '0','1.0', '10.0', '50.0', '100.0', '110.0','120.0','150.0','200.0'
*VFILL,VALUE2(1,1),DATA,0.0000,0.1350,0.4269,0.9546,1.3500,1.8762,2.2842,3.2108,4.3354
*VFILL,VALUE2(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE2(1,3),DATA,R10,R11,R12,R13,R14,R15,R16,R17,R18
*ENDIF
/POST26
*IF,I,EQ,1,THEN
ESOL,2,1,,EPCR,X,TIMEHARD
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/XRANGE,0,200
/YRANGE,0,5
/COLOR,CURVE,BLUE,1
PLVAR,2
/NOERASE
*ELSEIF,I,EQ,2,THEN
ESOL,3,1,,EPCR,X,STRAINHA
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/COLOR,CURVE,RED,1
/XRANGE,0,200
/YRANGE,0,5
PLVAR,3
*ENDIF
*ENDDO
/COM
/COM
/COM,----------- vmr027-cr10c-281 TIME HARDENING RESULTS COMPARISON -------------
/COM,
/COM, vmr027-cr10c-281.jpeg RESULTS SHOULD MATCH R0027 NAFEMS MANUAL
/COM, GRAPH RESULTS OF TEST 10(C).
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
/COM,
```

```
/COM,
/COM,----------- vmr027-cr10c-281 STRAIN HARDENING RESULTS COMPARISON -------------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL2(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3,'   ')
FINISH
/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' S2 ',' S7 '
*VFILL,VALUE1(1,1),DATA,S9,SH9
*VFILL,VALUE1(1,2),DATA,R9,R18
*DIM,LABEL3,CHAR,3
LABEL3(1) = 'vmr027-','cr10c-28','1'
/OUT,vmr027-cr10c-281,vrt
/COM
/COM,------------------- vmr027-cr10c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL3(1),LABEL3(2),LABEL3(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL3(1),LABEL3(2),LABEL3(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr027-cr10c-281,vrt
```

VM-R027-12B 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr12b-181
/TITLE,vmr027-cr12b-181,2D PLANE STRESS-UNIAXIAL DISPLACEMENT PRIMARY-SECONDARY CREEP
/COM,THE COMPARISON IS MADE GRAPHICALLY AND QUANTITATIVELY WITH THE
/COM,RESULTS OF THE TEST 12(B)FROM NAFEMS REPORT R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(PRIMARY AND SECONDARY CREEP)***
*SET,C1,0.5E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
*SET,C5,1E-16
*SET,C6,5
*SET,C7,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,11
TBDATA,1,C1,C2,C3,C4,C5,C6
TBDATA,7,C7
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
```

```
N,9,50,50
ET,1,181,,,
R,1,1,1,1,1,
E,1,5,9,8
E,5,2,6,9
E,9,6,3,7
E,8,9,7,4
NSEL,S,LOC,X,0
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,50
NSEL,R,LOC,X,0
D,ALL,UY,
NSEL,ALL
D,9,UZ,0
D,9,ROTX,0
D,9,ROTY,0
FINISH

/SOLU
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
```

```
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,5
/GROPT,DIVY,9
/XRANGE,0,1000
/YRANGE,0,225
ESOL,2,1,,S,X
PLVAR,2
PRVAR,2

/POST1
SET,1,1
*GET,SH1,NODE,3,S,X
R1=SH1/200.0
SET,,,,,,,9
*GET,SH6,NODE,3,S,X
R6=SH6/63.58
SET,,,,,,,14
*GET,SH7,NODE,3,S,X
R7=SH7/57.96
SET,,,,,,,54
*GET,SH8,NODE,3,S,X
R8=SH8/46.20
SET,,,,,,,104
*GET,SH9,NODE,3,S,X
R9=SH9/41.61
*DIM,VALUE,,5,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,200.00,63.58,57.96,46.20,41.61
*VFILL,VALUE(1,2),DATA,SH1,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R6,R7,R8,R9
/COM
/COM
/COM,--------- vmr027-cr12b-181 RESULTS COMPARISON-----------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F15.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR11X ',' ECR11Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr12b-18','1'

/OUT,vmr027-cr12b-181,vrt
/COM
/COM,------------------- vmr027-cr12b RESULTS COMPARISON ---------------------
/COM,
/COM,           |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,-----------------------------------------------------------
/OUT

FINISH
```

```
*LIST,vmr027-cr12b-181,vrt
```

VM-R027-12B 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr12b-182
/TITLE,vmr027-cr12b-182,2D PLANE STRESS-UNIAXIAL DISPLACEMENT PRIMARY-SECONDARY CREEP
/COM,THE COMPARISON IS MADE GRAPHICALLY AND QUANTITATIVELY WITH THE
/COM RESULTS OF THE TEST 12(B)FROM NAFEMS REPORT R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(PRIMARY AND SECONDARY CREEP)***
*SET,C1,0.5E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
*SET,C5,1E-16
*SET,C6,5
*SET,C7,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,11
TBDATA,1,C1,C2,C3,C4,C5,C6
TBDATA,7,C7
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
ET,1,182
KEYOPT,1,1,1
KEYOPT,1,3,0
E,1,5,9,8
E,5,2,6,9
E,9,6,3,7
E,8,9,7,4
NSEL,S,LOC,X,0
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,50
NSEL,R,LOC,X,0
D,ALL,UY,
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
/OUTPUT,SCRATCH
```

```
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,5
/GROPT,DIVY,9
/XRANGE,0,1000
/YRANGE,0,225
ESOL,2,1,,S,X
PLVAR,2
PRVAR,2

/POST1
SET,1,1
*GET,SH1,NODE,3,S,X
R1=SH1/200.0
SET,,,,,,,9
*GET,SH6,NODE,3,S,X
R6=SH6/63.58
SET,,,,,,,14
*GET,SH7,NODE,3,S,X
R7=SH7/57.96
SET,,,,,,,54
*GET,SH8,NODE,3,S,X
R8=SH8/46.20
SET,,,,,,,104
*GET,SH9,NODE,3,S,X
R9=SH9/41.61
*DIM,VALUE,,5,3
```

```
*DIM,LABEL,CHAR,10
LABEL(1) = '0','50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,200.0,63.58,57.96,46.20,41.61
*VFILL,VALUE(1,2),DATA,SH1,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R6,R7,R8,R9
/COM
/COM
/COM,--------- vmr027-cr12b-182 RESULTS COMPARISON----------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR11X ',' ECR11Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr12b-18','2'

/OUT,vmr027-cr12b-182,vrt
/COM
/COM,------------------- vmr027-cr12b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL    |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr12b-182,vrt
```

VM-R027-12B 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr12b-183
/TITLE,vmr027-cr12b-183,2D PLANE STRESS-UNIAXIAL DISPLACEMENT PRIMARY-SECONDARY CREEP
/COM,THE COMPARISON IS MADE GRAPHICALLY AND QUANTITATIVELY WITH
/COM THE RESULTS OF THE TEST 12(B) FROM NAFEMS REPORT R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(PRIMARY AND SECONDARY CREEP)***
*SET,C1,0.5E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
*SET,C5,1E-16
*SET,C6,5
*SET,C7,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,11
TBDATA,1,C1,C2,C3,C4,C5,C6
TBDATA,7,C7
N,1,0,0,0
```

```
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183
KEYOPT,1,3,0
E,1,2,3,4,5,6,7,8
NSEL,S,LOC,X,0
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,50
NSEL,R,LOC,X,0
D,ALL,UY,
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
OUTPR,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
```

```
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,5
/GROPT,DIVY,9
/XRANGE,0,1000
/YRANGE,0,225
ESOL,2,1,,S,X
PLVAR,2
PRVAR,2

/POST1
SET,1,1
*GET,SH1,NODE,3,S,X
R1=SH1/200.0
SET,,,,,,,9
*GET,SH6,NODE,3,S,X
R6=SH6/63.58
SET,,,,,,,14
*GET,SH7,NODE,3,S,X
R7=SH7/57.96
SET,,,,,,,54
*GET,SH8,NODE,3,S,X
R8=SH8/46.20
SET,,,,,,,104
*GET,SH9,NODE,3,S,X
R9=SH9/41.61
*DIM,VALUE,,5,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,200.0,63.58,57.96,46.20,41.61
*VFILL,VALUE(1,2),DATA,SH1,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R6,R7,R8,R9
/COM
/COM
/COM,--------- vmr027-cr12b-183 RESULTS COMPARISON-----------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR11X ',' ECR11Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr12b-18','3'

/OUT,vmr027-cr12b-183,vrt
/COM
/COM,------------------- vmr027-cr12b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,-----------------------------------------------------------
/OUT

FINISH
```

```
*LIST,vmr027-cr12b-183,vrt
```

VM-R027-12B 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr12b-281
/TITLE,vmr027-cr12b-281,2D PLANE STRESS-UNIAXIAL DISPLACEMENT PRIMARY-SECONDARY CREEP
/COM,THE COMPARISON IS MADE GRAPHICALLY AND QUANTITATIVELY WITH THE
/COM,RESULTS OF THE TEST 12(B)FROM NAFEMS REPORT R0027.
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(PRIMARY AND SECONDARY CREEP)***
*SET,C1,0.5E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
*SET,C5,1E-16
*SET,C6,5
*SET,C7,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,11
TBDATA,1,C1,C2,C3,C4,C5,C6
TBDATA,7,C7
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
N,10,25,0,0
N,11,75,0,0
N,12,0,25,0
N,13,50,25,0
N,14,100,25,0
N,15,25,50,0
N,16,75,50,0
N,17,0,75,0
N,18,50,75,0
N,19,100,75,0
N,20,25,100,0
N,21,75,100,0
ET,1,SHELL281,,,
R,1,1,1,1,1,
E,1,5,9,8,10,13,15,12
E,5,2,6,9,11,14,16,13
E,9,6,3,7,16,19,21,18
E,8,9,7,4,15,18,20,17
NSEL,S,LOC,X,0
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,50
NSEL,R,LOC,X,0
D,ALL,UY,
NSEL,ALL
D,ALL,UZ
/SOLU
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,ALL
RATE, OFF
```



```
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH
/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,5
/GROPT,DIVY,9
/XRANGE,0,1000
/YRANGE,0,225
ESOL,2,1,,S,X
PLVAR,2
PRVAR,2
/POST1
SET,1,1
*GET,SH1,NODE,3,S,X
R1=SH1/200.0
SET,,,,,,,9
*GET,SH6,NODE,3,S,X
R6=SH6/63.58
SET,,,,,,,14
*GET,SH7,NODE,3,S,X
```

```
R7=SH7/57.96
SET,,,,,,,54
*GET,SH8,NODE,3,S,X
R8=SH8/46.20
SET,,,,,,,104
*GET,SH9,NODE,3,S,X
R9=SH9/41.61
*DIM,VALUE,,5,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','50.0','100.0','500.0','1000.0'
*VFILL,VALUE(1,1),DATA,200.00,63.58,57.96,46.20,41.61
*VFILL,VALUE(1,2),DATA,SH1,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R6,R7,R8,R9
/COM
/COM
/COM,--------- vmr027-cr12b-281 RESULTS COMPARISON----------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.3,'   ',F13.3,'   ',1F13.3)
FINISH
/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR11X ',' ECR11Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr12b-28','1'
/OUT,vmr027-cr12b-281,vrt
/COM
/COM,---------------- vmr027-cr12b RESULTS COMPARISON ------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,---------------------------------------------------------------
/OUT
FINISH
*LIST,vmr027-cr12b-281,vrt
```

VM-R027-12C 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr12c-181
/TITLE,vmr027-cr12c-181,2D PLANE STRESS-STEPPED LOAD PRIMARY-SECONDARY CREEP
/COM, REFERENCE: TEST 12(C) FROM NAFEMS REPORT R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(PRIMARY AND SECONDARY CREEP)***
*SET,C1,0.5E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
*SET,C5,1E-16
*SET,C6,5
*SET,C7,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
```

```
TB,CREEP,1,,,11
TBDATA,1,C1,C2,C3,C4,C5,C6
TBDATA,7,C7
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
ET,1,181,,,
R,1,1,1,1,1,
E,1,5,9,8
E,5,2,6,9
E,9,6,3,7
E,8,9,7,4

NSEL,S,LOC,X,0
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,50
NSEL,R,LOC,X,0
D,ALL,UY,
NSEL,ALL
D,ALL,UZ
D,ALL,ROTX
D,ALL,ROTY

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-100
NSEL,ALL
RATE, ON
TIME, 1.0E-8
/OUT,SCRATCH
SOLVE
/OUT
RATE, ON
TIME,10
/OUT,SCRATCH
SOLVE
/OUT
RATE, ON
TIME,100
/OUT,SCRATCH
SOLVE
/OUT
RATE, ON
TIME,1000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON
TIME,10000
/OUT,SCRATCH
SOLVE
/OUT

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-110
NSEL,ALL
RATE,ON,ON
DELT,1000,999.999,1000.0001
AUTOS,OFF
OUTRES,ALL,ALL
TIME,11000
/OUT,SCRATCH
SOLVE
```

```
/OUT
RATE,ON,ON
DELT,1000
AUTOS,OFF
OUTRES,ALL,ALL
TIME,12000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
DELT,1000
AUTOS,OFF
OUTRES,ALL,ALL
TIME,15000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
DELT,1000
AUTOS,OFF
OUTRES,ALL,ALL
TIME,20000
/OUT,SCRATCH
SOLVE
/OUT

/POST26
ESOL,2,1,,EPCR,X
PRVAR,2
/AXLAB,Y,CREEP STRAIN
PLVAR,2

/POST1
SET,,,,,,,1
*GET,SH1,NODE,3,EPCR,X
R1=1.0
SET,,,,,,,2
*GET,SH2,NODE,3,EPCR,X
R2=SH2/0.000326
SET,,,,,,,3
*GET,SH3,NODE,3,EPCR,X
R3=SH3/0.00110
SET,,,,,,,4
*GET,SH4,NODE,3,EPCR,X
R4=SH4/0.00416
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,X
R5=SH5/0.02
SET,,,,,,,6
*GET,SH6,NODE,3,EPCR,X
R6=SH6/0.02240
SET,,,,,,,7
*GET,SH7,NODE,3,EPCR,X
R7=SH7/0.02476
SET,,,,,,,10
*GET,SH8,NODE,3,EPCR,X
R8=SH8/0.03167
SET,,,,,,,15
*GET,SH9,NODE,3,EPCR,X
R9=SH9/0.04278
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','10', '100', '1000', '10000', '11000','12000','15000','20000'
*VFILL,VALUE(1,1),DATA,0.0,0.000326,0.00110,0.00416,0.02,0.02240,0.02476,0.03167,0.04278
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/COM
/COM
/COM,--------- vmr027-cr12c-181 RESULTS COMPARISON-----------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
```

```
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.6,'   ',F13.6,'   ',1F13.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR11X ',' ECR11Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr12c-18','1'

/OUT,vmr027-cr12c-181,vrt
/COM
/COM,------------------- vmr027-cr12c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr12c-181,vrt
```

VM-R027-12C 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr12c-182
/TITLE,vmr027-cr12c-182,2D PLANE STRESS-STEPPED LOAD PRIMARY-SECONDARY CREEP
/COM, REFERENCE: TEST 12(C) FROM NAFEMS REPORT R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(PRIMARY AND SECONDARY CREEP)***
*SET,C1,0.5E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
*SET,C5,1E-16
*SET,C6,5
*SET,C7,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,11
TBDATA,1,C1,C2,C3,C4,C5,C6
TBDATA,7,C7
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
ET,1,182
KEYOPT,1,1,1
KEYOPT,1,3,0
```

```
E,1,5,9,8
E,5,2,6,9
E,9,6,3,7
E,8,9,7,4
NSEL,S,LOC,X,0
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,50
NSEL,R,LOC,X,0
D,ALL,UY,
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-100
NSEL,ALL
RATE, ON
TIME, 1.0E-8
/OUT,SCRATCH
SOLVE
/OUT
RATE, ON
TIME,10
/OUT,SCRATCH
SOLVE
/OUT
RATE, ON
TIME,100
/OUT,SCRATCH
SOLVE
/OUT
RATE, ON
TIME,1000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON
TIME,10000
/OUT,SCRATCH
SOLVE
/OUT

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-110
NSEL,ALL
RATE,ON,ON
DELT,1000,999.999,1000.0001
AUTOS,OFF
OUTRES,ALL,ALL
TIME,11000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
DELT,1000
AUTOS,OFF
OUTRES,ALL,ALL
TIME,12000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
DELT,1000
AUTOS,OFF
OUTRES,ALL,ALL
TIME,15000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
DELT,1000
```

```
AUTOS,OFF
OUTRES,ALL,ALL
TIME,20000
/OUT,SCRATCH
SOLVE
/OUT

/POST26
ESOL,2,1,,EPCR,X
PRVAR,2
/AXLAB,Y,CREEP STRAIN
PLVAR,2

/POST1
SET,,,,,,,1
*GET,SH1,NODE,3,EPCR,X
R1=1.0
SET,,,,,,,2
*GET,SH2,NODE,3,EPCR,X
R2=SH2/0.000326
SET,,,,,,,3
*GET,SH3,NODE,3,EPCR,X
R3=SH3/0.00110
SET,,,,,,,4
*GET,SH4,NODE,3,EPCR,X
R4=SH4/0.00416
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,X
R5=SH5/0.02
SET,,,,,,,6
*GET,SH6,NODE,3,EPCR,X
R6=SH6/0.02240
SET,,,,,,,7
*GET,SH7,NODE,3,EPCR,X
R7=SH7/0.02476
SET,,,,,,,10
*GET,SH8,NODE,3,EPCR,X
R8=SH8/0.03167
SET,,,,,,,15
*GET,SH9,NODE,3,EPCR,X
R9=SH9/0.04278
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','10', '100', '1000', '10000', '11000','12000','15000','20000'
*VFILL,VALUE(1,1),DATA,0.0,0.000326,0.00110,0.00416,0.02,0.02240,0.02476,0.03167,0.04278
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/COM
/COM
/COM,--------- vmr027-cr12c-182 RESULTS COMPARISON-----------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.6,'   ',F13.6,'   ',1F13.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR11X ',' ECR11Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr12c-18','2'

/OUT,vmr027-cr12c-182,vrt
/COM
/COM,------------------- vmr027-cr12c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
```

```
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,---------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr12c-182,vrt
```

VM-R027-12C 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr12c-183
/TITLE,vmr027-cr12c-183,2D PLANE STRESS-STEPPED LOAD PRIMARY-SECONDARY CREEP
/COM, REFERENCE: TEST 12(C) FROM NAFEMS REPORT R0027.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(PRIMARY AND SECONDARY CREEP)***
*SET,C1,0.5E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
*SET,C5,1E-16
*SET,C6,5
*SET,C7,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,11
TBDATA,1,C1,C2,C3,C4,C5,C6
TBDATA,7,C7
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183
KEYOPT,1,3,0
E,1,2,3,4,5,6,7,8
NSEL,S,LOC,X,0
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,50
NSEL,R,LOC,X,0
D,ALL,UY,
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-100
NSEL,ALL
RATE, ON
TIME, 1.0E-8
/OUT,SCRATCH
SOLVE
/OUT
RATE, ON
TIME,10
/OUT,SCRATCH
```

```
SOLVE
/OUT
RATE, ON
TIME,100
/OUT,SCRATCH
SOLVE
/OUT
RATE, ON
TIME,1000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON
TIME,10000
/OUT,SCRATCH
SOLVE
/OUT

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-110
NSEL,ALL
RATE,ON,ON
DELT,1000,999.999,1000.0001
AUTOS,OFF
OUTRES,ALL,ALL
TIME,11000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
DELT,1000
AUTOS,OFF
OUTRES,ALL,ALL
TIME,12000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
DELT,1000
AUTOS,OFF
OUTRES,ALL,ALL
TIME,15000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
DELT,1000
AUTOS,OFF
OUTRES,ALL,ALL
TIME,20000
/OUT,SCRATCH
SOLVE
/OUT

/POST26
ESOL,2,1,,EPCR,X
PRVAR,2
/AXLAB,Y,CREEP STRAIN
PLVAR,2

/POST1
SET,,,,,,,1
*GET,SH1,NODE,3,EPCR,X
R1=1.0
SET,,,,,,,2
*GET,SH2,NODE,3,EPCR,X
R2=SH2/0.000326
SET,,,,,,,3
*GET,SH3,NODE,3,EPCR,X
R3=SH3/0.00110
SET,,,,,,,4
```

```
*GET,SH4,NODE,3,EPCR,X
R4=SH4/0.00416
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,X
R5=SH5/0.02
SET,,,,,,,6
*GET,SH6,NODE,3,EPCR,X
R6=SH6/0.02240
SET,,,,,,,7
*GET,SH7,NODE,3,EPCR,X
R7=SH7/0.02476
SET,,,,,,,10
*GET,SH8,NODE,3,EPCR,X
R8=SH8/0.03167
SET,,,,,,,15
*GET,SH9,NODE,3,EPCR,X
R9=SH9/0.04278
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','10', '100', '1000', '10000', '11000','12000','15000','20000'
*VFILL,VALUE(1,1),DATA,0.0,0.000326,0.00110,0.00416,0.02,0.02240,0.02476,0.03167,0.04278
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/COM
/COM
/COM,--------- vmr027-cr12c-183 RESULTS COMPARISON-----------
/COM,
/COM,|   TIME    | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.6,'   ',F13.6,'   ',1F13.3)
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR11X ',' ECR11Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr12c-18','3'

/OUT,vmr027-cr12c-183,vrt
/COM
/COM,------------------- vmr027-cr12c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr027-cr12c-183,vrt
```

VM-R027-12C 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr027-cr12c-281
/TITLE,vmr027-cr12c-281,2D PLANE STRESS-STEPPED LOAD PRIMARY-SECONDARY CREEP
/COM, REFERENCE: TEST 12(C) FROM NAFEMS REPORT R0027.
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(PRIMARY AND SECONDARY CREEP)***
*SET,C1,0.5E-14
*SET,C2,5
```

```
*SET,C3,-0.5
*SET,C4,0
*SET,C5,1E-16
*SET,C6,5
*SET,C7,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,11
TBDATA,1,C1,C2,C3,C4,C5,C6
TBDATA,7,C7
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
N,9,50,50
N,10,25,0,0
N,11,75,0,0
N,12,0,25,0
N,13,50,25,0
N,14,100,25,0
N,15,25,50,0
N,16,75,50,0
N,17,0,75,0
N,18,50,75,0
N,19,100,75,0
N,20,25,100,0
N,21,75,100,0
ET,1,SHELL281,,,
R,1,1,1,1,1,
E,1,5,9,8,10,13,15,12
E,5,2,6,9,11,14,16,13
E,9,6,3,7,16,19,21,18
E,8,9,7,4,15,18,20,17
NSEL,S,LOC,X,0
D,ALL,UX,
NSEL,ALL
NSEL,S,LOC,Y,50
NSEL,R,LOC,X,0
D,ALL,UY,
NSEL,ALL
D,ALL,UZ
D,ALL,ROTX
D,ALL,ROTY
/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-100
NSEL,ALL
RATE, ON
TIME, 1.0E-8
/OUT,SCRATCH
SOLVE
/OUT
RATE, ON
TIME,10
/OUT,SCRATCH
SOLVE
/OUT
RATE, ON
TIME,100
/OUT,SCRATCH
SOLVE
/OUT
```

```
RATE, ON
TIME,1000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON
TIME,10000
/OUT,SCRATCH
SOLVE
/OUT
/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-110
NSEL,ALL
RATE,ON,ON
DELT,1000,999.999,1000.0001
AUTOS,OFF
OUTRES,ALL,ALL
TIME,11000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
DELT,1000
AUTOS,OFF
OUTRES,ALL,ALL
TIME,12000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
DELT,1000
AUTOS,OFF
OUTRES,ALL,ALL
TIME,15000
/OUT,SCRATCH
SOLVE
/OUT
RATE,ON,ON
DELT,1000
AUTOS,OFF
OUTRES,ALL,ALL
TIME,20000
/OUT,SCRATCH
SOLVE
/OUT
/POST26
ESOL,2,1,,EPCR,X
PRVAR,2
/AXLAB,Y,CREEP STRAIN
PLVAR,2
/POST1
SET,,,,,,,1
*GET,SH1,NODE,3,EPCR,X
R1=1.0
SET,,,,,,,2
*GET,SH2,NODE,3,EPCR,X
R2=SH2/0.000326
SET,,,,,,,3
*GET,SH3,NODE,3,EPCR,X
R3=SH3/0.00110
SET,,,,,,,4
*GET,SH4,NODE,3,EPCR,X
R4=SH4/0.00416
SET,,,,,,,5
*GET,SH5,NODE,3,EPCR,X
R5=SH5/0.02
SET,,,,,,,6
*GET,SH6,NODE,3,EPCR,X
R6=SH6/0.02240
SET,,,,,,,7
*GET,SH7,NODE,3,EPCR,X
```

```
R7=SH7/0.02476
SET,,,,,,,10
*GET,SH8,NODE,3,EPCR,X
R8=SH8/0.03167
SET,,,,,,,15
*GET,SH9,NODE,3,EPCR,X
R9=SH9/0.04278
*DIM,VALUE,,9,3
*DIM,LABEL,CHAR,10
LABEL(1) = '0','10', '100', '1000', '10000', '11000','12000','15000','20000'
*VFILL,VALUE(1,1),DATA,0.0,0.000326,0.00110,0.00416,0.02,0.02240,0.02476,0.03167,0.04278
*VFILL,VALUE(1,2),DATA,SH1,SH2,SH3,SH4,SH5,SH6,SH7,SH8,SH9
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9
/COM
/COM
/COM,--------- vmr027-cr12c-281 RESULTS COMPARISON----------
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X,A8,'   ',F8.6,'   ',F13.6,'   ',1F13.3)
FINISH
/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR11X ',' ECR11Y '
*VFILL,VALUE1(1,1),DATA,SH9
*VFILL,VALUE1(1,2),DATA,R9
*DIM,LABEL2,CHAR,3
LABEL2(1) = 'vmr027-','cr12c-28','1'
/OUT,vmr027-cr12c-281,vrt
/COM
/COM,---------------- vmr027-cr12c RESULTS COMPARISON ------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2),LABEL2(3)
(1X,A8,'      ',F13.3,'      ',F9.4,'     ',A7,A8,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr027-cr12c-281,vrt
```

VM-R029-T1 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr029-t1-181
/TITLE,vmr029-t1-181,ELASTIC LARGE DEFLECTION RESPONSE OF A Z-SHAPED CANTILEVER UNDER END LOAD
/COM, REFERENCE: NAFEMS GEOMETRIC NONLINEAR BEHAVIOUR OF 3D BEAMS AND SHELLS
/COM, MANUAL TEST 3DNLG-1
/PREP7
MP,EX,1,2.0E5
MP,NUXY,1,0.3
ET,1,SHELL181
SECT,1,SHELL
SECD,1.7
LENGTH = 60.0
THICK = 1.7
WIDTH = 20.0
MY_FORCE  = 2000.0
K,1,0,0,THICK
K,2,0,0,0
K,3,LENGTH,0,0
K,4,LENGTH,0,THICK
K,5,2.0*LENGTH,0,30.0
K,6,2.0*LENGTH,0,30.0+THICK
```

```
K,7,3.0*LENGTH,0,30.0
K,8,3.0*LENGTH,0,30.0+THICK
K,9, 0,WIDTH,THICK
K,10,0,WIDTH,0
K,11,LENGTH,WIDTH,0
K,12,LENGTH,WIDTH,THICK
K,13,2.0*LENGTH,WIDTH,30.0
K,14,2.0*LENGTH,WIDTH,30.0+THICK
K,15,3.0*LENGTH,WIDTH,30.0
K,16,3.0*LENGTH,WIDTH,30.0+THICK
V,2,3,11,10,1,4,12,9
V,3,5,13,11,4,6,14,12
V,5,7,15,13,6,8,16,14
ESIZE,10.0
AMESH,6
AMESH,11
AMESH,16
NSEL,S,LOC,X
D,ALL,ALL
NSEL,ALL
NSEL,S,LOC, X,3.0*LENGTH
NSEL,R,LOC, Y,0.0
NSEL,R,LOC, Z,30.0+THICK
F,ALL,FZ,MY_FORCE
NSEL,S,LOC, X,3.0*LENGTH
NSEL,R,LOC, Y,WIDTH
NSEL,R,LOC, Z, 30.0+THICK
F,ALL,FZ,MY_FORCE
NSEL,ALL
FINISH
/OUT,scratch
/SOLU
NLGEOM,ON
NSUB,200
OUTRES,ALL,ALL
SOLVE
FINIH
/OUT,
/POST1
PLNSOL,U,Z
FINISH
/POST26
NUMVAR,20
/GOLIST
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIP DEFLECTION
/AXLAB,Y,LOAD
/GTHK,AXIS,1
/GRTYP,0
/GROPT,ASCAL,ON
/GROPT,LOGX,OFF
/GROPT,LOGY,OFF
/GROPT,AXDV,1
/GROPT,AXNM,ON
/GROPT,AXNSC,1,
/GROPT,DIG1,4,
/GROPT,DIG2,3,
/XRANGE,0,150
/YRANGE,0,4000
/GOPR
/OUT,
NSOL,2,43,U,Z
RFORCE,3,10,F,Z,
RFORCE,4,16,F,Z,
RFORCE,5,2 ,F,Z,
ADD,6,3,4,5
PROD,7,6, , , , , ,-1,1,1,
```

```
XVAR,2
PLVAR,7
PRVAR,7,2
FINISH
/POST1
SET,LAST
*GET,UY1,NODE,43,U,Z
HF1=UY1/143.43
/GOPR
*STATUS,PARM
FINISH
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,2
LABEL(1) = 'vmr029-','t1-181'
*VFILL,VALUE(1,1),DATA,4000
*VFILL,VALUE(1,2),DATA,UY1
*VFILL,VALUE(1,3),DATA,HF1
/OUT,vmr029-t1-181,vrt
/COM
/COM,-------------- VMR029-T1 RESULTS COMPARISON--------------
/COM,
/COM,|  LOAD  |      Mechanical APDL      |   RATIO   |      TEST      |
/COM,
/COM,SHELL181
*VWRITE,VALUE(1,1), VALUE(1,2), VALUE(1,3), LABEL(1),LABEL(2)
(1X,F8.2,'     ',F12.2,'      ',F12.2,'      ',A7,A8)
/COM,
/COM,---------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t1-181,vrt
/out,scratch
```

VM-R029-T1 185 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T1-185
/TITLE,VMR029-T1-185,ELASTIC LARGE DEFLECTION RESPONSE OF A Z-SHAPED CANTILEVER UNDER END LOAD
/COM,REFERENCE NAFEMS 3D BEAMS AND SHELLS MANUAL TEST 3DNLG-1

/PREP7
MP,EX,1,2.0E5
MP,NUXY,1,0.3
ET,1,185
KEYOPT,1,2,2
K,1,
K,2,60.401315561,
K,3,120,30,
K,4,180,30,
K,5,180,31.7,
K,6,119.5986844,31.7,
K,7,60,1.7,
K,8,,1.7
L,1,2
L,2,3
L,3,4
L,4,5
L,5,6
L,6,7
L,7,8
L,8,1
L,2,7
L,3,6
AL,1,9,7,8
AL,2,10,6,9
AL,3,4,5,10
VOFFST,1,-20,
VOFFST,2,-20,
```

```
VOFFST,3,-20,
NUMMRG,ALL
LESIZE,9,,,1
LESIZE,1,,,9
LESIZE,17,,,3
LESIZE,2,,,9
LESIZE,3,,,9
LESIZE,10,,,1
LESIZE,25,,,3
MSHKEY,1
TYPE,1 $ MAT,1
VMESH,1,3
NUMMRG,NODE
NUMMRG,ELEM
NUMMRG,KP
ALLSEL,ALL
NSEL,S,LOC,X,0.0
D,ALL,ALL
ALLSEL,ALL
NSEL,S,LOC,X,180.0
NSEL,R,LOC,Y,31.7
F,ALL,FY,1000
ALLS,
FINISH

/SOLU
NLGEOM,ON
TIME,1
NSUBST,20,10000,10
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINISH

/POST26
/SHOW,,jpeg
/OUT
*DIM,XA,TABLE,11,1
*DIM,YA,TABLE,11,1
XA(  1,1)= 0
YA(  1,1)= 0
XA(  2,1)= 15
YA(  2,1)= 16
XA(  3,1)= 30
YA(  3,1)= 33
XA(  4,1)= 45
YA(  4,1)= 47.25
XA(  5,1)= 60
YA(  5,1)= 63
XA(  6,1)= 80.43
YA(  6,1)= 104.5
XA(  7,1)= 90
YA(  7,1)= 150
XA(  8,1)= 105
YA(  8,1)= 233.3
XA(  9,1)= 120
YA(  9,1)= 450
XA( 10,1)= 133.1
YA( 10,1)= 1263
XA( 11,1)= 143.4
YA( 11,1)= 4000
/XRANGE,0,150
/YRANGE,0,4000
/AXLAB,X,TIP DISPLACEMENT
/AXLAB,Y,LOAD
/COLOR,CURVE,YGRE
*VPLOT,XA(1,1),YA(1,1)
/NOERASE
NSOL,2,189,U,Y
ADD,3,1,,,APLOAD,,,4000
/COLOR,CURVE,MRED
XVAR,2
```

```
PLVAR,3
PRVAR,2,3
FINISH

/POST1
NSEL,S,NODE,,62,80,2
NSEL,A,NODE,,136,152,2
NSEL,A,NODE,,208,224,2
PRNSOL,U,COMP
PRNSOL,S,COMP
NSEL,ALL
SET,LIST
SET,LAST
*GET,UY3,NODE,189,U,Y
HF3=UY3/143.4
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,3
LABEL(1) = 'vmr029-','t1-185'
*VFILL,VALUE(1,1),DATA,4000.0
*VFILL,VALUE(1,2),DATA,UY3
*VFILL,VALUE(1,3),DATA,HF3
/OUT,vmr029-t1-185,vrt
/COM
/COM,-------------- VMR029-T1 RESULTS COMPARISON-------------
/COM,
/COM,|  LOAD  |      Mechanical APDL      |   RATIO   |      TEST      |
/COM,
/COM,SOLID185
*VWRITE,VALUE(1,1), VALUE(1,2), VALUE(1,3), LABEL(1),LABEL(2)
(1X,F8.2,'     ',F12.2,'      ',F12.2,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t1-185,vrt
```

VM-R029-T1 188 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T1-188
/TITLE,VMR029-T1-188,ELASTIC LARGE DEFLECTION RESPONSE OF A Z-SHAPED CANTILEVER UNDER END LOAD
/COM, REFERENCE: NAFEMS GEOMETRIC NONLINEAR BEHAVIOUR OF 3D BEAMS AND SHELLS
/COM, MANUAL TEST 3DNLG-1

/PREP7
SECN,1
SECT,1,BEAM,RECT
SECD,20,1.7
N,1,0.0
N,7,60.0
N,13,120.0,30.0
N,19,180.0,30.0
FILL,1,7
FILL,7,13
FILL,13,19
N,101,30,30
N,102,120,60
N,103,160,160
ET,1,188
E,1,2,101
E,2,3,101
E,3,4,101
E,4,5,101
E,5,6,101
E,6,7,101
E,7,8,102
E,8,9,102
E,9,10,102
```

```
E,10,11,102
E,11,12,102
E,12,13,102
E,13,14,103
E,14,15,103
E,15,16,103
E,16,17,103
E,17,18,103
E,18,19,103
MP,EX,1,2.0E5
MP,NUXY,1,0.3
FINISH

/SOLU
ANTYPE,0
NLGEOM,ON
SOLC,ON
NSUBST,100
D,1,ALL
F,19,FY,4000
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINISH

/POST26
/GOLIST
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIP DEFLECTION
/AXLAB,Y,LOAD
/GTHK,AXIS,1
/GRTYP,0
/GROPT,ASCAL,ON
/GROPT,LOGX,OFF
/GROPT,LOGY,OFF
/GROPT,AXDV,1
/GROPT,AXNM,ON
/GROPT,AXNSC,1,
/GROPT,DIG1,4,
/GROPT,DIG2,3,
/XRANGE,0,150
/YRANGE,0,4000
/GOPR
/OUT,
NSOL,2,19,U,Y,
RFORCE,3,1,F,Y,
PROD,4,3, , , , , ,-1,1,1,
XVAR,2
/SHOW,,jpeg
PLVAR,4
PRVAR,4,2
FINISH

/POST1
SET,1,LAST
*GET,UY1,NODE,19,U,Y
HF1=UY1/143.43
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,2
LABEL(1) = 'vmr029-','t1-188'
*VFILL,VALUE(1,1),DATA,4000.0
*VFILL,VALUE(1,2),DATA,UY1
*VFILL,VALUE(1,3),DATA,HF1
/OUT,vmr029-t1-188,vrt
/COM
/COM,-------------- VMR029-T1 RESULTS COMPARISON--------------
/COM,
```

```
/COM,|  LOAD  |      Mechanical APDL      |   RATIO   |      TEST      |
/COM,
/COM,BEAM188
*VWRITE,VALUE(1,1), VALUE(1,2), VALUE(1,3), LABEL(1),LABEL(2)
(1X,F8.2,'     ',F12.2,'      ',F12.2,'      ',A7,A8)
/COM,
/COM,-------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t1-188,vrt
```

VM-R029-T1 189 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T1-189
/TITLE,VMR029-T1-189,ELASTIC LARGE DEFLECTION RESPONSE OF A Z-SHAPED CANTILEVER UNDER END LOAD
/COM, REFERENCE: NAFEMS 3D BEAMS AND SHELL MANUAL TEST 3DNLG-1

/PREP7
SECN,1
SECT,1,BEAM,RECT
SECD,20,1.7
N,1,0.0
N,7,60.0
N,13,120.0,30.0
N,19,180.0,30.0
FILL,1,7
FILL,7,13
FILL,13,19
N,101,30,30
N,102,120,60
N,103,160,160
ET,1,189
E,1,3,2,101
E,3,5,4,101
E,5,7,6,101
E,7,9,8,102
E,9,11,10,102
E,11,13,12,102
E,13,15,14,103
E,15,17,16,103
E,16,19,18,103
MP,EX,1,2.0E5
MP,NUXY,1,0.3
FINISH

/SOLU
ANTYPE,0
NLGEOM,ON
SOLC,ON
NSUBST,100
D,1,ALL
F,19,FY,4000.0
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINISH

/POST26
/GOLIST
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIP DEFLECTION
/AXLAB,Y,LOAD
```

```
/GTHK,AXIS,1
/GRTYP,0
/GROPT,ASCAL,ON
/GROPT,LOGX,OFF
/GROPT,LOGY,OFF
/GROPT,AXDV,1
/GROPT,AXNM,ON
/GROPT,AXNSC,1,
/GROPT,DIG1,4,
/GROPT,DIG2,3,
/XRANGE,0,150
/YRANGE,0,4000
/GOPR
/OUT,
NSOL,2,19,U,Y,
RFORCE,3,1,F,Y,
PROD,4,3, , , , , ,-1,1,1,
XVAR,2
/SHOW,,jpeg
PLVAR,4
PRVAR,4,2

/POST1
SET,1,LAST
*GET,UY3,NODE,19,U,Y
HF3=UY3/143.4
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,3
LABEL(1) = 'vmr029-','t1-189'
*VFILL,VALUE(1,1),DATA,4000.0
*VFILL,VALUE(1,2),DATA,UY3
*VFILL,VALUE(1,3),DATA,HF3
/OUT,vmr029-t1-189,vrt
/COM
/COM,-------------- VMR029-T1 RESULTS COMPARISON--------------
/COM,
/COM,|  LOAD  |      Mechanical APDL      |   RATIO   |      TEST      |
/COM,
/COM,BEAM189
*VWRITE,VALUE(1,1), VALUE(1,2), VALUE(1,3), LABEL(1),LABEL(2)
(1X,F8.2,'     ',F12.2,'      ',F12.2,'      ',A7,A8)
/COM,
/COM,-----------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t1-189,vrt
```

VM-R029-T1 190 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr029-t1-190
/TITLE,vmr029-t1-190,ELASTIC LARGE DEFLECTION RESPONSE OF A Z-SHAPED CANTILEVER UNDER END LOAD
/COM, REFERENCE: NAFEMS GEOMETRIC NONLINEAR BEHAVIOUR OF 3D BEAMS AND SHELLS
/COM, MANUAL TEST 3DNLG-1

/PREP7
MP,EX,1,2.0E5
MP,NUXY,1,0.3
ET,1,190,,0
KEYOPT,1,8,1
LENGTH = 60.0
THICK = 1.7
WIDTH = 20.0
MY_FORCE  = 2000.0
K,1,0,0,THICK
K,2,0,0,0
k,3,LENGTH,0,0
k,4,LENGTH,0,THICK
```

```
K,5,2.0*LENGTH,0,30.0
K,6,2.0*LENGTH,0,30.0+THICK
K,7,3.0*LENGTH,0,30.0
K,8,3.0*LENGTH,0,30.0+THICK
K,9, 0,WIDTH,THICK
K,10,0,WIDTH,0
K,11,LENGTH,WIDTH,0
K,12,LENGTH,WIDTH,THICK
K,13,2.0*LENGTH,WIDTH,30.0
K,14,2.0*LENGTH,WIDTH,30.0+THICK
K,15,3.0*LENGTH,WIDTH,30.0
K,16,3.0*LENGTH,WIDTH,30.0+THICK
V,2,3,11,10,1,4,12,9
V,3,5,13,11,4,6,14,12
V,5,7,15,13,6,8,16,14
VEORIENT,1,THIN
VEORIENT,2,THIN
VEORIENT,3,THIN
ESIZE,10.0
VMESH,1
VMESH,2
VMESH,3
NSEL,S,LOC,X
D,ALL,ALL
NSEL,ALL
NSEL,S,LOC, X,3.0*LENGTH
NSEL,R,LOC, Y,0.0
NSEL,R,LOC, Z,30.0+THICK
F,ALL,FZ,MY_FORCE
NSEL,S,LOC, X,3.0*LENGTH
NSEL,R,LOC, Y,WIDTH
NSEL,R,LOC, Z, 30.0+THICK
F,ALL,FZ,MY_FORCE
NSEL,ALL
FINI

/SOLU
NLGEOM,ON
NSUB,200
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINI

/POST26
NUMVAR,20
/GOLIST
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIP DEFLECTION
/AXLAB,Y,LOAD
/GTHK,AXIS,1
/GRTYP,0
/GROPT,ASCAL,ON
/GROPT,LOGX,OFF
/GROPT,LOGY,OFF
/GROPT,AXDV,1
/GROPT,AXNM,ON
/GROPT,AXNSC,1,
/GROPT,DIG1,4,
/GROPT,DIG2,3,
/XRANGE,0,150
/YRANGE,0,4000
/GOPR
/OUT,
NSOL,2,85,U,Z
RFORCE,3,1,F,Z,
RFORCE,4,10,F,Z,
```

```
RFORCE,5,16,F,Z,
RFORCE,6,23,F,Z,
RFORCE,7,31,F,Z,
RFORCE,8,37,F,Z,
ADD,9,3,4,5
ADD,10,6,7,8
ADD,11,9,10
PROD,12,11, , , , , ,-1,1,1,
XVAR,2
/SHOW,,jpeg
PLVAR,12
PRVAR,12,2
FINISH

/POST1
SET,LIST,2
SET,LAST
*GET,UY1,NODE,85,U,Z
HF1=UY1/143.43
/GOPR
*STATUS,PARM
FINISH
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,2
LABEL(1) = 'vmr029-','t1-190'
*VFILL,VALUE(1,1),DATA,4000
*VFILL,VALUE(1,2),DATA,UY1
*VFILL,VALUE(1,3),DATA,HF1
/OUT,vmr029-t1-190,vrt
/COM
/COM,-------------- VMR029-T1 RESULTS COMPARISON--------------
/COM,
/COM,|  LOAD  |      Mechanical APDL      |   RATIO   |      TEST      |
/COM,
/COM,SOLSH190
*VWRITE,VALUE(1,1), VALUE(1,2), VALUE(1,3), LABEL(1),LABEL(2)
(1X,F8.2,'     ',F12.2,'      ',F12.2,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t1-190,vrt
```

VM-R029-T1 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr029-t1-281
/TITLE,vmr029-t1-281,ELASTIC LARGE DEFLECTION RESPONSE OF A Z-SHAPED CANTILEVER UNDER END LOAD
/COM, REFERENCE: NAFEMS GEOMETRIC NONLINEAR BEHAVIOUR OF 3D BEAMS AND SHELLS
/COM, MANUAL TEST 3DNLG-1
/PREP7
MP,EX,1,2.0E5
MP,NUXY,1,0.3
ET,1,SHELL281
SECT,1,SHELL
SECD,1.7
LENGTH = 60.0
THICK = 1.7
WIDTH = 20.0
MY_FORCE  = 2000.0
K,1,0,0,THICK
K,2,0,0,0
K,3,LENGTH,0,0
K,4,LENGTH,0,THICK
K,5,2.0*LENGTH,0,30.0
K,6,2.0*LENGTH,0,30.0+THICK
K,7,3.0*LENGTH,0,30.0
K,8,3.0*LENGTH,0,30.0+THICK
```

```
K,9, 0,WIDTH,THICK
K,10,0,WIDTH,0
K,11,LENGTH,WIDTH,0
K,12,LENGTH,WIDTH,THICK
K,13,2.0*LENGTH,WIDTH,30.0
K,14,2.0*LENGTH,WIDTH,30.0+THICK
K,15,3.0*LENGTH,WIDTH,30.0
K,16,3.0*LENGTH,WIDTH,30.0+THICK
V,2,3,11,10,1,4,12,9
V,3,5,13,11,4,6,14,12
V,5,7,15,13,6,8,16,14
ESIZE,10.0
AMESH,6
AMESH,11
AMESH,16
NSEL,S,LOC,X
D,ALL,ALL
NSEL,ALL
NSEL,S,LOC, X,3.0*LENGTH
NSEL,R,LOC, Y,0.0
NSEL,R,LOC, Z,30.0+THICK
F,ALL,FZ,MY_FORCE
NSEL,S,LOC, X,3.0*LENGTH
NSEL,R,LOC, Y,WIDTH
NSEL,R,LOC, Z, 30.0+THICK
F,ALL,FZ,MY_FORCE
NSEL,ALL
FINISH
/SOLU
NLGEOM,ON
NSUB,100
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINI
/POST1
PLNSOL,U,Z
/POST26
NUMVAR,20
/GOLIST
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIP DEFLECTION
/AXLAB,Y,LOAD
/GTHK,AXIS,1
/GRTYP,0
/GROPT,ASCAL,ON
/GROPT,LOGX,OFF
/GROPT,LOGY,OFF
/GROPT,AXDV,1
/GROPT,AXNM,ON
/GROPT,AXNSC,1,
/GROPT,DIG1,4,
/GROPT,DIG2,3,
/XRANGE,0,150
/YRANGE,0,4000
/GOPR
/OUT,
NSOL,2,110,U,Z
RFORCE,3,2,F,Z
RFORCE,4,32,F,Z
RFORCE,5,31,F,Z
RFORCE,6,30,F,Z
RFORCE,7,18,F,Z
ADD,8,3,4,5
ADD,9,6,7
ADD,10,8,9
PROD,11,10, , , , , ,-1,1,1,
```

```
XVAR,2
PLVAR,11
PRVAR,11,2
FINISH
/POST1
SET,LAST
*GET,UY1,NODE,110,U,Z
HF1=UY1/143.43
/GOPR
*STATUS,PARM
FINISH
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,2
LABEL(1) = 'vmr029-','t1-281'
*VFILL,VALUE(1,1),DATA,4000
*VFILL,VALUE(1,2),DATA,UY1
*VFILL,VALUE(1,3),DATA,HF1
/OUT,vmr029-t1-281,vrt
/COM
/COM,-------------- VMR029-T1 RESULTS COMPARISON--------------
/COM,
/COM,|  LOAD  |      Mechanical APDL      |   RATIO   |      TEST      |
/COM,
/COM,SHELL281
*VWRITE,VALUE(1,1), VALUE(1,2), VALUE(1,3), LABEL(1),LABEL(2)
(1X,F8.2,'     ',F12.2,'      ',F12.2,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t1-281,vrt
```

VM-R029-T4 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T4-181
/TITLE,VMR029-T4-181,LATERAL-TORSIONAL BUCKLING OF AN ELASTIC CANTILEVER SUBJECTED TO TRANSVERSE END LOAD
/COM,REFERENCE NAFEMS 3D BEAMS AND SHELLS MANUAL TEST 3DNLG-4
/FILNAME,vmr029-t4-181
/PREP7
ET,  1,SHELL181,,,2
R,1,0.2,0.2,0.2,0.2
MP,EX,1,1E4
MP,NUXY,1,0
MP,GXY,1,5000
BLOCK,0,100,0,5,0,5
LSEL,S,LINE,,9,10
LESIZE,ALL, , ,6
LSEL,S,LINE,,4,5
LESIZE,ALL, , ,10
TYPE,1
REAL,1
MAT,1
AMESH,3
NSEL,S,LOC,X,0
D,ALL,ALL
NSEL,S,LOC,X,100
NSEL,R,LOC,Z,2.5
*GET,NTIP,NODE,0,NUM,MAX
NSEL,S,LOC,X,100
NSEL,R,LOC,Z,0
*GET,ND1,NODE,0,NUM,MAX
NSEL,S,LOC,X,100
NSEL,R,LOC,Z,5
*GET,ND2,NODE,0,NUM,MAX
ALLSEL,ALL
F,NTIP,FZ,-1
ALLSEL,ALL
```

```
FINISH
/SOLU
ANTYPE,STATIC
RESCONTROL,LINEAR,ALL,1         ! RESTART FILES FOR SUBSEQUENT LINEAR PERTURBATION
EQSLV,SPARSE
/OUT,SCRATCH
SOLVE
FINISH
/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB ! PERFORM A PERTURBATION ANALYSIS
PERTURB,BUCKLE,,,ALLKEEP        ! PERTURBED BUCKLING SOLVE
SOLVE,ELFORM                    ! REFORM ELEMENT MATRICES

OUTRES,ALL,ALL
bucopt,SUBSP,4,,,range
MXPAND,4,,,YES
SOLVE
FINISH

/PREP7
UPGEOM,0.001/4,1,1,vmr029-t4-181,rstp
NSEL,S,NODE,,ND1
NSEL,A,NODE,,ND2
NLIST
NSEL,ALL
FINISH

/SOLU
ANTYPE,STATIC
OUTRES,ALL,ALL
NLGEOM,ON
ARCLEN,ON,1,0.0001
ARCTRM,U,1.0,NTIP,UY
NSUBST,1000
SOLVE
FINISH

/POST26
NSOL,2,NTIP,U,Y,TIPDISP
ADD,3,1,,,APLOAD,,,1,
/XRANGE,0,0.06
/YRANGE,0,0.02
/GROPT,DIVX,6
/AXLAB,X,TIP LATERAL DISP
/AXLAB,Y,LOAD
/COLOR,CURVE,YGRE
XVAR,2
PLVAR,3
/OUT,
PRVAR,2,4

/POST1
SET,1,19
*GET,APLOAD,TIME
R=APLOAD/0.01892
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,3
LABEL(1) = 'PCR','vmr029-','t4-181'
*VFILL,VALUE(1,1),DATA,APLOAD
*VFILL,VALUE(1,2),DATA,R
/OUT,vmr029-t4-181,vrt
/COM
/COM,-------------- VMR029-T4 RESULTS COMPARISON ---------------
/COM,
/COM,         |   Mechanical APDL   |   RATIO   |      TEST      |
/COM,
/COM,SHELL181
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2),LABEL(2),LABEL(3)
(1X,' ',A4,'       ',F10.5,'      ',F12.4,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
```

```
FINISH
*LIST,vmr029-t4-181,vrt
```

VM-R029-T4 185 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T4-185
/TITLE,VMR029-T4-185,LATERAL-TORSIONAL BUCKLING OF AN ELASTIC CANTILEVER SUBJECTED TO TRANSVERSE END LOAD
/COM,REFERENCE: NAFEMS 3D BEAMS AND SHELLS MANUAL TEST 3DNLG-4

/FILENAME,vmr029-t4-185
/OUT,SCRATCH
/PREP7
MP,EX,1,1.0E4
MP,NUXY,1,0.0
ET,1,185
KEYOPT,1,2,2
K,1,
K,2,100,
K,3,100,0.2
K,4,,0.2
L,1,2
L,2,3
L,3,4
L,4,1
AL,1,2,3,4
VOFFST,1,-5
LESIZE,1,,,40
LESIZE,2,,,2
LESIZE,11,,,4
MSHKEY,1
TYPE,1 $ MAT,1
VMESH,1
NSEL,S,LOC,X,0.0
D,ALL,ALL
ALLSEL,ALL
F,374,FZ,1.0
ALLSEL,ALL
FINISH
/SOLU
ANTYPE,STATIC
RESCONTROL,LINEAR,ALL,1          ! RESTART FILES FOR SUBSEQUENT LINEAR PERTURBATION
EQSLV,SPARSE
SOLVE
FINISH
/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB ! PERFORM A PERTURBATION ANALYSIS
PERTURB,BUCKLE,,,ALLKEEP        ! PERTURBED BUCKLING SOLVE
SOLVE,ELFORM

OUTRES,ALL,ALL
bucopt,LANB,4,,,range
MXPAND,4,,,YES
SOLVE
FINISH
/PREP7
UPGEOM,0.001/4,1,1,vmr029-t4-185,rstp
FINISH
/SOLU
ANTYPE,STATIC
OUTRES,ALL,ALL
NLGEOM,ON
ARCLEN,ON,25,0.0001
ARCTRM,U,1.0,374,UY
NSUBST,10000
SOLVE
FINISH
/POST26
```

```
/SHOW,,jpeg
NSOL,2,374,U,Y,TIPDISP
ADD,3,1,,,APLOAD,,,1,
/XRANGE,0,0.06
/YRANGE,0,0.020
/GROPT,DIVX,6
/AXLAB,X,TIP LATERAL DISP
/AXLAB,Y,LOAD
/COLOR,CURVE,YGRE
XVAR,2
PLVAR,3
PRVAR,2,3

/POST1
/OUT,
SET,1,15
*GET,APLOAD,TIME
R=APLOAD/0.01892
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,3
LABEL(1) = 'PCR','vmr029-','t4-185'
*VFILL,VALUE(1,1),DATA,APLOAD
*VFILL,VALUE(1,2),DATA,R
/OUT,vmr029-t4-185,vrt
/COM
/COM,-------------- VMR029-T4 RESULTS COMPARISON ---------------
/COM,
/COM,          |   Mechanical APDL   |   RATIO   |      TEST      |
/COM,
/COM,SOLID185
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2),LABEL(2),LABEL(3)
(1X,' ',A4,'       ',F10.5,'      ',F12.4,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t4-185,vrt
```

VM-R029-T4 188 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T4-188
/TITLE,VMR029-T4-188,LATERAL-TORSIONAL BUCKLING OF AN ELASTIC CANTILEVER SUBJECTED TO TRANSVERSE END LOAD
/COM, REFERENCE NAFEMS 3D BEAMS AND SHELLS MANUAL TEST 3DNLG-4
/FILENAME,vmr029-t4-188

/PREP7
MP,EX,1,1E4
MP,NUXY,1,0
MP,GXY,1,5000
ET,1,188
SECT,1,BEAM,RECT
SECD,.2,5.0
N,1
N,2,10
N,3,20
N,4,30
N,5,40
N,6,50
N,7,60
N,8,70
N,9,80
N,10,90
N,11,100
N,101 , 50,50
TYPE,1
MAT,1
SECN,1
```

```
E,1,2,101
E,2,3,101
E,3,4,101
E,4,5,101
E,5,6,101
E,6,7,101
E,7,8,101
E,8,9,101
E,9,10,101
E,10,11,101
NSEL,S,LOC,X,100
*GET,NTIP,NODE,0,NUM,MAX
NSEL,ALL
D,1,ALL
F,NTIP,FY,1.0
FINISH

/SOLU
ANTYPE,STATIC
RESCONTROL,LINEAR,ALL,1          ! RESTART FILES FOR SUBSEQUENT LINEAR PERTURBATION
SOLVE
FINISH

/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB ! PERFORM A PERTURBATION ANALYSIS
PERTURB,BUCKLE,,,ALLKEEP        ! PERTURBED BUCKLING SOLVE
SOLVE,ELFORM

OUTRES,ALL,ALL
bucopt,LANB,4,,,range
MXPAND,4,,,YES
SOLVE
FINISH


/PREP7
UPGEOM,0.001/3,1,1,vmr029-t4-188,rstp
FINISH

/SOLU
ANTYPE,STATIC
OUTRES,ALL,ALL
NLGEOM,ON
ARCLEN,ON,5,0.0001
ARCTRM,U,1.0,NTIP,UZ
NSUBST,10000
/OUT,SCRATCH
SOLVE
FINISH

/POST26
/SHOW,,jpeg
NSOL,2,NTIP,U,Z,TIPDISP
ADD,3,1,,,APLOAD,,,1,
/XRANGE,0,0.06
/YRANGE,0,0.02
/GROPT,DIVX,6
/AXLAB,X,TIP LATERAL DISP
/AXLAB,Y,LOAD
/COLOR,CURVE,YGRE
XVAR,2
PLVAR,3
/OUT,
PRVAR,2,4

/POST1
SET,1,122
*GET,APLOAD,TIME
R=APLOAD/0.01892
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,3
LABEL(1) = 'PCR','vmr029-','t4-188'
```

```
*VFILL,VALUE(1,1),DATA,APLOAD
*VFILL,VALUE(1,2),DATA,R
/OUT,vmr029-t4-188,vrt
/COM
/COM,-------------- VMR029-T4 RESULTS COMPARISON ---------------
/COM,
/COM,          |   Mechanical APDL   |   RATIO   |      TEST      |
/COM,
/COM,BEAM188
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2),LABEL(2),LABEL(3)
(1X,' ',A4,'       ',F10.5,'      ',F12.4,'      ',A7,A8)
/COM,
/COM,-------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t4-188,vrt
```

VM-R029-T4 189 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T4-189
/TITLE,VMR029-T4-189,LATERAL-TORSIONAL BUCKLING OF AN ELASTIC CANTILEVER SUBJECTED TO TRANSVERSE END LOAD
/COM,REFERENCE NAFEMS 3D BEAMS AND SHELLS MANUAL TEST 3DNLG-4
/FILNAME,vmr029-t4-189

/PREP7
MP,EX,1,1E4
MP,NUXY,1,0
MP,GXY,1,5000
ET,1,189
SECT,1,BEAM,RECT
SECD,.2,5.0
N,1
N,2,10
N,3,20
N,4,30
N,5,40
N,6,50
N,7,60
N,8,70
N,9,80
N,10,90
N,11,100
N,101,50,50
TYPE,1
MAT,1
SECN,1
E,1,3,2,101
E,3,5,4,101
E,5,7,6,101
E,7,9,8,101
E,9,11,10,101
NSEL,S,LOC,X,100
*GET,NTIP,NODE,0,NUM,MAX
NSEL,ALL
D,1,ALL
F,NTIP,FY,1.0
FINISH

/SOLU
ANTYPE,STATIC
RESCONTROL,LINEAR,ALL,1             ! RESTART FILES FOR SUBSEQUENT LINEAR PERTURBATION
SOLVE
FINISH

/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB ! PERFORM A PERTURBATION ANALYSIS
PERTURB,BUCKLE,,,ALLKEEP        ! PERTURBED BUCKLING SOLVE
```

```
SOLVE,ELFORM

OUTRES,ALL,ALL
bucopt,LANB,4,,,range
MXPAND,4,,,YES
SOLVE
FINISH

/PREP7
UPGEOM,0.001/3,1,1,vmr029-t4-189,rstp
FINISH

/SOLU
ANTYPE,STATIC
OUTRES,ALL,ALL
NLGEOM,ON
ARCLEN,ON,1,0.0001
ARCTRM,U,1.0,NTIP,UZ
NSUBST,10000
/OUT,SCRATCH
SOLVE
FINISH

/POST26
/SHOW,,jpeg
NSOL,2,NTIP,U,Z,TIPDISP
ADD,3,1,,,APLOAD,,,1,
/XRANGE,0,0.06
/YRANGE,0,0.02
/GROPT,DIVX,6
/AXLAB,X,TIP LATERAL DISP
/AXLAB,Y,LOAD
/COLOR,CURVE,YGRE
XVAR,2
PLVAR,3
/OUT,
PRVAR,2,4
FINISH

/POST1
SET,1,595
*GET,APLOAD,TIME
R=APLOAD/0.01892
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,3
LABEL(1) = 'PCR','vmr029-','t4-189'
*VFILL,VALUE(1,1),DATA,APLOAD
*VFILL,VALUE(1,2),DATA,R
/OUT,vmr029-t4-189,vrt
/COM
/COM,-------------- VMR029-T4 RESULTS COMPARISON ---------------
/COM,
/COM,         |   Mechanical APDL   |   RATIO   |      TEST      |
/COM,
/COM,BEAM189
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2),LABEL(2),LABEL(3)
(1X,' ',A4,'       ',F10.5,'      ',F13.4,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t4-189,vrt
```

VM-R029-T4 190 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T4-190
/TITLE,VMR029-T4-190,LATERAL-TORSIONAL BUCKLING OF AN ELASTIC CANTILEVER SUBJECTED TO TRANSVERSE END LOAD
```

```
/COM,REFERENCE NAFEMS 3D BEAMS AND SHELLS MANUAL TEST 3DNLG-4

/conf,npro,1
/FILENAME,vmr029-t4-190

/prep7
cdread,all,vmr029-t4-190,cdb

/OUT,SCRATCH
/SOLU
ANTYPE,STATIC
RESCONTROL,LINEAR,ALL,1             ! RESTART FILES FOR SUBSEQUENT LINEAR PERTURBATION
EQSLV,SPARSE
SOLVE
FINISH
/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB ! PERFORM A PERTURBATION ANALYSIS
PERTURB,BUCKLE,,,ALLKEEP        ! PERTURBED BUCKLING SOLVE
SOLVE,ELFORM

OUTRES,ALL,ALL
BUCOPT,LANB,4,
MXPAND,4,,,YES
SOLVE
FINISH

/PREP7
UPGEOM,0.001/4,1,1,vmr029-t4-190,rstp
FINISH

/SOLU
ANTYPE,STATIC
OUTRES,ALL,ALL
NLGEOM,ON
ARCLEN,ON,2,0.0001
ARCTRM,U,1.0,374,UY
NSUBST,1000
SOLVE
FINISH

/POST26
/SHOW,,jpeg
NSOL,2,374,U,Y,TIPDISP
ADD,3,1,,,APLOAD,,,1,
/XRANGE,0,0.06
/YRANGE,0,0.020
/GROPT,DIVX,6
/AXLAB,X,TIP LATERAL DISP
/AXLAB,Y,LOAD
/COLOR,CURVE,YGRE
XVAR,2
PLVAR,3
PRVAR,2,3

/POST1
/OUT,
SET,1,11
*GET,APLOAD,TIME
R=APLOAD/0.01892
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,3
LABEL(1) = 'PCR','vmr029-','t4-190'
*VFILL,VALUE(1,1),DATA,APLOAD
*VFILL,VALUE(1,2),DATA,R
/OUT,vmr029-t4-190,vrt
/COM
/COM,-------------- VMR029-T4 RESULTS COMPARISON ---------------
/COM,
/COM,         |   Mechanical APDL   |   RATIO   |      TEST      |
/COM,
/COM,SOLSH190
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2),LABEL(2),LABEL(3)
```

```
(1X,' ',A4,'        ',F10.5,'      ',F13.4,'      ',A7,A8)
/COM,
/COM,-------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t4-190,vrt
```

VM-R029-T4 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T4-281
/TITLE,VMR029-T4-281,LATERAL-TORSIONAL BUCKLING OF AN ELASTIC CANTILEVER SUBJECTED TO TRANSVERSE END LOAD
/COM,REFERENCE NAFEMS 3D BEAMS AND SHELLS MANUAL TEST 3DNLG-4
/FILNAME,vmr029-t4-281

/PREP7
ET,  1,281
R,1,0.2,0.2,0.2,0.2
MP,EX,1,1E4
MP,NUXY,1,0
MP,GXY,1,5000
BLOCK,0,100,0,5,0,5
LSEL,S,LINE,,9,10
LESIZE,ALL, , ,6
LSEL,S,LINE,,4,5
LESIZE,ALL, , ,10
TYPE,1
REAL,1
MAT,1
AMESH,3
NSEL,S,LOC,X,0
D,ALL,ALL
NSEL,S,LOC,X,100
NSEL,R,LOC,Z,2.5
*GET,NTIP,NODE,0,NUM,MAX
NSEL,S,LOC,X,100
NSEL,R,LOC,Z,0
*GET,ND1,NODE,0,NUM,MAX
NSEL,S,LOC,X,100
NSEL,R,LOC,Z,5
*GET,ND2,NODE,0,NUM,MAX
ALLSEL,ALL
F,NTIP,FZ,-1
ALLSEL,ALL
FINISH

/SOLU
ANTYPE,STATIC
RESCONTROL,LINEAR,ALL,1          ! RESTART FILES FOR SUBSEQUENT LINEAR PERTURBATION
EQSLV,SPARSE
SOLVE
FINISH

/SOLU
ANTYPE,STATIC,RESTART,,,PERTURB ! PERFORM A PERTURBATION ANALYSIS
PERTURB,BUCKLE,,,ALLKEEP        ! PERTURBED BUCKLING SOLVE
SOLVE,ELFORM

OUTRES,ALL,ALL
OUTRES,ALL,ALL
BUCOPT,SUBSPACE,4,0,,RANGE
MXPAND,4,,,YES
SOLVE
FINISH

/PREP7
UPGEOM,0.0015,1,1,vmr029-t4-281,rstp
NSEL,S,NODE,,ND1
```

```
NSEL,A,NODE,,ND2
NLIST
NSEL,ALL
FINISH

/SOLU
ANTYPE,STATIC
OUTRES,ALL,ALL
NLGEOM,ON
ARCLEN,ON,2,0.0001
ARCTRM,U,1.0,NTIP,UY
NSUBST,1000
/OUT,SCRATCH
SOLVE
FINISH

/POST26
NSOL,2,NTIP,U,Y,TIPDISP
ADD,3,1,,,APLOAD,,,1,
/XRANGE,0,0.06
/YRANGE,0,0.02
/GROPT,DIVX,6
/AXLAB,X,TIP LATERAL DISP
/AXLAB,Y,LOAD
/COLOR,CURVE,YGRE
XVAR,2
PLVAR,3
/OUT,
PRVAR,2,4
FINISH

/POST1
SET,1,12
*GET,APLOAD,TIME
R=APLOAD/0.01892
*DIM,VALUE,,1,3
*DIM,LABEL,CHAR,3
LABEL(1) = 'PCR','vmr029-','t4-281'
*VFILL,VALUE(1,1),DATA,APLOAD
*VFILL,VALUE(1,2),DATA,R
/OUT,vmr029-t4-281,vrt
/COM
/COM,-------------- VMR029-T4 RESULTS COMPARISON ---------------
/COM,
/COM,          |   Mechanical APDL   |   RATIO   |      TEST      |
/COM,
/COM,SHELL281
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2),LABEL(2),LABEL(3)
(1X,' ',A4,'       ',F10.5,'      ',F13.4,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t4-281,vrt
```

VM-R029-T5 185 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T5-185
/TITLE,VMR029-T5-185, LARGE DEFLECTION OF A CURVED ELASTIC CANTILEVER UNDER TRANSVERSE END LOAD
/COM,REFERENCE NAFEMS 3D BEAMS AND SHELLS MANUAL TEST 3DNLG-5

/PREP7
W=1.0
H=1.0
R=100
THETA=45
F=3000.0
```

```
ET,1,185
KEYOPT,1,2,2
MP,EX,1,1E7
MP,NUXY,1,0.3
K,1,0,-H/2,-W/2
K,2,0,-H/2,W/2
K,3,0,H/2,W/2
K,4,0,H/2,-W/2
K,5,0,0,R
K,6,0,1,R
A,1,2,3,4
VROTAT,ALL, , , , , ,5,6,-45, ,
LESIZE,ALL,,,1
LESIZE,9,,,16
LESIZE,10,,,16
LESIZE,11,,,16
LESIZE,12,,,16
VMESH,ALL
NSEL,S,LOC,X,0
D,ALL,ALL
NSEL,S,LOC,Z,28.5,30
F,ALL,FY,750
ALLSEL,ALL
ESEL,S,,,1
ESEL,A,,,4
ESEL,A,,,16
CM,ELESOL,ELEM
ALLSEL,ALL
FINISH

/SOLVE
NLGEOM,ON
AUTOTS,ON
NSUBST,100,100000,10
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINISH
/SHOW,,jpeg

/POST26
*DIM,XUX,TABLE,11,1
*DIM,YUX,TABLE,11,1
XUX(1,1)= 0
YUX(1,1)= 0
XUX(2,1)= 300
YUX(2,1)= -7.14
XUX(3,1)= 600
YUX(3,1)= -13.68
XUX(4,1)= 900
YUX(4,1)= -18
XUX(5,1)= 1200
YUX(5,1)= -20.5
XUX(6,1)= 1500
YUX(6,1)= -21.5
XUX(7,1)= 1800
YUX(7,1)= -22.8
XUX(8,1)= 2100
YUX(8,1)= -23.7
XUX(9,1)= 2400
YUX(9,1)= -24.4
XUX(10,1)= 2700
YUX(10,1)= -24.6
XUX(11,1)= 3000
YUX(11,1)= -25

/XRANGE,0,3000
/YRANGE,-60,90
/AXLAB,X,LOAD
/AXLAB,Y,TIP DISPLACEMENT
/COLOR,CURVE,YGRE
/GCOLUMN,1,'  X_REF'
```

```
*VPLOT,XUX(1,1),YUX(1,1)
/OUT,
/NOERASE
NSOL,2,3,U,Z,UX
PROD,7,1, , ,LOAD, , ,3000.0,0,0,
/COLOR,CURVE,MRED
XVAR,7
PLVAR,2
/NOERASE
*DIM,XUY,TABLE,11,1
*DIM,YUY,TABLE,11,1
XUY(1,1)= 0
YUY(1,1)= 0
XUY(2,1)= 300
YUY(2,1)= -12.18
XUY(3,1)= 600
YUY(3,1)= -23.87
XUY(4,1)= 900
YUY(4,1)= -30
XUY(5,1)= 1200
YUY(5,1)= -33.5
XUY(6,1)= 1500
YUY(6,1)= -38
XUY(7,1)= 1800
YUY(7,1)= -40
XUY(8,1)= 2100
YUY(8,1)= -42.5
XUY(9,1)= 2400
YUY(9,1)= -44
XUY(10,1)= 2700
YUY(10,1)= -45
XUY(11,1)= 3000
YUY(11,1)= -47.31

/COLOR,CURVE,YGRE
/GCOLUMN,1,'  Y_REF'
*VPLOT,XUY(1,1),YUY(1,1)
/NOERASE
NSOL,3,3,U,X,UY
/COLOR,CURVE,MRED
XVAR,7
PLVAR,3
/NOERASE
*DIM,XUZ,TABLE,11,1
*DIM,YUZ,TABLE,11,1
XUZ(1,1)= 0
YUZ(1,1)= 0
XUZ(2,1)= 300
YUZ(2,1)= 40.53
XUZ(3,1)= 600
YUZ(3,1)= 53.71
XUZ(4,1)= 900
YUZ(4,1)= 60
XUZ(5,1)= 1200
YUZ(5,1)= 62
XUZ(6,1)= 1500
YUZ(6,1)= 63
XUZ(7,1)= 1800
YUZ(7,1)= 64.5
XUZ(8,1)= 2100
YUZ(8,1)= 65.5
XUZ(9,1)= 2400
YUZ(9,1)= 66
XUZ(10,1)= 2700
YUZ(10,1)= 67
XUZ(11,1)= 3000
YUZ(11,1)= 68.09

/COLOR,CURVE,YGRE
/GCOLUMN,1,'  Z_REF'
*VPLOT,XUZ(1,1),YUZ(1,1)
/NOERASE
```

```
NSOL,4,3,U,Y,UZ
/COLOR,CURVE,MRED
XVAR,7
PLVAR,4
FINISH

/POST1
SET,,,1,,0.1,,
*GET,UX_300,NODE,3,U,Z
*GET,UY_300,NODE,3,U,X
*GET,UZ_300,NODE,3,U,Y
SET,,,1,,0.15,,
*GET,UX_450,NODE,3,U,Z
*GET,UY_450,NODE,3,U,X
*GET,UZ_450,NODE,3,U,Y
SET,,,1,,0.2,,
*GET,UX_600,NODE,3,U,Z
*GET,UY_600,NODE,3,U,X
*GET,UZ_600,NODE,3,U,Y
SET,,,1,,1.0,,
*GET,UX_3000,NODE,3,U,Z
*GET,UY_3000,NODE,3,U,X
*GET,UZ_3000,NODE,3,U,Y
*DIM,LABEL1,CHAR,1,4
LABEL1(1,1) = ' 300'
LABEL1(1,2) = ' 450'
LABEL1(1,3) = ' 600'
LABEL1(1,4) = '3000'
*DIM,VALUE1,CHAR,1,4
VALUE1(1,1) = '-7.14'
VALUE1(1,2) = '-10.86'
VALUE1(1,3) = '-13.68'
VALUE1(1,4) = '-24.97'
*DIM,VALUE2,CHAR,1,4
VALUE2(1,1) = '-6.98'
VALUE2(1,2) = '-10.70'
VALUE2(1,3) = '-13.51'
VALUE2(1,4) = '-25.00'
*DIM,ERROR1,,1,4
*VFILL,ERROR1(1,1),DATA,UX_300
*VFILL,ERROR1(1,2),DATA,UX_450
*VFILL,ERROR1(1,3),DATA,UX_600
*VFILL,ERROR1(1,4),DATA,UX_3000


/COM, ************************* NOTE ****************************
/COM,
/COM, THE GLOBAL CS OF THIS MODEL DOES NOT MATCH THE CS OF NAFEMS
/COM, TEST. HERE IS THE CORRESPODANCE:
/COM,                  NAFEMS         Mechanical APDL
/COM,                    X      >>>     Z
/COM,                    Y      >>>     X
/COM,                    Z      >>>     Y
/COM,
/COM,  -------------  TIP DISPLACEMENT:  UX   --------------
/COM,
/COM,                 |      NAFEMS TEST      |   Mechanical APDL   |
/COM,         |  LOAD  |   REF.   |  NUM.RES.  |  SOL.185  |
/COM,
*VWRITE,LABEL1(1,1),VALUE1(1,1),VALUE2(1,1),ERROR1(1,1)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F8.4)
*VWRITE,LABEL1(1,2),VALUE1(1,2),VALUE2(1,2),ERROR1(1,2)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F8.4)
*VWRITE,LABEL1(1,3),VALUE1(1,3),VALUE2(1,3),ERROR1(1,3)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F8.4)
*VWRITE,LABEL1(1,4),VALUE1(1,4),VALUE2(1,4),ERROR1(1,4)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F8.4)
/COM,
/COM,  ----------------------------------------------------
/OUT,SCRATCH
VALUE1(1,1) = '-12.18'
VALUE1(1,2) = '-18.78'
```

```
VALUE1(1,3) = '-23.87'
VALUE1(1,4) = '-47.31'
VALUE2(1,1) = '-11.91'
VALUE2(1,2) = '-18.45'
VALUE2(1,3) = '-23.54'
VALUE2(1,4) = '-47.70'
*VFILL,ERROR1(1,1),DATA,UY_300
*VFILL,ERROR1(1,2),DATA,UY_450
*VFILL,ERROR1(1,3),DATA,UY_600
*VFILL,ERROR1(1,4),DATA,UY_3000
/OUT
/COM,  -------------  TIP DISPLACEMENT:  UY   --------------
/COM,
/COM,                  |      NAFEMS TEST      |   Mechanical APDL   |
/COM,         |  LOAD  |   REF.   |  NUM.RES.  |  SOL.185  |
/COM,
*VWRITE,LABEL1(1,1),VALUE1(1,1),VALUE2(1,1),ERROR1(1,1)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F8.4)
*VWRITE,LABEL1(1,2),VALUE1(1,2),VALUE2(1,2),ERROR1(1,2)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F8.4)
*VWRITE,LABEL1(1,3),VALUE1(1,3),VALUE2(1,3),ERROR1(1,3)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F8.4)
*VWRITE,LABEL1(1,4),VALUE1(1,4),VALUE2(1,4),ERROR1(1,4)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F8.4)
/COM,
/COM,  ----------------------------------------------------
/OUT,SCRATCH
VALUE1(1,1) = '40.53'
VALUE1(1,2) = '48.79'
VALUE1(1,3) = '53.71'
VALUE1(1,4) = '68.09'
VALUE2(1,1) = '40.15'
VALUE2(1,2) = '48.48'
VALUE2(1,3) = '53.47'
VALUE2(1,4) = '68.56'
*VFILL,ERROR1(1,1),DATA,UZ_300
*VFILL,ERROR1(1,2),DATA,UZ_450
*VFILL,ERROR1(1,3),DATA,UZ_600
*VFILL,ERROR1(1,4),DATA,UZ_3000
/OUT
/COM,  -------------  TIP DISPLACEMENT:  UZ   --------------
/COM,
/COM,                  |      NAFEMS TEST      |   Mechanical APDL   |
/COM,         |  LOAD  |   REF.   |  NUM.RES.  |  SOL.185  |
/COM,
*VWRITE,LABEL1(1,1),VALUE1(1,1),VALUE2(1,1),ERROR1(1,1)
(1X,'           ',A4,'      ',A5,'      ',A5,'      ',F8.4)
*VWRITE,LABEL1(1,2),VALUE1(1,2),VALUE2(1,2),ERROR1(1,2)
(1X,'           ',A4,'      ',A5,'      ',A5,'      ',F8.4)
*VWRITE,LABEL1(1,3),VALUE1(1,3),VALUE2(1,3),ERROR1(1,3)
(1X,'           ',A4,'      ',A5,'      ',A5,'      ',F8.4)
*VWRITE,LABEL1(1,4),VALUE1(1,4),VALUE2(1,4),ERROR1(1,4)
(1X,'           ',A4,'      ',A5,'      ',A5,'      ',F8.4)
/COM,
/COM,  ----------------------------------------------------
ESEL,,,,ELESOL
NSLE
ESEL,ALL
PRNSOL,S,COMP
PRNSOL,EPTO,COMP
FINISH

/POST1
/COM,                 !WARNING!
/COM,  Mechanical APDL RESULTS GIVEN IN DIFFERENT CS THAN
/COM,  NAFEMS MANUAL, CS RESULTS SHOULD BE TAKEN AS:
/COM,                  X >>> Z
/COM,                  Y >>> X
/COM,                  Z >>> Y
SET,1,23
*GET,UX1,NODE,52,U,Z
*GET,UY1,NODE,52,U,X
```

```
*GET,UZ1,NODE,52,U,Y
*GET,APLOAD,TIME
RX=ABS(UX1/24.97)
RY=ABS(UY1/47.31)
RZ=ABS(UZ1/68.09)
*DIM,VALUE,,3,2
*DIM,LABEL2,CHAR,3
*DIM,LABEL3,CHAR,3
*DIM,LABEL,CHAR,3
LABEL2(1) = 'UX','UY','UZ'
LABEL(1) = 'vmr029-','vmr029-','vmr029-'
LABEL3(1) = 't5-185','t5-185','t5-185'
*VFILL,VALUE(1,1),DATA,ABS(UX1),ABS(UY1),ABS(UZ1)
*VFILL,VALUE(1,2),DATA,RX,RY,RZ
/OUT,vmr029-t5-185,vrt
/COM
/COM,-------------- VMR029-T5 RESULTS COMPARISON ---------------
/COM,
/COM,          |    Mechanical APDL    |   RATIO   |     INPUT     |
/COM,
/COM,SOLID185
*VWRITE,LABEL2(1),VALUE(1,1),VALUE(1,2),LABEL(1),LABEL3(1)
(1X,'   ',A2,'       ',F12.4,'      ',F13.4,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t5-185,vrt
```

VM-R029-T5 188 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T5-188
/TITLE,VMR029-T5-188,LARGE DEFLECTION OF A CURVED ELASTIC CANTILEVER UNDER TRANSVERSE END LOAD
/COM, REFERENCE: NAFEMS BENCHMARK TEST FOR BEAMS AND SHELLS TEST 3DNLG-5

/PREP7
CSYS,1
T = 45/8.0
N,1,100.0,0.0
N,2,100.0,-T
N,3,100.0,-2*T
N,4,100.0,-3*T
N,5,100.0,-4*T
N,6,100.0,-5*T
N,7,100.0,-6*T
N,8,100.0,-7*T
N,9,100.0,-8*T
ET,1,188
SECN,1
N,101,0.0,
CSYS,0
E,1,2,101
E,2,3,101
E,3,4,101
E,4,5,101
E,5,6,101
E,6,7,101
E,7,8,101
E,8,9,101
SECT,1,BEAM,RECT
SECD,1,1
MP,EX,1,1E7
MP,GXY,1,0.5E7
MP,NUXY,1,0.0
D,1,ALL

/SOLU
```

```
NLGEOM,ON
OUTRES,ALL,ALL
F,9,FZ,3000
SOLC,ON
NSUBST,40,200
/OUT,SCRATCH
SOLVE
FINISH
/SHOW,,jpeg

/POST26
*DIM,XUX,TABLE,11,1
*DIM,YUX,TABLE,11,1
XUX(1,1)= 0
YUX(1,1)= 0
XUX(2,1)= 300
YUX(2,1)= -7.14
XUX(3,1)= 600
YUX(3,1)= -13.68
XUX(4,1)= 900
YUX(4,1)= -18
XUX(5,1)= 1200
YUX(5,1)= -20.5
XUX(6,1)= 1500
YUX(6,1)= -21.5
XUX(7,1)= 1800
YUX(7,1)= -22.8
XUX(8,1)= 2100
YUX(8,1)= -23.7
XUX(9,1)= 2400
YUX(9,1)= -24.4
XUX(10,1)= 2700
YUX(10,1)= -24.6
XUX(11,1)= 3000
YUX(11,1)= -25

/XRANGE,0,3000
/YRANGE,-60,90
/AXLAB,X,LOAD
/AXLAB,Y,TIP DISPLACEMENT
/COLOR,CURVE,YGRE
/GCOLUMN,1,'  REF_UX'
*VPLOT,XUX(1,1),YUX(1,1)
/NOERASE
/OUT,
NSOL,2,9,U,Z,UZ
PROD,7,1, , ,LOAD, , ,3000.0,0,0,
/COLOR,CURVE,MRED
XVAR,7
PLVAR,2
/NOERASE
*DIM,XUY,TABLE,11,1
*DIM,YUY,TABLE,11,1
XUY(1,1)= 0
YUY(1,1)= 0
XUY(2,1)= 300
YUY(2,1)= -12.18
XUY(3,1)= 600
YUY(3,1)= -23.87
XUY(4,1)= 900
YUY(4,1)= -30
XUY(5,1)= 1200
YUY(5,1)= -33.5
XUY(6,1)= 1500
YUY(6,1)= -38
XUY(7,1)= 1800
YUY(7,1)= -40
XUY(8,1)= 2100
YUY(8,1)= -42.5
XUY(9,1)= 2400
YUY(9,1)= -44
XUY(10,1)= 2700
```

```
YUY(10,1)= -45
XUY(11,1)= 3000
YUY(11,1)= -47.31

/COLOR,CURVE,YGRE
/GCOLUMN,1,'  REF_UY'
*VPLOT,XUY(1,1),YUY(1,1)
/NOERASE
NSOL,3,9,U,X,UX
PROD,5,3,,,UX,,,-1
/COLOR,CURVE,MRED
XVAR,7
PLVAR,5
/NOERASE
*DIM,XUZ,TABLE,11,1
*DIM,YUZ,TABLE,11,1
XUZ(1,1)= 0
YUZ(1,1)= 0
XUZ(2,1)= 300
YUZ(2,1)= 40.53
XUZ(3,1)= 600
YUZ(3,1)= 53.71
XUZ(4,1)= 900
YUZ(4,1)= 60
XUZ(5,1)= 1200
YUZ(5,1)= 62
XUZ(6,1)= 1500
YUZ(6,1)= 63
XUZ(7,1)= 1800
YUZ(7,1)= 64.5
XUZ(8,1)= 2100
YUZ(8,1)= 65.5
XUZ(9,1)= 2400
YUZ(9,1)= 66
XUZ(10,1)= 2700
YUZ(10,1)= 67
XUZ(11,1)= 3000
YUZ(11,1)= 68.09

/COLOR,CURVE,YGRE
/GCOLUMN,1,'  REF_UZ'
*VPLOT,XUZ(1,1),YUZ(1,1)
/NOERASE
NSOL,4,9,U,Y,UY
PROD,6,4,,,UY,,,-1
/COLOR,CURVE,MRED
XVAR,7
PLVAR,6
FINISH

/POST1
SET,LAST
PRNSOL,DOF
*GET,UX1,NODE,9,U,X
*GET,UY1,NODE,9,U,Y
*GET,UZ1,NODE,9,U,Z
*GET,APLOAD,TIME
RX=ABS(UX1/24.97)
RY=ABS(UY1/47.31)
RZ=ABS(UZ1/68.09)
*DIM,VALUE,,3,2
*DIM,LABEL2,CHAR,3
*DIM,LABEL,CHAR,3
*DIM,LABEL3,CHAR,3
LABEL2(1) = 'UX','UY','UZ'
LABEL(1) = 'vmr029-','vmr029-','vmr029-'
LABEL3(1) = 't5-188','t5-188','t5-188'
*VFILL,VALUE(1,1),DATA,ABS(UX1),ABS(UY1),ABS(UZ1)
*VFILL,VALUE(1,2),DATA,RX,RY,RZ
/OUT,vmr029-t5-188,vrt
/COM
/COM,-------------- VMR029-T5 RESULTS COMPARISON ---------------
```

```
/COM,
/COM,         |    Mechanical APDL    |   RATIO   |      INPUT      |
/COM,
/COM,BEAM188
*VWRITE,LABEL2(1),VALUE(1,1),VALUE(1,2),LABEL(1),LABEL3(1)
(1X,'   ',A2,'       ',F12.4,'      ',F13.4,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t5-188,vrt
```

VM-R029-T5 189 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T5-189
/TITLE,VMR029-T5-189,LARGE DEFLECTION OF A CURVED ELASTIC CANTILEVER UNDER TRANSVERSE END LOAD
/COM, REFERENCE: NAFEMS BENCHMARK TEST FOR BEAMS AND SHELLS TEST 3DNLG-5

/PREP7
CSYS,1
T = 45/8.0
N,1,100.0,0.0
N,2,100.0,-0.5*T
N,3,100.0,-1.0*T
N,4,100.0,-1.5*T
N,5,100.0,-2.0*T
N,6,100.0,-2.5*T
N,7,100.0,-3.0*T
N,8,100.0,-3.5*T
N,9,100.0,-4.0*T
N,10,100.0,-4.5*T
N,11,100.0,-5.0*T
N,12,100.0,-5.5*T
N,13,100.0,-6.0*T
N,14,100.0,-6.5*T
N,15,100.0,-7.0*T
N,16,100.0,-7.5*T
N,17,100.0,-8.0*T
ET,1,189
SECN,1
N,101,0.0,
CSYS,0
E,1,3,2,101
E,3,5,4,101
E,5,7,6,101
E,7,9,8,101
E,9,11,10,101
E,11,13,12,101
E,13,15,14,101
E,15,17,16,101
SECT,1,BEAM,RECT
SECD,1,1
MP,EX,1,1E7
MP,GXY,1,0.5E7
MP,NUXY,1,0.0
D,1,ALL

/SOLU
NLGEOM,ON
OUTRES,ALL,ALL
F,17,FZ,3000
SOLC,ON
NSUBST,20,200
/OUT,SCRATCH
SOLVE
FINISH
```

```
/SHOW,,jpeg

/POST26
*DIM,XUX,TABLE,11,1
*DIM,YUX,TABLE,11,1
XUX(1,1)= 0
YUX(1,1)= 0
XUX(2,1)= 300
YUX(2,1)= -7.14
XUX(3,1)= 600
YUX(3,1)= -13.68
XUX(4,1)= 900
YUX(4,1)= -18
XUX(5,1)= 1200
YUX(5,1)= -20.5
XUX(6,1)= 1500
YUX(6,1)= -21.5
XUX(7,1)= 1800
YUX(7,1)= -22.8
XUX(8,1)= 2100
YUX(8,1)= -23.7
XUX(9,1)= 2400
YUX(9,1)= -24.4
XUX(10,1)= 2700
YUX(10,1)= -24.6
XUX(11,1)= 3000
YUX(11,1)= -25

/XRANGE,0,3000
/YRANGE,-60,90
/AXLAB,X,LOAD
/AXLAB,Y,TIP DISPLACEMENT
/COLOR,CURVE,YGRE
/GCOLUMN,1,'  REF_UX'
*VPLOT,XUX(1,1),YUX(1,1)
/NOERASE
/OUT,
NSOL,2,17,U,Z,UZ
PROD,7,1, , ,LOAD, , ,3000.0,0,0,
/COLOR,CURVE,MRED
XVAR,7
PLVAR,2
/NOERASE
*DIM,XUY,TABLE,11,1
*DIM,YUY,TABLE,11,1
XUY(1,1)= 0
YUY(1,1)= 0
XUY(2,1)= 300
YUY(2,1)= -12.18
XUY(3,1)= 600
YUY(3,1)= -23.87
XUY(4,1)= 900
YUY(4,1)= -30
XUY(5,1)= 1200
YUY(5,1)= -33.5
XUY(6,1)= 1500
YUY(6,1)= -38
XUY(7,1)= 1800
YUY(7,1)= -40
XUY(8,1)= 2100
YUY(8,1)= -42.5
XUY(9,1)= 2400
YUY(9,1)= -44
XUY(10,1)= 2700
YUY(10,1)= -45
XUY(11,1)= 3000
YUY(11,1)= -47.31

/COLOR,CURVE,YGRE
/GCOLUMN,1,'  REF_UY'
*VPLOT,XUY(1,1),YUY(1,1)
/NOERASE
```

```
NSOL,3,17,U,X,UX
PROD,5,3,,,UX,,,-1
/COLOR,CURVE,MRED
XVAR,7
PLVAR,5
/NOERASE
*DIM,XUZ,TABLE,11,1
*DIM,YUZ,TABLE,11,1
XUZ(1,1)= 0
YUZ(1,1)= 0
XUZ(2,1)= 300
YUZ(2,1)= 40.53
XUZ(3,1)= 600
YUZ(3,1)= 53.71
XUZ(4,1)= 900
YUZ(4,1)= 60
XUZ(5,1)= 1200
YUZ(5,1)= 62
XUZ(6,1)= 1500
YUZ(6,1)= 63
XUZ(7,1)= 1800
YUZ(7,1)= 64.5
XUZ(8,1)= 2100
YUZ(8,1)= 65.5
XUZ(9,1)= 2400
YUZ(9,1)= 66
XUZ(10,1)= 2700
YUZ(10,1)= 67
XUZ(11,1)= 3000
YUZ(11,1)= 68.09

/COLOR,CURVE,YGRE
/GCOLUMN,1,'  REF_UZ'
*VPLOT,XUZ(1,1),YUZ(1,1)
/NOERASE
NSOL,4,17,U,Y,UY
PROD,6,4,,,UY,,,-1
/COLOR,CURVE,MRED
XVAR,7
PLVAR,6
FINISH

/POST1
SET,LAST
PRNSOL,DOF
*GET,UX1,NODE,17,U,X
*GET,UY1,NODE,17,U,Y
*GET,UZ1,NODE,17,U,Z
*GET,APLOAD,TIME
RX=ABS(UX1/24.97)
RY=ABS(UY1/47.31)
RZ=ABS(UZ1/68.09)
*DIM,VALUE,,3,2
*DIM,LABEL2,CHAR,3
*DIM,LABEL,CHAR,3
*DIM,LABEL3,CHAR,3
LABEL2(1) = 'UX','UY','UZ'
LABEL(1) = 'vmr029-','vmr029-','vmr029-'
LABEL3(1) = 't5-189','t5-189','t5-189'
*VFILL,VALUE(1,1),DATA,ABS(UX1),ABS(UY1),ABS(UZ1)
*VFILL,VALUE(1,2),DATA,RX,RY,RZ
/OUT,vmr029-t5-189,vrt
/COM
/COM,-------------- VMR029-T5  RESULTS COMPARISON ---------------
/COM,
/COM,         |    Mechanical APDL    |   RATIO   |      INPUT      |
/COM,
/COM,BEAM189
*VWRITE,LABEL2(1),VALUE(1,1),VALUE(1,2),LABEL(1),LABEL3(1)
(1X,'   ',A2,'       ',F12.4,'      ',F13.4,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
```

```
/OUT
FINISH
*LIST,vmr029-t5-189,vrt
FINISH
```

VM-R029-T5 190 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T5-190
/TITLE,VMR029-T5-190, LARGE DEFLECTION OF A CURVED ELASTIC CANTILEVER UNDER TRANSVERSE END LOAD
/COM,REFERENCE NAFEMS 3D BEAMS AND SHELLS MANUAL TEST 3DNLG-5

/PREP7
W=1.0
H=1.0
R=100
THETA=45
F=3000.0
ET,1,190
MP,EX,1,1E7
MP,NUXY,1,0.3
K,1,0,-H/2,-W/2
K,2,0,-H/2,W/2
K,3,0,H/2,W/2
K,4,0,H/2,-W/2
K,5,0,0,R
K,6,0,1,R
A,1,2,3,4
VROTAT,ALL, , , , , ,5,6,-45, ,
LESIZE,ALL,,,1
LESIZE,9,,,16
LESIZE,10,,,16
LESIZE,11,,,16
LESIZE,12,,,16
VEORIENT,1,THIN
VMESH,ALL
NSEL,S,LOC,X,0
D,ALL,ALL
NSEL,S,LOC,Z,28.5,30
F,ALL,FY,750
ALLSEL,ALL
ESEL,S,,,1
ESEL,A,,,4
ESEL,A,,,16
CM,ELESOL,ELEM
ALLSEL,ALL
FINISH

/SOLVE
NLGEOM,ON
AUTOTS,ON
NSUBST,100,100000,40
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINISH
/SHOW,,jpeg

/POST26
*DIM,XUX,TABLE,11,1
*DIM,YUX,TABLE,11,1
XUX(1,1)= 0
YUX(1,1)= 0
XUX(2,1)= 300
YUX(2,1)= -7.14
XUX(3,1)= 600
YUX(3,1)= -13.68
XUX(4,1)= 900
```

```
YUX(4,1)= -18
XUX(5,1)= 1200
YUX(5,1)= -20.5
XUX(6,1)= 1500
YUX(6,1)= -21.5
XUX(7,1)= 1800
YUX(7,1)= -22.8
XUX(8,1)= 2100
YUX(8,1)= -23.7
XUX(9,1)= 2400
YUX(9,1)= -24.4
XUX(10,1)= 2700
YUX(10,1)= -24.6
XUX(11,1)= 3000
YUX(11,1)= -25

/XRANGE,0,3000
/YRANGE,-60,90
/AXLAB,X,LOAD
/AXLAB,Y,RADIAL DISPLACEMENT
/COLOR,CURVE,YGRE
/GCOLUMN,1,'  X_REF'
*VPLOT,XUX(1,1),YUX(1,1)
/NOERASE
/OUT,
NSOL,2,3,U,Z,UX
PROD,7,1, , ,LOAD, , ,3000.0,0,0,
/COLOR,CURVE,MRED
XVAR,7
PLVAR,2
/NOERASE
*DIM,XUY,TABLE,11,1
*DIM,YUY,TABLE,11,1
XUY(1,1)= 0
YUY(1,1)= 0
XUY(2,1)= 300
YUY(2,1)= -12.18
XUY(3,1)= 600
YUY(3,1)= -23.87
XUY(4,1)= 900
YUY(4,1)= -30
XUY(5,1)= 1200
YUY(5,1)= -33.5
XUY(6,1)= 1500
YUY(6,1)= -38
XUY(7,1)= 1800
YUY(7,1)= -40
XUY(8,1)= 2100
YUY(8,1)= -42.5
XUY(9,1)= 2400
YUY(9,1)= -44
XUY(10,1)= 2700
YUY(10,1)= -45
XUY(11,1)= 3000
YUY(11,1)= -47.31

/COLOR,CURVE,YGRE
/GCOLUMN,1,'  Y_REF'
*VPLOT,XUY(1,1),YUY(1,1)
/NOERASE
NSOL,3,3,U,X,UY
/COLOR,CURVE,MRED
XVAR,7
PLVAR,3
/NOERASE
*DIM,XUZ,TABLE,11,1
*DIM,YUZ,TABLE,11,1
XUZ(1,1)= 0
YUZ(1,1)= 0
XUZ(2,1)= 300
YUZ(2,1)= 40.53
XUZ(3,1)= 600
```

```
YUZ(3,1)= 53.71
XUZ(4,1)= 900
YUZ(4,1)= 60
XUZ(5,1)= 1200
YUZ(5,1)= 62
XUZ(6,1)= 1500
YUZ(6,1)= 63
XUZ(7,1)= 1800
YUZ(7,1)= 64.5
XUZ(8,1)= 2100
YUZ(8,1)= 65.5
XUZ(9,1)= 2400
YUZ(9,1)= 66
XUZ(10,1)= 2700
YUZ(10,1)= 67
XUZ(11,1)= 3000
YUZ(11,1)= 68.09

/COLOR,CURVE,YGRE
/GCOLUMN,1,'  Z_REF'
*VPLOT,XUZ(1,1),YUZ(1,1)
/NOERASE
NSOL,4,3,U,Y,UZ
/COLOR,CURVE,MRED
XVAR,7
PLVAR,4
FINISH

/POST1
SET,,,1,,0.1,,
*GET,UX_300,NODE,3,U,Z
*GET,UY_300,NODE,3,U,X
*GET,UZ_300,NODE,3,U,Y
SET,,,1,,0.15,,
*GET,UX_450,NODE,3,U,Z
*GET,UY_450,NODE,3,U,X
*GET,UZ_450,NODE,3,U,Y
SET,,,1,,0.2,,
*GET,UX_600,NODE,3,U,Z
*GET,UY_600,NODE,3,U,X
*GET,UZ_600,NODE,3,U,Y
SET,,,1,,1.0,,
*GET,UX_3000,NODE,3,U,Z
*GET,UY_3000,NODE,3,U,X
*GET,UZ_3000,NODE,3,U,Y
*DIM,LABEL1,CHAR,1,4
LABEL1(1,1) = ' 300'
LABEL1(1,2) = ' 450'
LABEL1(1,3) = ' 600'
LABEL1(1,4) = '3000'
*DIM,VALUE1,CHAR,1,4
VALUE1(1,1) = '-7.14'
VALUE1(1,2) = '-10.86'
VALUE1(1,3) = '-13.68'
VALUE1(1,4) = '-24.97'
*DIM,VALUE2,CHAR,1,4
VALUE2(1,1) = '-6.98'
VALUE2(1,2) = '-10.70'
VALUE2(1,3) = '-13.51'
VALUE2(1,4) = '-25.00'
*DIM,ERROR1,,1,4
*VFILL,ERROR1(1,1),DATA,UX_300
*VFILL,ERROR1(1,2),DATA,UX_450
*VFILL,ERROR1(1,3),DATA,UX_600
*VFILL,ERROR1(1,4),DATA,UX_3000

/COM, ************************* NOTE ****************************
/COM,
/COM, THE GLOBAL CS OF THIS MODEL DOES NOT MATCH THE CS OF NAFEMS
/COM, TEST. HERE IS THE CORRESPODANCE:
/COM,                   NAFEMS         Mechanical APDL
/COM,                     X      >>>     Z
```

```
/COM,                     Y      >>>     X
/COM,                     Z      >>>     Y
/COM,
/COM,  -------------  TIP DISPLACEMENT:  UX   --------------
/COM,
/COM,                  |      NAFEMS TEST      |   Mechanical APDL   |
/COM,         |  LOAD  |   REF.   |  NUM.RES.  |  SOL.190  |
/COM,
*VWRITE,LABEL1(1,1),VALUE1(1,1),VALUE2(1,1),ERROR1(1,1)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F10.4)
*VWRITE,LABEL1(1,2),VALUE1(1,2),VALUE2(1,2),ERROR1(1,2)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F10.4)
*VWRITE,LABEL1(1,3),VALUE1(1,3),VALUE2(1,3),ERROR1(1,3)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F10.4)
*VWRITE,LABEL1(1,4),VALUE1(1,4),VALUE2(1,4),ERROR1(1,4)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F10.4)
/COM,
/COM,  -----------------------------------------------------
/OUT,SCRATCH
VALUE1(1,1) = '-12.18'
VALUE1(1,2) = '-18.78'
VALUE1(1,3) = '-23.87'
VALUE1(1,4) = '-47.31'
VALUE2(1,1) = '-11.91'
VALUE2(1,2) = '-18.45'
VALUE2(1,3) = '-23.54'
VALUE2(1,4) = '-47.70'
*VFILL,ERROR1(1,1),DATA,UY_300
*VFILL,ERROR1(1,2),DATA,UY_450
*VFILL,ERROR1(1,3),DATA,UY_600
*VFILL,ERROR1(1,4),DATA,UY_3000
/OUT
/COM,  -------------  TIP DISPLACEMENT:  UY   --------------
/COM,
/COM,                  |      NAFEMS TEST      |   Mechanical APDL   |
/COM,         |  LOAD  |   REF.   |  NUM.RES.  |  SOL.190  |
/COM,
*VWRITE,LABEL1(1,1),VALUE1(1,1),VALUE2(1,1),ERROR1(1,1)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F10.4)
*VWRITE,LABEL1(1,2),VALUE1(1,2),VALUE2(1,2),ERROR1(1,2)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F10.4)
*VWRITE,LABEL1(1,3),VALUE1(1,3),VALUE2(1,3),ERROR1(1,3)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F10.4)
*VWRITE,LABEL1(1,4),VALUE1(1,4),VALUE2(1,4),ERROR1(1,4)
(1X,'            ',A4,'     ',A6,'     ',A6,'      ',F10.4)
/COM,
/COM,  -----------------------------------------------------
/OUT,SCRATCH
VALUE1(1,1) = '40.53'
VALUE1(1,2) = '48.79'
VALUE1(1,3) = '53.71'
VALUE1(1,4) = '68.09'
VALUE2(1,1) = '40.15'
VALUE2(1,2) = '48.48'
VALUE2(1,3) = '53.47'
VALUE2(1,4) = '68.56'
*VFILL,ERROR1(1,1),DATA,UZ_300
*VFILL,ERROR1(1,2),DATA,UZ_450
*VFILL,ERROR1(1,3),DATA,UZ_600
*VFILL,ERROR1(1,4),DATA,UZ_3000
/OUT
/COM,  -------------  TIP DISPLACEMENT:  UZ   --------------
/COM,
/COM,                  |      NAFEMS TEST      |   Mechanical APDL   |
/COM,         |  LOAD  |   REF.   |  NUM.RES.  |   SOL.190      |
/COM,
*VWRITE,LABEL1(1,1),VALUE1(1,1),VALUE2(1,1),ERROR1(1,1)
(1X,'            ',A4,'      ',A5,'      ',A5,'      ',F10.4)
*VWRITE,LABEL1(1,2),VALUE1(1,2),VALUE2(1,2),ERROR1(1,2)
(1X,'            ',A4,'      ',A5,'      ',A5,'      ',F10.4)
*VWRITE,LABEL1(1,3),VALUE1(1,3),VALUE2(1,3),ERROR1(1,3)
(1X,'            ',A4,'      ',A5,'      ',A5,'      ',F10.4)
```

```
*VWRITE,LABEL1(1,4),VALUE1(1,4),VALUE2(1,4),ERROR1(1,4)
(1X,'             ',A4,'      ',A5,'      ',A5,'      ',F10.4)
/COM,
/COM,  ---------------------------------------------------
ESEL,,,,ELESOL
NSLE
ESEL,ALL
PRNSOL,S,COMP
PRNSOL,EPTO,COMP
FINISH

/POST1
/COM,                 !WARNING!
/COM,  Mechanical APDL RESULTS GIVEN IN DIFFERENT CS THAN
/COM,  NAFEMS MANUAL, CS RESULTS SHOULD BE TAKEN AS:
/COM,                  X >>> Z
/COM,                  Y >>> X
/COM,                  Z >>> Y
SET,LAST
*GET,UX1,NODE,52,U,Z
*GET,UY1,NODE,52,U,X
*GET,UZ1,NODE,52,U,Y
*GET,APLOAD,TIME
RX=ABS(UX1/24.97)
RY=ABS(UY1/47.31)
RZ=ABS(UZ1/68.09)
*DIM,VALUE,,3,2
*DIM,LABEL2,CHAR,3
*DIM,LABEL3,CHAR,3
*DIM,LABEL,CHAR,3
LABEL2(1) = 'UX','UY','UZ'
LABEL(1) = 'vmr029-','vmr029-','vmr029-'
LABEL3(1) = 't5-190','t5-190','t5-190'
*VFILL,VALUE(1,1),DATA,ABS(UX1),ABS(UY1),ABS(UZ1)
*VFILL,VALUE(1,2),DATA,RX,RY,RZ
/OUT,vmr029-t5-190,vrt
/COM
/COM,-------------- VMR029-T5 RESULTS COMPARISON ---------------
/COM,
/COM,          |    Mechanical APDL    |   RATIO   |     INPUT     |
/COM,
/COM,SOLSH190
*VWRITE,LABEL2(1),VALUE(1,1),VALUE(1,2),LABEL(1),LABEL3(1)
(1X,'   ',A2,'       ',F12.4,'      ',F13.4,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t5-190,vrt
```

VM-R029-T7 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T7-181
/TITLE,VMR029-T7-181,LARGE DISPLACEMENT ELASTIC RESPONSE OF A HINGED SPHERICAL SHELL UNDER UNIFORM PRESSURE LOAD
/COM, REF. 'NAFEMS ASSEMBLY BENCHMARK TESTS FOR 3D BEAMS AND SHELLS
/COM,       TEST 3DNLG-7
/PREP7
L=1570
T=100
P=0.1
ET,1,SHELL181
R,1,100,100,100,100
RMODIF,1,7,30000,30000
MP,EX,1,69
MP,NUXY,1,0.3
K,1,
K,6,5*L/8,,0.00020285*((5*L/8)*(3*L/8))
```

```
K,9,L,,0
LARC,       1,       9,       6
K,15,,3*L/4,0.00020285*((3*L/4)*(L/4))
K,17,,L,0
LARC,       1,      17,      15
ADRAG,1, , , , , ,2
KWPAVE,2
WPRO,,90.000000,
ASBW,1
ADELE,2, , ,1
LSLA,S,1
LESIZE,ALL,,,16
AMESH,ALL
DL,ALL, ,UX,
DL,ALL, ,UY,
DL,ALL, ,UZ,
SFE,ALL,2,PRES,,P
ALLSEL,ALL
FINISH
/SOLVE
NLGEOM,ON
NSUBST,200,2000,25
OUTRES,ALL,ALL
ARCLEN,ON,,
AUTOTS,-1
/OUT,SCRATCH
SOLVE
FINISH
/OUT
/POST26
*DIM,X,TABLE,11,1
*DIM,Y,TABLE,11,1
X(  1,1)= 0
Y(  1,1)= 0
X(  2,1)= 30
Y(  2,1)= 0.042
X(  3,1)= 60
Y(  3,1)= 0.06
X(  4,1)= 90
Y(  4,1)= 0.063
X(  5,1)= 120
Y(  5,1)= 0.056
X(  6,1)= 150
Y(  6,1)= 0.048
X(  7,1)= 180
Y(  7,1)= 0.037
X(  8,1)= 210
Y(  8,1)= 0.031
X(  9,1)= 240
Y(  9,1)= 0.03
X( 10,1)= 270
Y( 10,1)= 0.05
X( 11,1)= 300
Y( 11,1)= 0.096
/XRANGE,0,420
/YRANGE,0,0.1
/AXLAB,X,CENTRAL DEFLECTION
/AXLAB,Y,APPLIED PRESSURE
/GROPT,DIVX,11
/COLOR,CURVE,YGRE
*VPLOT,X(1,1),Y(1,1)
/NOERASE
NSOL,2,177,U,Z,DISP.
PROD,3,2, , ,DISP., , ,-1.0,0,0,
PROD,7,1, , ,LOAD, , ,0.1,0,0,
/COLOR,CURVE,MRED
XVAR,3
PLVAR,7
/OUT,
PRVAR,1,3,7
FINISH
```

```
/POST1
SET,LAST
NSEL,S,NODE,,177
PRNSOL,U,COMP
*GET,VAL8,NODE,177,U,Z
*SET,UA_8,-1*VAL8
*DIM,LABEL1,CHAR,1,2
LABEL1(1,1) = '0.1012'
LABEL1(1,2) = '       '
*DIM,VALUE1,CHAR,1,2
VALUE1(1,1) = '303.1'
*DIM,LABEL2,CHAR,1,3
LABEL2(1,1) = '177'
*DIM,ERROR1,,1,3
*VFILL,ERROR1(1,1),DATA,UA_8
/OUT,
/COM,
/COM,  -------------      CENTRAL DISPLACEMENT      -------------
/COM,
/COM,                  |   NAFEMS   |       Mechanical APDL     |
/COM,         |  LOAD  |  NUM.RES.  |  NODE   |   SHL.181       |
/COM,
*VWRITE,LABEL1(1,1),VALUE1(1,1),LABEL2(1,1),ERROR1(1,1)
(1X,'            ',A6,'     ',A5,'       ',A4,'    ',F12.3)
/COM,
/COM,  ----------------------------------------------------------
SET,1,15
*GET,PRES1,TIME
SET,1,26
*GET,PRES2,TIME
V1=PRES1*0.1
V2=PRES2*0.1
R1=V1/0.06495
R2=V2/0.03084
*DIM,VALUE,,2,2
*DIM,LABEL3,CHAR,2
*DIM,LABEL,CHAR,2
*DIM,LABEL4,CHAR,2
*VFILL,VALUE(1,1),DATA,V1,V2
*VFILL,VALUE(1,2),DATA,R1,R2
LABEL3(1) = 'LIMIT1','LIMIT2'
LABEL(1) = 'vmr029-','vmr029-'
LABEL4(1) = 't7-181','t7-181'
/OUT,vmr029-t7-181,vrt
/COM
/COM,-------------- VMR029-T7  RESULTS COMPARISON ---------------
/COM,
/COM,          |    Mechanical APDL    |   RATIO   |      INPUT      |
/COM,
/COM,SHELL181
*VWRITE,LABEL3(1),VALUE(1,1),VALUE(1,2),LABEL(1),LABEL4(1)
(1X,A6,'        ',F12.5,'      ',F13.5,'      ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t7-181,vrt
```

VM-R029-T7 185 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T7-185
/TITLE,VMR029-T7-185,LARGE DISPLACEMENT ELASTRIC RESPONSE OF A HINGED SPHERICAL SHELL UNDER UNIFORM PRESSURE LOA
/COM, REF. NAFEMS ASSEMBLY BENCHMARK TESTS FOR 3D BEAMS AND SHELLS TEST 3DNLG-7

/PREP7
L=1570
T=100
```

```
P=0.1
ET,1,185
KEYOPT,1,2,2
MP,EX,1,69
MP,NUXY,1,0.3
K,1,
K,6,5*L/8,,0.00020285*((5*L/8)*(3*L/8))
K,9,L,,0
LARC,       1,       9,       6
K,15,,3*L/4,0.00020285*((3*L/4)*(L/4))
K,17,,L,0
LARC,       1,      17,      15
ADRAG,1,,,,,,2
VEXT,ALL,,,0,0,T/2,,,,
VEXT,1,,,0,0,-T/2,,,,
K,111,10000,1570,10000
K,112,10000,1570,-10000
K,113,-10000,1570,-10000
K,114,-10000,1570,10000
A,111,112,113,114
VSBA,1,12,,,KEEP
VSBA,2,12
VDELE,1,3
LESIZE,ALL,,,8
LESIZE,10,,,1
LESIZE,11,,,1
LESIZE,12,,,1
LESIZE,13,,,1
LESIZE,18,,,1
LESIZE,19,,,1
LESIZE,20,,,1
LESIZE,21,,,1
VMESH,ALL
NUMMRG,ALL, , , ,LOW
DL,26, ,ALL,
DL,5, ,ALL,
DL,2, ,ALL,
DL,1, ,ALL,
VSEL,S, , ,4
ESLV,S
SFE,ALL,6,PRES,,P
ALLSEL,ALL
ESEL,S,,,1
ESEL,A,,,35
ESEL,A,,,92
CM,ELESOL,ELEM
ALLSEL,ALL
FINISH

/SOLVE
NLGEOM,ON
NSUBST,200,1000,25
OUTRES,ALL,ALL
ARCLEN,ON,,
AUTOTS,-1
/OUT,SCRATCH
SOLVE
FINISH

/SHOW,,jpeg
/OUT

/POST26
*DIM,X,TABLE,11,1
*DIM,Y,TABLE,11,1
X(1,1)= 0
Y(1,1)= 0
X(2,1)= 30
Y(2,1)= 0.042
X(3,1)= 60
Y(3,1)= 0.06
X(4,1)= 90
```

```
Y(4,1)= 0.063
X(5,1)= 120
Y(5,1)= 0.056
X(6,1)= 150
Y(6,1)= 0.048
X(7,1)= 180
Y(7,1)= 0.037
X(8,1)= 210
Y(8,1)= 0.031
X(9,1)= 240
Y(9,1)= 0.03
X(10,1)= 270
Y(10,1)= 0.05
X(11,1)= 300
Y(11,1)= 0.096
/XRANGE,0,420
/YRANGE,0,0.1
/AXLAB,X,CENTRAL DEFLECTION
/AXLAB,Y,APPLIED PRESSURE
/COLOR,CURVE,YGRE
/GCOLUMN,1,REF,
*VPLOT,X(1,1),Y(1,1)
/NOERASE
NSOL,2,138,U,Z,DISP.
PROD,3,2,,,DISP.,,,-1.0,0,0,
PROD,7,1,,,LOAD,,,0.1,0,0,
/COLOR,CURVE,MRED
XVAR,3
PLVAR,7
PRVAR,1,,3,7
FINISH

/POST1
SET, , ,1, ,1.012, ,
*GET,VAL8,NODE,138,U,Z
*SET,UA_8,-1*VAL8
*GET,VAL9,NODE,219,U,Z
*SET,UA_9,-1*VAL9
*GET,VAL7,NODE,57,U,Z
*SET,UA_7,-1*VAL7
*DIM,LABEL1,CHAR,1,2
LABEL1(1,1) = '0.1012'
LABEL1(1,2) = '      '
*DIM,VALUE1,CHAR,1,2
VALUE1(1,1) = '303.1'
VALUE1(1,2) = '     '
*DIM,LABEL2,CHAR,1,3
LABEL2(1,1) = ' TOP '
LABEL2(1,2) = ' MID.'
LABEL2(1,3) = 'BOTT.'
*DIM,ERROR1,,1,3
*VFILL,ERROR1(1,1),DATA,UA_8
*VFILL,ERROR1(1,2),DATA,UA_7
*VFILL,ERROR1(1,3),DATA,UA_9
/COM,------------------------NOTE-------------------------------
/COM,GRAPHICAL DIFFERENCES IN RESULTS ARE DUE TO DIFFERENT
/COM,ELEMENT FORMULATIONS BETWEEN SHELLS/SOLID AND DUE TO DIFFERENT
/COM,GEOMETRY BECAUSE OF THE ASSUMPTIONS MADE IN SHELL ELEMENTS.

/OUT,
/COM,
/COM,  -------------      CENTRAL DISPLACEMENT      -------------
/COM,
/COM,                  |   NAFEMS   |       Mechanical APDL         |
/COM,         |  LOAD  |  NUM.RES.  |  LAYER   |   SOL.185  |
/COM,
*VWRITE,LABEL1(1,1),VALUE1(1,1),LABEL2(1,1),ERROR1(1,1)
(1X,'           ',A6,'     ',A5,'       ',A5,'    ',F12.3)
*VWRITE,LABEL1(1,2),VALUE1(1,2),LABEL2(1,2),ERROR1(1,2)
(1X,'           ',A6,'     ',A5,'       ',A5,'    ',F12.3)
*VWRITE,LABEL1(1,2),VALUE1(1,2),LABEL2(1,3),ERROR1(1,3)
(1X,'           ',A6,'     ',A5,'       ',A5,'    ',F12.3)
```

```
/COM,
/COM,  ----------------------------------------------------------

ESEL,,,,ELESOL
NSLE
ESEL,ALL
PRNSOL,S,COMP
PRNSOL,EPTO,COMP

SET,1,16
*GET,PRES1,TIME
SET,1,25
*GET,PRES2,TIME
V1=PRES1*0.1
V2=PRES2*0.1
R1=V1/0.06495
R2=V2/0.03084
*DIM,VALUE,,2,2
*DIM,LABEL3,CHAR,2
*DIM,LABEL,CHAR,2
*DIM,LABEL4,CHAR,2
*VFILL,VALUE(1,1),DATA,V1,V2
*VFILL,VALUE(1,2),DATA,R1,R2
LABEL3(1) = 'LIMIT1','LIMIT2'
LABEL(1) = 'vmr029-','vmr029-'
LABEL4(1) = 't7-185','t7-185'
/OUT,vmr029-t7-185,vrt
/COM
/COM,-------------- VMR029-T7  RESULTS COMPARISON ---------------
/COM,
/COM,           |    Mechanical APDL    |   RATIO   |      INPUT      |
/COM,
/COM,SOLID185
*VWRITE,LABEL3(1),VALUE(1,1),VALUE(1,2),LABEL(1),LABEL4(1)
(1X,A6,'        ',F12.5,'      ',F13.5,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t7-185,vrt
```

VM-R029-T7 190 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T7-190
/TITLE,VMR029-T7-190,LARGE DISPLACEMENT ELASTRIC RESPONSE OF A HINGED SPHERICAL SHELL UNDER UNIFORM PRESSURE LOADING
/COM, REF. NAFEMS ASSEMBLY BENCHMARK TESTS FOR 3D BEAMS AND SHELLS
/COM, TEST 3DNLG-7

/PREP7
L=1570
T=100
P=0.1
ET,1,190
MP,EX,1,69
MP,NUXY,1,0.3
K,1,
K,6,5*L/8,,0.00020285*((5*L/8)*(3*L/8))
K,9,L,,0
LARC,       1,       9,       6
K,15,,3*L/4,0.00020285*((3*L/4)*(L/4))
K,17,,L,0
LARC,       1,      17,      15
ADRAG,1,,,,,,2
VEXT,ALL,,,0,0,T/2,,,,
VEXT,1,,,0,0,-T/2,,,,
K,111,10000,1570,10000
K,112,10000,1570,-10000
```

```
K,113,-10000,1570,-10000
K,114,-10000,1570,10000
A,111,112,113,114
VSBA,1,12,,,KEEP
VSBA,2,12
VDELE,1,3
LESIZE,ALL,,,8
LESIZE,10,,,1
LESIZE,11,,,1
LESIZE,12,,,1
LESIZE,13,,,1
LESIZE,18,,,1
LESIZE,19,,,1
LESIZE,20,,,1
LESIZE,21,,,1
VMESH,ALL
NUMMRG,ALL, , , ,LOW
DL,26,,ALL,
DL,5,,ALL,
DL,2,,ALL,
DL,1,,ALL,
VSEL,S,,,4
ESLV,S
SFE,ALL,6,PRES,,P
ALLSEL,ALL
ESEL,S,,,1
ESEL,A,,,35
ESEL,A,,,92
CM,ELESOL,ELEM
ALLSEL,ALL
FINISH

/SOLU
NLGEOM,ON
NSUBST,200,1000,25
OUTRES,ALL,ALL
ARCLEN,ON,,
AUTOTS,-1
/OUT,SCRATCH
SOLVE
FINISH
/SHOW,,jpeg

/OUT
/POST26
*DIM,X,TABLE,11,1
*DIM,Y,TABLE,11,1
X(1,1)= 0
Y(1,1)= 0
X(2,1)= 30
Y(2,1)= 0.042
X(3,1)= 60
Y(3,1)= 0.06
X(4,1)= 90
Y(4,1)= 0.063
X(5,1)= 120
Y(5,1)= 0.056
X(6,1)= 150
Y(6,1)= 0.048
X(7,1)= 180
Y(7,1)= 0.037
X(8,1)= 210
Y(8,1)= 0.031
X(9,1)= 240
Y(9,1)= 0.03
X(10,1)= 270
Y(10,1)= 0.05
X(11,1)= 300
Y(11,1)= 0.096
/XRANGE,0,420
/YRANGE,0,0.1
/AXLAB,X,CENTRAL DEFLECTION
```

```
/AXLAB,Y,APPLIED PRESSURE
/COLOR,CURVE,YGRE
*VPLOT,X(1,1),Y(1,1)
/NOERASE
NSOL,2,138,U,Z,DISP.
PROD,3,2,,,DISP.,,,-1.0,0,0,
PROD,7,1,,,LOAD,,,0.1,0,0,
/COLOR,CURVE,MRED
XVAR,3
PLVAR,7
PRVAR,1,,3,7
FINISH

/POST1
SET, , ,1, ,1.012, ,
*GET,VAL8,NODE,138,U,Z
*SET,UA_8,-1*VAL8
*GET,VAL9,NODE,219,U,Z
*SET,UA_9,-1*VAL9
*GET,VAL7,NODE,57,U,Z
*SET,UA_7,-1*VAL7
*DIM,LABEL1,CHAR,1,2
LABEL1(1,1) = '0.1012'
LABEL1(1,2) = '      '
*DIM,VALUE1,CHAR,1,2
VALUE1(1,1) = '303.1'
VALUE1(1,2) = '     '
*DIM,LABEL2,CHAR,1,3
LABEL2(1,1) = ' TOP '
LABEL2(1,2) = ' MID.'
LABEL2(1,3) = 'BOTT.'
*DIM,ERROR1,,1,3
*VFILL,ERROR1(1,1),DATA,UA_8
*VFILL,ERROR1(1,2),DATA,UA_7
*VFILL,ERROR1(1,3),DATA,UA_9

/OUT,
/COM,
/COM,  -------------      CENTRAL DISPLACEMENT      -------------
/COM,
/COM,                  |   NAFEMS   |       Mechanical APDL         |
/COM,         |  LOAD  |  NUM.RES.  |  LAYER   |   SOL.190  |
/COM,
*VWRITE,LABEL1(1,1),VALUE1(1,1),LABEL2(1,1),ERROR1(1,1)
(1X,'           ',A6,'     ',A5,'       ',A5,'    ',F12.3)
*VWRITE,LABEL1(1,2),VALUE1(1,2),LABEL2(1,2),ERROR1(1,2)
(1X,'           ',A6,'     ',A5,'       ',A5,'    ',F12.3)
*VWRITE,LABEL1(1,2),VALUE1(1,2),LABEL2(1,3),ERROR1(1,3)
(1X,'           ',A6,'     ',A5,'       ',A5,'    ',F12.3)
/COM,
/COM,  ----------------------------------------------------------

ESEL,,,,ELESOL
NSLE
ESEL,ALL
PRNSOL,S,COMP
PRNSOL,EPTO,COMP

SET,1,16
*GET,PRES1,TIME
SET,1,25
*GET,PRES2,TIME
V1=PRES1*0.1
V2=PRES2*0.1
R1=V1/0.06495
R2=V2/0.03084
*DIM,VALUE,,2,2
*DIM,LABEL3,CHAR,3
*DIM,LABEL,CHAR,3
*DIM,LABEL4,CHAR,3
*VFILL,VALUE(1,1),DATA,V1,V2
*VFILL,VALUE(1,2),DATA,R1,R2
```

```
LABEL3(1) = 'LIMIT1','LIMIT2'
LABEL(1) = 'vmr029-','vmr029-'
LABEL4(1) = 't7-190','t7-190'
/OUT,vmr029-t7-190,vrt
/COM
/COM,-------------- VMR029-T7  RESULTS COMPARISON ---------------
/COM,
/COM,          |    Mechanical APDL    |   RATIO   |      INPUT      |
/COM,
/COM,SOLSH190
*VWRITE,LABEL3(1),VALUE(1,1),VALUE(1,2),LABEL(1),LABEL4(1)
(1X,A6,'        ',F12.5,'      ',F13.5,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t7-190,vrt
```

VM-R029-T7 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T7-281
/TITLE,VMR029-T7-281,LARGE DISPLACEMENT ELASTIC RESPONSE OF A HINGED SPHERICAL SHELL UNDER UNIFORM PRESSURE LOAD
/COM, REF. 'NAFEMS ASSEMBLY BENCHMARK TESTS FOR 3D BEAMS AND SHELLS
/COM,       TEST 3DNLG-7
/PREP7
L=1570
T=100
P=0.1
ET,1,281
R,1,100,100,100,100
RMODIF,1,7,30000,30000
MP,EX,1,69
MP,NUXY,1,0.3
K,1,
K,6,5*L/8,,0.00020285*((5*L/8)*(3*L/8))
K,9,L,,0
LARC,       1,        9,        6
K,15,,3*L/4,0.00020285*((3*L/4)*(L/4))
K,17,,L,0
LARC,       1,       17,       15
ADRAG,1, , , , , ,2
KWPAVE,2
WPRO,,90.000000,
ASBW,1
ADELE,2, , ,1
LSLA,S,1
LESIZE,ALL,,,16
AMESH,ALL
DL,ALL, ,UX,
DL,ALL, ,UY,
DL,ALL, ,UZ,
SFE,ALL,2,PRES,,P
ALLSEL,ALL
FINISH
/SOLVE
NLGEOM,ON
NSUBST,200,2000,25
OUTRES,ALL,ALL
ARCLEN,1,,
AUTOTS,-1
/OUT,SCRATCH
SOLVE
FINISH
/OUT
/POST26
*DIM,X,TABLE,11,1
*DIM,Y,TABLE,11,1
```

```
X(  1,1)= 0
Y(  1,1)= 0
X(  2,1)= 30
Y(  2,1)= 0.042
X(  3,1)= 60
Y(  3,1)= 0.06
X(  4,1)= 90
Y(  4,1)= 0.063
X(  5,1)= 120
Y(  5,1)= 0.056
X(  6,1)= 150
Y(  6,1)= 0.048
X(  7,1)= 180
Y(  7,1)= 0.037
X(  8,1)= 210
Y(  8,1)= 0.031
X(  9,1)= 240
Y(  9,1)= 0.03
X( 10,1)= 270
Y( 10,1)= 0.05
X( 11,1)= 300
Y( 11,1)= 0.096
/XRANGE,0,330
/YRANGE,0,0.1
/AXLAB,X,CENTRAL DEFLECTION
/AXLAB,Y,APPLIED PRESSURE
/GROPT,DIVX,11
/COLOR,CURVE,YGRE
*VPLOT,X(1,1),Y(1,1)
/NOERASE
NSOL,2,481,U,Z,DISP.          ! CENTER NODE
PROD,3,2, , ,DISP., , ,-1,0,0,
PROD,7,1, , ,LOAD, , ,0.1,0,0,
/COLOR,CURVE,MRED
XVAR,3
PLVAR,7
PRVAR,1,3,7
FINISH
/POST1
NSEL,S,NODE,,481             ! CENTER NODE
PRNSOL,U,COMP
SET,LAST
*GET,VAL8,NODE,481,U,Z
*SET,UA_8,-1*VAL8
*DIM,LABEL1,CHAR,1,2
LABEL1(1,1) = '0.1012'
LABEL1(1,2) = '      '
*DIM,VALUE1,CHAR,1,2
VALUE1(1,1) = '303.1'
*DIM,LABEL2,CHAR,1,3
LABEL2(1,1) = '481'
*DIM,ERROR1,,1,3
*VFILL,ERROR1(1,1),DATA,UA_8
/OUT,
/COM,
/COM,  -------------      CENTRAL DISPLACEMENT      -------------
/COM,
/COM,                  |   NAFEMS   |       Mechanical APDL         |
/COM,         |  LOAD  |  NUM.RES.  |  NODE   |   SHL.281  |
/COM,
*VWRITE,LABEL1(1,1),VALUE1(1,1),LABEL2(1,1),ERROR1(1,1)
(1X,'           ',A6,'     ',A5,'       ',A4,'    ',F12.3)
/COM,
/COM,  ---------------------------------------------------------
SET,LIST
SET,1,15
*GET,PRES1,TIME
SET,1,26
*GET,PRES2,TIME
V1=PRES1*0.1
V2=PRES2*0.1
R1=V1/0.06495
```

```
R2=V2/0.03084
*DIM,VALUE,,2,2
*DIM,LABEL3,CHAR,2
*DIM,LABEL,CHAR,2
*DIM,LABEL4,CHAR,2
*VFILL,VALUE(1,1),DATA,V1,V2
*VFILL,VALUE(1,2),DATA,R1,R2
LABEL3(1) = 'LIMIT1','LIMIT2'
LABEL(1) = 'vmr029-','vmr029-'
LABEL4(1) = 't7-281','t7-281'
/OUT,vmr029-t7-281,vrt
/COM
/COM,-------------- VMR029-T7  RESULTS COMPARISON ---------------
/COM,
/COM,          |    Mechanical APDL    |   RATIO   |      INPUT      |
/COM,
/COM,SHELL281
*VWRITE,LABEL3(1),VALUE(1,1),VALUE(1,2),LABEL(1),LABEL4(1)
(1X,A6,'        ',F12.5,'      ',F13.5,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t7-281,vrt
```

VM-R029-T9 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY, VMR029-T9-181
/TITLE, VMR029-T9-181,LARGE ELASTIC DEFLECTION OF A PINCHED HEMISPHERICAL SHELL
/COM, REF. NAFEMS ASSEMBLY BENCHMARK TESTS FOR 3D BEAMS AND SHELLS
/COM,       TEST 3DNLG-9
/PREP7
RM=10.00
T=0.04
THETA=18
F=100.0
ET,1,181
R,1,0.04,0.04,0.04,0.04
MP,EX,1,6.825E7
MP,NUXY,1,0.3
K,1,
K,2,,RM
PCIRC,RM,RM+T,0,90-THETA,
AROTAT,3, , , , , ,1,2,-90, ,
LESIZE,ALL,,,8
AMESH,2
NSEL,S,LOC,Z,RM
NSEL,R,LOC,X,0
NSEL,R,LOC,Y,0
D,ALL,UY,0.0
CSYS,2
NSEL,S,LOC,X,RM
NSEL,R,LOC,Y,0
NSEL,R,LOC,Z,0
F,ALL,FX,F
NSEL,S,LOC,X,RM
NSEL,R,LOC,Y,0
NSEL,R,LOC,Z,90
F,ALL,FX,-1*F
NSEL,S,LOC,Z,0
NSEL,R,LOC,Y,0,90
DSYM,SYMM,Z,2
NSEL,S,LOC,Y,90
NSEL,R,LOC,Z,0,91
DSYM,SYMM,Y,2
NSEL,S,LOC,Y,0
NSEL,R,LOC,Z,90
```

```
DSYM,SYMM,Z,2
ALLSEL,ALL
FINISH
/SOLU
NLGEOM,ON
AUTOTS,ON
NSUBST,100,100000,40
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINISH
/POST26
*DIM,XA,TABLE,11,1
*DIM,YA,TABLE,11,1
XA(  1,1)= 0
YA(  1,1)= 0
XA(  2,1)= 10
YA(  2,1)= 1.0
XA(  3,1)= 20
YA(  3,1)= 1.75
XA(  4,1)= 30
YA(  4,1)= 2.625
XA(  5,1)= 40
YA(  5,1)= 3.23
XA(  6,1)= 50
YA(  6,1)= 3.875
XA(  7,1)= 60
YA(  7,1)= 4.29
XA(  8,1)= 70
YA(  8,1)= 4.815
XA(  9,1)= 80
YA(  9,1)= 5.185
XA( 10,1)= 90
YA( 10,1)= 5.52
XA( 11,1)= 100
YA( 11,1)= 5.875
/XRANGE,0,100
/YRANGE,0,6
/AXLAB,X,LOAD
/AXLAB,Y,RADIAL DISPLACEMENT
/COLOR,CURVE,YGRE
/GCOLUMN,1,REF,
*VPLOT,XA(1,1),YA(1,1)
/NOERASE
/OUT,
NSOL,2,2,U,X,UR_A
PROD,3,2, , ,'   URATA', , ,-1.0,0,0,
PROD,7,1, , ,LOAD, , ,100.0,0,0,
/COLOR,CURVE,MRED
XVAR,7
PLVAR,3
/NOERASE
*DIM,XB,TABLE,11,1
*DIM,YB,TABLE,11,1
XB(  1,1)= 0
YB(  1,1)= 0
XB(  2,1)= 10
YB(  2,1)= 0.88
XB(  3,1)= 20
YB(  3,1)= 1.5
XB(  4,1)= 30
YB(  4,1)= 2
XB(  5,1)= 40
YB(  5,1)= 2.30
XB(  6,1)= 50
YB(  6,1)= 2.63
XB(  7,1)= 60
YB(  7,1)= 2.82
XB(  8,1)= 70
YB(  8,1)= 3
XB(  9,1)= 80
YB(  9,1)= 3.16
```

```
XB( 10,1)= 90
YB( 10,1)= 3.30
XB( 11,1)= 100
YB( 11,1)= 3.42
/COLOR,CURVE,YGRE
/GCOLUMN,1,REF,
*VPLOT,XB(1,1),YB(1,1)
/NOERASE
NSOL,5,1,U,X,'   URATB'
/COLOR,CURVE,MRED
XVAR,7
PLVAR,5
FINISH
/POST1
NSEL,ALL
SET,1,42
*GET,UB,NODE,1,U,X
*GET,UA,NODE,2,U,Z
RA=UA/(-5.9)
RB=UB/3.42
*DIM,VALUE3,,2,2
*DIM,LABEL2,CHAR,2
*DIM,LABEL4,CHAR,2
*DIM,LABEL5,CHAR,2
LABEL2(1) = 'NODE A','NODE B',
LABEL4(1) = 'vmr029-','vmr029-'
LABEL5(1) = 't9-181','t9-181'
*VFILL,VALUE3(1,1),DATA,UA,UB
*VFILL,VALUE3(1,2),DATA,RA,RB
/OUT,vmr029-t9-181,vrt
/COM
/COM,-------------- VMR029-T9 RESULTS COMPARISON ---------------
/COM,
/COM,          |    Mechanical APDL    |   RATIO   |      INPUT      |
/COM,
/COM,SHELL181
*VWRITE,LABEL2(1),VALUE3(1,1),VALUE3(1,2),LABEL4(1),LABEL5(1)
(1X,A6,'       ',F12.4,'      ',F13.4,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t9-181,vrt
```

VM-R029-T9 185 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T9-185
/TITLE,VMR029-T9-185,LARGE ELASTIC DEFLECTION OF A PINCHED HEMISPHERICAL SHELL
/COM, REF. NAFEMS ASSEMBLY BENCHMARK TESTS FOR 3D BEAMS AND SHELLS
/COM, TEST 3DNLG-9

/PREP7
RM=10.02
T=0.04
THETA=18
F=100.0
ET,1,185
KEYOPT,1,2,2
MP,EX,1,6.825E7
MP,NUXY,1,0.3
K,1,
K,2,,RM+2*T
PCIRC,RM+T/2,RM-T/2,0,90-THETA,
VROTAT,ALL,,,,,,1,2,-90,,
LESIZE,ALL,,,32
LESIZE,2,,,1
LESIZE,4,,,1
```

```
LESIZE,6,,,1
LESIZE,8,,,1
VMESH,ALL
NSEL,S,LOC,Z,RM+T/2,RM+T
NSEL,R,LOC,X,0
NSEL,R,LOC,Y,0
D,ALL,UY,0.0
CSYS,2
NSEL,S,LOC,X,RM+T/2,RM+T
NSEL,R,LOC,Y,0
NSEL,R,LOC,Z,0
F,ALL,FX,F
NSEL,S,LOC,X,RM+T/2,RM+T
NSEL,R,LOC,Y,0
NSEL,R,LOC,Z,90
NROTAT,ALL
F,ALL,FX,-1*F
NSEL,S,LOC,Z,0
NSEL,R,LOC,Y,0,90
DSYM,SYMM,Z,2
NSEL,S,LOC,Y,90
NSEL,R,LOC,Z,0,91
DSYM,SYMM,Y,2
NSEL,S,LOC,Y,0
NSEL,R,LOC,Z,90
DSYM,SYMM,Z,2
ALLSEL,ALL
ESEL,S,,,1
ESEL,A,,,120
ESEL,A,,,1024
CM,ELESOL,ELEM
ALLSEL,ALL
FINISH

/SOLU
NLGEOM,ON
AUTOTS,ON
NSUBST,100,100000,10
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINISH

/SHOW,,jpeg
/POST26
*DIM,XA,TABLE,11,1
*DIM,YA,TABLE,11,1
XA(1,1)= 0
YA(1,1)= 0
XA(2,1)= 10
YA(2,1)= 1.0
XA(3,1)= 20
YA(3,1)= 1.75
XA(4,1)= 30
YA(4,1)= 2.625
XA(5,1)= 40
YA(5,1)= 3.23
XA(6,1)= 50
YA(6,1)= 3.875
XA(7,1)= 60
YA(7,1)= 4.29
XA(8,1)= 70
YA(8,1)= 4.815
XA(9,1)= 80
YA(9,1)= 5.185
XA(10,1)= 90
YA(10,1)= 5.52
XA(11,1)= 100
YA(11,1)= 5.875
/XRANGE,0,100
/YRANGE,0,6
/AXLAB,X,LOAD
```

```
/AXLAB,Y,DISPLACEMENT
/COLOR,CURVE,YGRE
/GCOLUMN,1,REF,
*VPLOT,XA(1,1),YA(1,1)

/NOERASE
/OUT,
NSOL,2,2,U,X,UR_A
PROD,3,2, , ,UR AT A, , ,-1.0,0,0,
PROD,7,1, , ,LOAD, , ,100.0,0,0,
/COLOR,CURVE,MRED
XVAR,7
PLVAR,3
/NOERASE
*DIM,XB,TABLE,11,1
*DIM,YB,TABLE,11,1
XB(1,1)= 0
YB(1,1)= 0
XB(2,1)= 10
YB(2,1)= 0.88
XB(3,1)= 20
YB(3,1)= 1.5
XB(4,1)= 30
YB(4,1)= 2
XB(5,1)= 40
YB(5,1)= 2.30
XB(6,1)= 50
YB(6,1)= 2.63
XB(7,1)= 60
YB(7,1)= 2.82
XB(8,1)= 70
YB(8,1)= 3
XB(9,1)= 80
YB(9,1)= 3.16
XB(10,1)= 90
YB(10,1)= 3.30
XB(11,1)= 100
YB(11,1)= 3.42

/COLOR,CURVE,YGRE
/GCOLUMN,1,REF,
*VPLOT,XB(1,1),YB(1,1)
/NOERASE
NSOL,5,1,U,X,UR AT B
/COLOR,CURVE,MRED
XVAR,7
PLVAR,5
FINISH

/POST1
RSYS,2
SET, , ,1, ,0.4, ,
*GET,UB_4,NODE,1,U,X
*GET,UA_4,NODE,2,U,X
SET, , ,1, ,0.6, ,
*GET,UB_6,NODE,1,U,X
*GET,UA_6,NODE,2,U,X
SET, , ,1, ,0.9, ,
*GET,UB_9,NODE,1,U,X
*GET,UA_9,NODE,2,U,X
SET, , ,1, ,1.0, ,
*GET,UB_10,NODE,1,U,X
*GET,UA_10,NODE,2,U,X

*DIM,LABEL1,CHAR,1,4
LABEL1(1,1) = '40'
LABEL1(1,2) = '60'
LABEL1(1,3) = '90'
LABEL1(1,4) = '100'

*DIM,VALUE1,CHAR,1,4
VALUE1(1,1) = '-3.28'
```



```
VALUE1(1,2) = '-4.36'
VALUE1(1,3) = '-5.61'
VALUE1(1,4) = '-5.9 '

*DIM,VALUE2,CHAR,1,4
VALUE2(1,1) = '-3.23'
VALUE2(1,2) = '-4.29'
VALUE2(1,3) = '-5.52'
VALUE2(1,4) = '     '

*DIM,ERROR1,,1,4
*VFILL,ERROR1(1,1),DATA,UA_4
*VFILL,ERROR1(1,2),DATA,UA_6
*VFILL,ERROR1(1,3),DATA,UA_9
*VFILL,ERROR1(1,4),DATA,UA_10

/COM,                     N O T E
/COM, NUMERICAL RESULTS FROM NAFEMS TEST MAY APPEAR MORE
/COM, ACCURATE THAN SOLID185 BECAUSE THOSE ARE SHELL RESULTS.

/COM,
/COM,  ------   RADIAL DISPLACEMENT UNDER LOAD (NODE A(2))  ------
/COM,
/COM,                  |      NAFEMS TEST      |   Mechanical APDL   |
/COM,         |  LOAD  |   REF.   |  NUM.RES.  |      SOL.185    |
/COM,
*VWRITE,LABEL1(1,1),VALUE2(1,1),VALUE1(1,1),ERROR1(1,1)
(1X,'              ',A3,'     ',A5,'       ',A5,'      ',F12.5)
*VWRITE,LABEL1(1,2),VALUE2(1,2),VALUE1(1,2),ERROR1(1,2)
(1X,'              ',A3,'     ',A5,'       ',A5,'      ',F12.5)
*VWRITE,LABEL1(1,3),VALUE2(1,3),VALUE1(1,3),ERROR1(1,3)
(1X,'              ',A3,'     ',A5,'       ',A5,'      ',F12.5)
*VWRITE,LABEL1(1,4),VALUE2(1,4),VALUE1(1,4),ERROR1(1,4)
(1X,'              ',A3,'     ',A5,'       ',A5,'      ',F12.5)
/COM,
/COM,  ----------------------------------------------------------

*DIM,LABELB,CHAR,1,4
LABELB(1,1) = '40'
LABELB(1,2) = '60'
LABELB(1,3) = '90'
LABELB(1,4) = '100'

*DIM,VALUEB,CHAR,1,4
VALUEB(1,1) = '2.33'
VALUEB(1,2) = '2.83'
VALUEB(1,3) = '3.31'
VALUEB(1,4) = '3.42'

*DIM,VALUEB1,CHAR,1,4
VALUEB1(1,1) = '2.30'
VALUEB1(1,2) = '2.82'
VALUEB1(1,3) = '3.30'
VALUEB1(1,4) = '    '

*DIM,ERRORB,,1,4
*VFILL,ERRORB(1,1),DATA,UB_4
*VFILL,ERRORB(1,2),DATA,UB_6
*VFILL,ERRORB(1,3),DATA,UB_9
*VFILL,ERRORB(1,4),DATA,UB_10

/OUT,
/COM,
/COM,
/COM,  ------  RADIAL DISPLACEMENT UNDER LOAD (NODE B(1))  ------
/COM,
/COM,                  |    NAFEMS TEST      |   Mechanical APDL   |
/COM,         |  LOAD  |  REF.  |  NUM.RES.  |      SOL.185   |
/COM,
*VWRITE,LABELB(1,1),VALUEB1(1,1),VALUEB(1,1),ERRORB(1,1)
(1X,'              ',A3,'     ',A4,'       ',A4,'      ',F12.5)
*VWRITE,LABELB(1,2),VALUEB1(1,2),VALUEB(1,2),ERRORB(1,2)
```

```
(1X,'              ',A3,'     ',A4,'       ',A4,'      ',F12.5)
*VWRITE,LABELB(1,3),VALUEB1(1,3),VALUEB(1,3),ERRORB(1,3)
(1X,'              ',A3,'     ',A4,'       ',A4,'      ',F12.5)
*VWRITE,LABELB(1,4),VALUEB1(1,4),VALUEB(1,4),ERRORB(1,4)
(1X,'              ',A3,'     ',A4,'       ',A4,'      ',F12.5)
/COM,
/COM,  ----------------------------------------------------------


ESEL,,,,ELESOL
NSLE
ESEL,ALL
PRNSOL,S,COMP
PRNSOL,EPTO,COMP
FINISH

/POST1
NSEL,ALL
SET,LAST
*GET,UB,NODE,1,U,X
*GET,UA,NODE,2,U,X
RA=UA/(-5.9)
RB=UB/3.42
*DIM,VALUE3,,2,2
*DIM,LABEL2,CHAR,2
*DIM,LABEL4,CHAR,2
*DIM,LABEL5,CHAR,2
LABEL2(1) = 'NODE A','NODE B',
LABEL4(1) = 'vmr029-','vmr029-'
LABEL5(1) = 't9-185','t9-185'
*VFILL,VALUE3(1,1),DATA,UA,UB
*VFILL,VALUE3(1,2),DATA,RA,RB
/OUT,vmr029-t9-185,vrt
/COM
/COM,-------------- VMR029-T9  RESULTS COMPARISON ---------------
/COM,
/COM,           |    Mechanical APDL    |   RATIO   |      INPUT      |
/COM,
/COM,SOLID185
*VWRITE,LABEL2(1),VALUE3(1,1),VALUE3(1,2),LABEL4(1),LABEL5(1)
(1X,A6,'       ',F12.4,'      ',F13.4,'      ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t9-185,vrt
```

VM-R029-T9 190 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR029-T9-190
/TITLE,VMR029-T9-190,LARGE ELASTIC DEFLECTION OF A PINCHED HEMISPHERICAL SHELL
/COM, REF. NAFEMS ASSEMBLY BENCHMARK TESTS FOR 3D BEAMS AND SHELLS TEST 3DNLG-9

/PREP7
RM=10.02
T=0.04
THETA=18
F=100.0
ET,1,190
MP,EX,1,6.825E7
MP,NUXY,1,0.3
K,1,
K,2,,RM+2*T
PCIRC,RM+T/2,RM-T/2,0,90-THETA,
VROTAT,ALL, , , , , ,1,2,-90, ,
LESIZE,ALL,,,32
LESIZE,2,,,1
```

```
LESIZE,4,,,1
LESIZE,6,,,1
LESIZE,8,,,1
VEORIENT,1,THIN
VMESH,ALL
NSEL,S,LOC,Z,RM+T/2,RM+T
NSEL,R,LOC,X,0
NSEL,R,LOC,Y,0
D,ALL,UY,0.0
CSYS,2
NSEL,S,LOC,X,RM+T/2,RM+T
NSEL,R,LOC,Y,0
NSEL,R,LOC,Z,0
F,ALL,FX,F
NSEL,S,LOC,X,RM+T/2,RM+T
NSEL,R,LOC,Y,0
NSEL,R,LOC,Z,90
NROTAT,ALL
F,ALL,FX,-1*F
NSEL,S,LOC,Z,0
NSEL,R,LOC,Y,0,90
DSYM,SYMM,Z,2
NSEL,S,LOC,Y,90
NSEL,R,LOC,Z,0,91
DSYM,SYMM,Y,2
NSEL,S,LOC,Y,0
NSEL,R,LOC,Z,90
DSYM,SYMM,Z,2
ALLSEL,ALL
ESEL,S,,,1
ESEL,A,,,120
ESEL,A,,,1024
CM,ELESOL,ELEM
ALLSEL,ALL
FINISH

/SOLU
NLGEOM,ON
AUTOTS,ON
NSUBST,100,100000,40
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINISH

/SHOW,,jpeg
/POST26
*DIM,XA,TABLE,11,1
*DIM,YA,TABLE,11,1
XA(  1,1)= 0
YA(  1,1)= 0
XA(  2,1)= 10
YA(  2,1)= 1.0
XA(  3,1)= 20
YA(  3,1)= 1.75
XA(  4,1)= 30
YA(  4,1)= 2.625
XA(  5,1)= 40
YA(  5,1)= 3.23
XA(  6,1)= 50
YA(  6,1)= 3.875
XA(  7,1)= 60
YA(  7,1)= 4.29
XA(  8,1)= 70
YA(  8,1)= 4.815
XA(  9,1)= 80
YA(  9,1)= 5.185
XA( 10,1)= 90
YA( 10,1)= 5.52
XA( 11,1)= 100
YA( 11,1)= 5.875
/XRANGE,0,100
```

```
/YRANGE,0,6
/AXLAB,X,LOAD
/AXLAB,Y,RADIAL DISPLACEMENT
/COLOR,CURVE,YGRE
/GCOLUMN,1,REF,
*VPLOT,XA(1,1),YA(1,1)
/NOERASE
/OUT,
NSOL,2,2,U,X,UR_A
PROD,3,2, , ,'   URATA', , ,-1.0,0,0,
PROD,7,1, , ,LOAD, , ,100.0,0,0,
/COLOR,CURVE,MRED
XVAR,7
PLVAR,3
/NOERASE
*DIM,XB,TABLE,11,1
*DIM,YB,TABLE,11,1
XB(  1,1)= 0
YB(  1,1)= 0
XB(  2,1)= 10
YB(  2,1)= 0.88
XB(  3,1)= 20
YB(  3,1)= 1.5
XB(  4,1)= 30
YB(  4,1)= 2
XB(  5,1)= 40
YB(  5,1)= 2.30
XB(  6,1)= 50
YB(  6,1)= 2.63
XB(  7,1)= 60
YB(  7,1)= 2.82
XB(  8,1)= 70
YB(  8,1)= 3
XB(  9,1)= 80
YB(  9,1)= 3.16
XB( 10,1)= 90
YB( 10,1)= 3.30
XB( 11,1)= 100
YB( 11,1)= 3.42
/COLOR,CURVE,YGRE
/GCOLUMN,1,REF,
*VPLOT,XB(1,1),YB(1,1)
/NOERASE
NSOL,5,1,U,X,'   URATB'
/COLOR,CURVE,MRED
XVAR,7
PLVAR,5
FINISH

/POST1
RSYS,2
SET, , ,1, ,0.4, ,
*GET,UB_4,NODE,1,U,X
*GET,UA_4,NODE,2,U,X
SET, , ,1, ,0.6, ,
*GET,UB_6,NODE,1,U,X
*GET,UA_6,NODE,2,U,X
SET, , ,1, ,0.9, ,
*GET,UB_9,NODE,1,U,X
*GET,UA_9,NODE,2,U,X
SET, , ,1, ,1.0, ,
*GET,UB_10,NODE,1,U,X
*GET,UA_10,NODE,2,U,X

*DIM,LABEL1,CHAR,1,4
LABEL1(1,1) = '40'
LABEL1(1,2) = '60'
LABEL1(1,3) = '90'
LABEL1(1,4) = '100'

*DIM,VALUE1,CHAR,1,4
VALUE1(1,1) = '-3.28'
```

```
VALUE1(1,2) = '-4.36'
VALUE1(1,3) = '-5.61'
VALUE1(1,4) = '-5.9 '

*DIM,VALUE2,CHAR,1,4
VALUE2(1,1) = '-3.23'
VALUE2(1,2) = '-4.29'
VALUE2(1,3) = '-5.52'
VALUE2(1,4) = '     '

*DIM,ERROR1,,1,4
*VFILL,ERROR1(1,1),DATA,UA_4
*VFILL,ERROR1(1,2),DATA,UA_6
*VFILL,ERROR1(1,3),DATA,UA_9
*VFILL,ERROR1(1,4),DATA,UA_10

/COM,
/COM,  ------   RADIAL DISPLACEMENT UNDER LOAD (NODE A(2))  ------
/COM,
/COM,                  |      NAFEMS TEST      |   Mechanical APDL   |
/COM,         |  LOAD  |   REF.   |  NUM.RES.  |  SOL.190  |
/COM,
*VWRITE,LABEL1(1,1),VALUE2(1,1),VALUE1(1,1),ERROR1(1,1)
(1X,'              ',A3,'     ',A5,'       ',A5,'      ',F10.5)
*VWRITE,LABEL1(1,2),VALUE2(1,2),VALUE1(1,2),ERROR1(1,2)
(1X,'              ',A3,'     ',A5,'       ',A5,'      ',F10.5)
*VWRITE,LABEL1(1,3),VALUE2(1,3),VALUE1(1,3),ERROR1(1,3)
(1X,'              ',A3,'     ',A5,'       ',A5,'      ',F10.5)
*VWRITE,LABEL1(1,4),VALUE2(1,4),VALUE1(1,4),ERROR1(1,4)
(1X,'              ',A3,'     ',A5,'       ',A5,'      ',F10.5)
/COM,
/COM,  ----------------------------------------------------------

*DIM,LABELB,CHAR,1,4
LABELB(1,1) = '40'
LABELB(1,2) = '60'
LABELB(1,3) = '90'
LABELB(1,4) = '100'

*DIM,VALUEB,CHAR,1,4
VALUEB(1,1) = '2.33'
VALUEB(1,2) = '2.83'
VALUEB(1,3) = '3.31'
VALUEB(1,4) = '3.42'

*DIM,VALUEB1,CHAR,1,4
VALUEB1(1,1) = '2.30'
VALUEB1(1,2) = '2.82'
VALUEB1(1,3) = '3.30'
VALUEB1(1,4) = '    '

*DIM,ERRORB,,1,4
*VFILL,ERRORB(1,1),DATA,UB_4
*VFILL,ERRORB(1,2),DATA,UB_6
*VFILL,ERRORB(1,3),DATA,UB_9
*VFILL,ERRORB(1,4),DATA,UB_10

/OUT,
/COM,
/COM,  ------  RADIAL DISPLACEMENT UNDER LOAD (NODE B(1))  ------
/COM,
/COM,                  |    NAFEMS TEST      |   Mechanical APDL   |
/COM,         |  LOAD  |  REF.  |  NUM.RES.  |     SOL.190     |
/COM,
*VWRITE,LABELB(1,1),VALUEB1(1,1),VALUEB(1,1),ERRORB(1,1)
(1X,'              ',A3,'     ',A4,'       ',A4,'      ',F12.5)
*VWRITE,LABELB(1,2),VALUEB1(1,2),VALUEB(1,2),ERRORB(1,2)
(1X,'              ',A3,'     ',A4,'       ',A4,'      ',F12.5)
*VWRITE,LABELB(1,3),VALUEB1(1,3),VALUEB(1,3),ERRORB(1,3)
(1X,'              ',A3,'     ',A4,'       ',A4,'      ',F12.5)
*VWRITE,LABELB(1,4),VALUEB1(1,4),VALUEB(1,4),ERRORB(1,4)
(1X,'              ',A3,'     ',A4,'       ',A4,'      ',F12.5)
```

```
/COM,
/COM,  ----------------------------------------------------------

ESEL,,,,ELESOL
NSLE
ESEL,ALL
PRNSOL,S,COMP
PRNSOL,EPTO,COMP
FINISH

/POST1
NSEL,ALL
SET,LAST
*GET,UB,NODE,1,U,X
*GET,UA,NODE,2,U,X
RA=UA/(-5.9)
RB=UB/3.42
*DIM,VALUE3,,2,2
*DIM,LABEL2,CHAR,2
*DIM,LABEL4,CHAR,2
*DIM,LABEL5,CHAR,2
LABEL2(1) = 'NODE A','NODE B',
LABEL4(1) = 'vmr029-','vmr029-'
LABEL5(1) = 't9-190','t9-190'
*VFILL,VALUE3(1,1),DATA,UA,UB
*VFILL,VALUE3(1,2),DATA,RA,RB
/OUT,vmr029-t9-190,vrt
/COM
/COM,-------------- VMR029-T9 RESULTS COMPARISON ---------------
/COM,
/COM,          |    Mechanical APDL    |   RATIO   |      INPUT      |
/COM,
/COM,SOLSH190
*VWRITE,LABEL2(1),VALUE3(1,1),VALUE3(1,2),LABEL4(1),LABEL5(1)
(1X,A6,'       ',F12.4,'      ',F13.4,'      ',A7,A8)
/COM,
/COM,---------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t9-190,vrt
```

VM-R029-T9 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY, VMR029-T9-281
/TITLE, VMR029-T9-281,LARGE ELASTIC DEFLECTION OF A PINCHED HEMISPHERICAL SHELL
/COM, REF. NAFEMS ASSEMBLY BENCHMARK TESTS FOR 3D BEAMS AND SHELLS
/COM,       TEST 3DNLG-9

/PREP7
RM=10.00
T=0.04
THETA=18
F=100.0
ET,1,SHELL281
R,1,0.04,0.04,0.04,0.04
MP,EX,1,6.825E7
MP,NUXY,1,0.3
K,1,
K,2,,RM
PCIRC,RM,RM+T,0,90-THETA,
AROTAT,3, , , , , ,1,2,-90, ,
LESIZE,ALL,,,8
AMESH,2
NSEL,S,LOC,Z,RM
NSEL,R,LOC,X,0
NSEL,R,LOC,Y,0
D,ALL,UY,0.0
```

```
CSYS,2
NSEL,S,LOC,X,RM
NSEL,R,LOC,Y,0
NSEL,R,LOC,Z,0
F,ALL,FX,F
NSEL,S,LOC,X,RM
NSEL,R,LOC,Y,0
NSEL,R,LOC,Z,90
F,ALL,FX,-1*F
NSEL,S,LOC,Z,0
NSEL,R,LOC,Y,0,90
DSYM,SYMM,Z,2
NSEL,S,LOC,Y,90
NSEL,R,LOC,Z,0,91
DSYM,SYMM,Y,2
NSEL,S,LOC,Y,0
NSEL,R,LOC,Z,90
DSYM,SYMM,Z,2
ALLSEL,ALL
FINISH

/SOLU
NLGEOM,ON
AUTOTS,ON
NSUBST,100,100000,35
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
FINISH

/SHOW,,jpeg
/POST26
*DIM,XA,TABLE,11,1
*DIM,YA,TABLE,11,1
XA(  1,1)= 0
YA(  1,1)= 0
XA(  2,1)= 10
YA(  2,1)= 1.0
XA(  3,1)= 20
YA(  3,1)= 1.75
XA(  4,1)= 30
YA(  4,1)= 2.625
XA(  5,1)= 40
YA(  5,1)= 3.23
XA(  6,1)= 50
YA(  6,1)= 3.875
XA(  7,1)= 60
YA(  7,1)= 4.29
XA(  8,1)= 70
YA(  8,1)= 4.815
XA(  9,1)= 80
YA(  9,1)= 5.185
XA( 10,1)= 90
YA( 10,1)= 5.52
XA( 11,1)= 100
YA( 11,1)= 5.875
/XRANGE,0,100
/YRANGE,0,6
/AXLAB,X,LOAD
/AXLAB,Y,RADIAL DISPLACEMENT
/COLOR,CURVE,YGRE
/GCOLUMN,1,REF,
*VPLOT,XA(1,1),YA(1,1)
/NOERASE
/OUT,
NSOL,2,2,U,X,UR_A
PROD,3,2, , ,'   URATA', , ,-1.0,0,0,
PROD,7,1, , ,LOAD, , ,100.0,0,0,
/COLOR,CURVE,MRED
XVAR,7
PLVAR,3
/NOERASE
```

```
*DIM,XB,TABLE,11,1
*DIM,YB,TABLE,11,1
XB(  1,1)= 0
YB(  1,1)= 0
XB(  2,1)= 10
YB(  2,1)= 0.88
XB(  3,1)= 20
YB(  3,1)= 1.5
XB(  4,1)= 30
YB(  4,1)= 2
XB(  5,1)= 40
YB(  5,1)= 2.30
XB(  6,1)= 50
YB(  6,1)= 2.63
XB(  7,1)= 60
YB(  7,1)= 2.82
XB(  8,1)= 70
YB(  8,1)= 3
XB(  9,1)= 80
YB(  9,1)= 3.16
XB( 10,1)= 90
YB( 10,1)= 3.30
XB( 11,1)= 100
YB( 11,1)= 3.42
/COLOR,CURVE,YGRE
/GCOLUMN,1,REF,
*VPLOT,XB(1,1),YB(1,1)
/NOERASE
NSOL,5,1,U,X,'   URATB'
/COLOR,CURVE,MRED
XVAR,7
PLVAR,5
FINISH

/POST1
NSEL,ALL
SET,LAST
*GET,UB,NODE,1,U,X
*GET,UA,NODE,2,U,Z
RA=UA/(-5.9)
RB=UB/3.42
*DIM,VALUE3,,2,2
*DIM,LABEL2,CHAR,2
*DIM,LABEL4,CHAR,2
*DIM,LABEL5,CHAR,2
LABEL2(1) = 'NODE A','NODE B',
LABEL4(1) = 'vmr029-','vmr029-'
LABEL5(1) = 't9-281','t9-281'
*VFILL,VALUE3(1,1),DATA,UA,UB
*VFILL,VALUE3(1,2),DATA,RA,RB
/OUT,vmr029-t9-281,vrt
/COM
/COM,-------------- VMR029-T9 RESULTS COMPARISON ---------------
/COM,
/COM,          |    Mechanical APDL    |   RATIO   |      INPUT      |
/COM,
/COM,SHELL281
*VWRITE,LABEL2(1),VALUE3(1,1),VALUE3(1,2),LABEL4(1),LABEL5(1)
(1X,A6,'       ',F10.4,'      ',F13.4,'      ',A7,A8)
/COM,
/COM,-------------------------------------------------------------
/OUT
FINISH
*LIST,vmr029-t9-281,vrt
```

VMR031-T1 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
```

```
/verify,vmr031-t1-281
/TITLE,vmr031-t1-281,LAMINATED STRIP UNDER THREE POINT BENDING
/COM, REFERENCE: PROBLEM NO 1 FROM NAFEMS R0031
/COM,
/PREP7
C*** USING SHELL281
ET,1,SHELL281
KEYOPT,1,1,0
KEYOPT,1,8,2  !STORES DATA FOR TOP,BOTTOM AND MID FOR ALL LAYERS
KEYOPT,1,9,0

MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,1,,1e5
MPDATA,EY,1,,5e3
MPDATA,EZ,1,,0.00001
MPDATA,PRXY,1,,0.4
MPDATA,PRYZ,1,,0.3
MPDATA,PRXZ,1,,0
MPDATA,GXY,1,,3e3
MPDATA,GYZ,1,,2e3
MPDATA,GXZ,1,,2e3
SECT,1,SHELL,,
SECDATA, 0.1,1,0.0,3
SECDATA, 0.1,1,90,3
SECDATA, 0.1,1,0.0,3
SECDATA, 0.4,1,90,3
SECDATA, 0.1,1,0.0,3
SECDATA, 0.1,1,90,3
SECDATA, 0.1,1,0.0,3
SECOFFSET,BOT
SECCONTROL,,,, , , ,
RECTNG,,25,,5,


ET,2,SURF156  !SURFACE ELEMENTS TO APPLY THE LOAD
KEYOPT,2,2,1
KEYOPT,2,4,0  !WITH MIDSIDE NODE
KEYOPT,2,5,1  !WITHOUT ORIENTATION NODE
KEYOPT,2,7,0

K,,10,,,
K,,10,5,,
L,5,6
ASBL,1,5

LESIZE,2,,,1
LESIZE,4,,,1
*REP,2,1
LESIZE,6,,,3
*REP,2,1
LESIZE,8,,,2
*REP,2,1
AMESH,2,3

LOCAL,13,0,0,0,0,0,0,0
CSYS,0
TYPE,2
ESYS,13
E,1,8,9
ALLSEL,ALL
ESEL,S,TYPE,,2
SFE,ALL,3,PRESS,1,-10
ESEL,ALL
EPLOT

DL,9,3,SYMM
DL,7,2,SYMM
DL,2,2,SYMM
DL,5,,UZ,0
DL,5,,UX,0
DL,5,,UY,0
```

```
FINISH

/SOLUTION
SOLVE
FINISH

/POST1
SET,LAST
LAYER,1
SHELL,BOT
PLNSOL,U,Z
*GET,DISP,PLNSOL,0,MIN
*STAT,DISP

PLNSOL,S,X
*GET,BENDING_STRESS,PLNSOL,0,MAX
*STAT,BENDING_STRESS

*DIM,LABEL,CHAR,2,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'DEFLECTI','BEND STR'
LABEL(1,2) = 'ON mm','ESS MPa '
*VFILL,VALUE(1,1),DATA,-1.06,683.9
*VFILL,VALUE(1,2),DATA,DISP,BENDING_STRESS
*VFILL,VALUE(1,3),DATA,ABS((DISP)/(-1.06) ) ,ABS((BENDING_STRESS)/683.9 )

/NOPR
/COM
/OUT,vmr031-t1-281,vrt
/COM,------------------- VMr031-t1-281 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,USING SHELL281
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,'   ',F10.3,'  ',F14.3,'   ',1F15.3)
/COM,
/COM,
/COM,-----------------------------------------------------------------

/OUT
FINISH
*list,vmr031-t1-281,vrt
```

VMR031-T2 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr031-t2-281
/TITLE,vmr031-t2-281,WRAPPED THICK CYLINDER UNDER PRESSURE AND THERMAL LOADING
 C*** USING SHELL281 LOADED WITH INTERNAL PRESSURE
/COM, REFERENCE: PROBLEM NO 2 FROM NAFEMS: R0031
/COM,

/PREP7
ET,1,SHELL281
KEYOPT,1,1,0
KEYOPT,1,8,2  !STORES DATA FOR TOP,BOTTOM AND MID FOR ALL LAYERS
KEYOPT,1,9,0

MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,1,,2.1e5
MPDATA,PRXY,1,,0.3
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,2,,5000
MPDATA,EY,2,,1.3e5
```

```
MPDATA,EZ,2,,5e3
MPDATA,PRXY,2,,0
MPDATA,PRYZ,2,,0.25
MPDATA,PRXZ,2,,0.25
MPDATA,GXY,2,,5e3
MPDATA,GYZ,2,,1e4
MPDATA,GXZ,2,,5e3

SECT,1,SHELL,,
SECDATA,2,1,0.0,3
SECDATA,2,2,0.0,3
SECOFFSET,BOT
SECCONTROL,,,, , , ,

CSYS,1
K,1,23                ! DEFINE MODEL GEOMETRY
K,2,23,,100
KGEN,2,1,2,1,,90
A,1,2,4,3
ESIZE,,4
AMESH,1
CSYS,0
ENSYM,,,,ALL

DL,3,,SYMM
DL,1,,SYMM
DL,4,,UZ,0

SFE,ALL,1,PRESS,,200
EPLOT
FINISH

/SOLUTION
SOLVE
FINISH

/POST1

LAYER,1
SHELL,BOTTOM
RSYS,1
*SET,n1,node(23,0,0)
*GET,sy1,node,n1,s,y
*STAT,sy1

LAYER, 1
SHELL,TOP
RSYS,1
*SET,n1,node(23,0,0)
*GET,sy2,node,n1,s,y
*STAT,sy2

LAYER, 2
SHELL,BOTTOM
RSYS,1
*SET,n1,node(23,0,0)
*GET,sy3,node,n1,s,y
*STAT,sy3

LAYER, 2
SHELL,TOP
RSYS,1
*SET,n1,node(23,0,0)
*GET,sy4,node,n1,s,y
*STAT,sy4

 *DIM,LABEL,CHAR,4,5
*DIM,VALUE,,4,3
LABEL(1,1) = 'HOOP STR','HOOP STR','HOOP STR','HOOP STR'
LABEL(1,2) = 'ESS INNE','ESS INNE ','ESS OUTE','ESS OUTE'
LABEL(1,3) = 'R CYLNDE','R CYLNDE','R CYLNDE','R CYLNDE'
LABEL(1,4) = 'R @ R=23','R @ R=25','R @ R=25','R @ R=27'
```

```
LABEL(1,5) = ' in MPa',' in MPa',' in MPa',' in MPa'
*VFILL,VALUE(1,1),DATA,1565.3,1429.7,874.7,759.1
*VFILL,VALUE(1,2),DATA,SY1,SY2,SY3,SY4
*VFILL,VALUE(1,3),DATA,ABS((SY1)/(1565.3)) ,ABS((SY2)/(1429.7)),ABS((SY3)/(874.7)),ABS((SY4)/(759.1))
SAVE,TABLE_1


FINI
/CLEAR,NOSTART


C*** USING SHELL281 LOADED WITH INTERNAL PRESSURE AND UNIFORM TEMPERATURE RAISE
/PREP7
ET,1,shell281
KEYOPT,1,1,0
KEYOPT,1,8,2  !STORES DATA FOR TOP,BOTTOM AND MID FOR ALL LAYERS
KEYOPT,1,9,0

MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,ALPX,1,,2e-5
MPDATA,EX,1,,2.1e5
MPDATA,PRXY,1,,0.3
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,ALPX,2,,
MPDATA,ALPY,2,,3e-6
MPDATA,ALPZ,2,,2e-5
MPDATA,EX,2,,5000
MPDATA,EY,2,,1.3e5
MPDATA,EZ,2,,5e3
MPDATA,PRXY,2,,0
MPDATA,PRYZ,2,,0.25
MPDATA,PRXZ,2,,0.25
MPDATA,GXY,2,,5e3
MPDATA,GYZ,2,,1e4
MPDATA,GXZ,2,,5e3

SECT,1,SHELL,,
SECDATA,2,1,0.0,3
SECDATA,2,2,0.0,3
SECOFFSET,BOT
SECCONTROL,,,, , , ,

CSYS,1
K,1,23               ! DEFINE MODEL GEOMETRY
K,2,23,,100
KGEN,2,1,2,1,,90
A,1,2,4,3
ESIZE,,4
AMESH,1
CSYS,0
ENSYM,,,,all

DL,3,,SYMM
DL,1,,SYMM
DL,4,,UZ,0

TUNIF,130,   !UNIFORM TEMPERSTURE RAISE
SFE,ALL,1,PRESS,,200
EPLOT
FINISH

/SOLUTION
SOLVE
FINISH

/POST1

LAYER,1
SHELL,BOTTOM
RSYS,1
```

```
*SET,n1,node(23,0,0)
*GET,sy1,node,n1,s,y
*STAT,sy1

LAYER, 1
SHELL,TOP
RSYS,1
*SET,n1,node(23,0,0)
*GET,sy2,node,n1,s,y
*STAT,sy2

LAYER, 2
SHELL,BOTTOM
RSYS,1
*SET,n1,node(23,0,0)
*GET,sy3,node,n1,s,y
*STAT,sy3

LAYER, 2
SHELL,TOP
RSYS,1
*SET,n1,node(23,0,0)
*GET,sy4,node,n1,s,y
*STAT,sy4

 *DIM,LABEL,CHAR,4,5
*DIM,VALUE,,4,3
LABEL(1,1) = 'HOOP STR','HOOP STR','HOOP STR','HOOP STR'
LABEL(1,2) = 'ESS INNE','ESS INNE ','ESS OUTE','ESS OUTE'
LABEL(1,3) = 'R CYLNDE','R CYLNDE','R CYLNDE','R CYLNDE'
LABEL(1,4) = 'R @ R=23','R @ R=25','R @ R=25','R @ R=27'
LABEL(1,5) = ' in MPa',' in MPa',' in MPa',' in MPa'
*VFILL,VALUE(1,1),DATA,1381.0,1259.6,1056.0,936.1
*VFILL,VALUE(1,2),DATA,SY1,SY2,SY3,SY4
*VFILL,VALUE(1,3),DATA,ABS((SY1)/(1381.0)) ,ABS((SY2)/(1259.6)),ABS((SY3)/(1056.0)),ABS((SY4)/(936.1))
SAVE,TABLE_2


/NOPR
/COM
/OUT,vmr031-t2-281,vrt
/COM,------------------- VMr031-t2-281 RESULTS COMPARISON ---------------------
/COM,
/COM,                                    |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
RESUME,TABLE_1
/COM,USING SHELL281 with internal pressure
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),LABEL(1,3),LABEL(1,4),LABEL(1,5),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,A8,A8,A8'   ',F10.3,'  ',F12.3,'   ',1F10.3)
/COM,
RESUME,TABLE_2
/COM,USING SHELL281 with internal pressure and uniform temperature raise
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),LABEL(1,3),LABEL(1,4),LABEL(1,5),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,A8,A8,A8'   ',F10.3,'  ',F12.3,'   ',1F10.3)
/COM,
/COM,-----------------------------------------------------------------

/OUT
FINISH
*list,vmr031-t2-281,vrt
```

VMR031-T3 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr031-t3-181
/TITLE,vmr031-t3-181,THREE-LAYER SANDWICH SHELL UNDER NORMAL PRESSURE LOADING
```

```
/COM, REFERENCE: PROBLEM NO 3 FROM NAFEMS: R0031
/COM,

C*** USING SHELL181
/PREP7
ET,1,SHELL181

KEYOPT,1,1,0
KEYOPT,1,3,2  !FULL INTEGRATION
KEYOPT,1,8,2  !STORES DATA FOR TOP,BOTTOM AND MID FOR ALL LAYERS
KEYOPT,1,9,0

MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,1,,1e7
MPDATA,EY,1,,4e6
MPDATA,EZ,1,,4e6
MPDATA,PRXY,1,,0.3
MPDATA,PRYZ,1,,0.4
MPDATA,PRXZ,1,,0.3
MPDATA,GXY,1,,1.875e6
MPDATA,GYZ,1,,1.425e6
MPDATA,GXZ,1,,1.875e6
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,2,,1e-6
MPDATA,EY,2,,1e-6
MPDATA,EZ,2,,1e-6
MPDATA,PRXY,2,,0.3
MPDATA,PRYZ,2,,0.3
MPDATA,PRXZ,2,,0.3
MPDATA,GXY,2,,1e-6
MPDATA,GYZ,2,,1.2e4
MPDATA,GXZ,2,,3e4
SECT,1,SHELL,,
SECDATA, 0.028,1,0.0,3
SECDATA, 0.75,2,0.0,3
SECDATA, 0.028,1,0.0,3
SECOFFSET,MID
SECCONTROL,,,, , , ,
RECTNG,,5,,5,

LESIZE,ALL,,,4
AMESH,1
ALLSEL,ALL

DL,1,1,ux,0
DL,1,1,uz,0
DL,1,1,roty,0
DL,2,1,ux,0
DL,2,1,roty,0
DL,3,1,uy,0
DL,3,1,rotx,0
DL,4,1,uy,0
DL,4,1,uz,0
DL,4,1,rotx,0
SFE,ALL,2,PRESS,,100
ALLSEL,ALL
FINI

/SOLUTION
SOLVE
FINISH

/POST1
SET,LAST
LAYER,1
SHELL,TOP
*SET,n1,node(5,5,0)
*GET,uz,node,n1,u,z
*STAT,uz
*GET,sx,node,n1,s,x
```

```
*STAT,sx
*GET,sy,node,n1,s,y
*STAT,sy
*SET,n2,node(2.5,2.5,0)
*GET,sxy,node,n2,s,xy
*STAT,sxy

*DIM,LABEL,CHAR,4,5
*DIM,VALUE,,4,3
LABEL(1,1) = 'CENTRAL ','SIGMAxx','SIGMAyy','TAUxy AT'
LABEL(1,2) = 'TRANSVER','AT THE C','AT THE C',' QUARTER'
LABEL(1,3) = 'SE DISPL','ENTRE OF ','ENTRE OF',' OF TOP '
LABEL(1,4) = 'ACEMENT',' TOP SHE',' TOP SHE','SHEET'
LABEL(1,5) = ' in','ET psi','ET psi',' psi'
*VFILL,VALUE(1,1),DATA,-0.123,34449,13350,-5067.5
*VFILL,VALUE(1,2),DATA,uz,sx,sy,sxy
*VFILL,VALUE(1,3),DATA,ABS((uz)/(-0.123)),ABS((sx)/(34449)),ABS((sy)/(13350)),ABS((sxy)/(-5067.5))
/NOPR
/COM
/OUT,vmr031-t3-181,vrt
/COM,------------------- VMr031-t3-181 RESULTS COMPARISON ---------------------
/COM,
/COM,                   |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,USING SHELL181
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),LABEL(1,3),LABEL(1,4),LABEL(1,5),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,A8,A8,A8'   ',F10.3,'  ',F12.3,'   ',1F10.3)
/COM,
/COM,
/OUT
FINISH
*list,vmr031-t3-181,vrt
```

VMR031-T3 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vmr031-t3-281
/TITLE,vmr031-t3-281,THREE-LAYER SANDWICH SHELL UNDER NORMAL PRESSURE LOADING
/COM, REFERENCE: PROBLEM NO 3 FROM NAFEMS: R0031


C*** USING SHELL281
/PREP7

ET,1,SHELL281
KEYOPT,1,1,0
KEYOPT,1,8,2  !STORES DATA FOR TOP,BOTTOM AND MID FOR ALL LAYERS
KEYOPT,1,9,0

MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,1,,1e7
MPDATA,EY,1,,4e6
MPDATA,EZ,1,,4e6
MPDATA,PRXY,1,,0.3
MPDATA,PRYZ,1,,0.4
MPDATA,PRXZ,1,,0.3
MPDATA,GXY,1,,1.875e6
MPDATA,GYZ,1,,1.425e6
MPDATA,GXZ,1,,1.875e6
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,2,,1e-6
MPDATA,EY,2,,1e-6
MPDATA,EZ,2,,1e-6
MPDATA,PRXY,2,,0.3
MPDATA,PRYZ,2,,0.3
```

```
MPDATA,PRXZ,2,,0.3
MPDATA,GXY,2,,1e-6
MPDATA,GYZ,2,,1.2e4
MPDATA,GXZ,2,,3e4

SECT,1,SHELL,,
SECDATA, 0.028,1,0.0,3
SECDATA, 0.75,2,0.0,3
SECDATA, 0.028,1,0.0,3
SECOFFSET,MID
SECCONTROL,,,, , , ,
RECTNG,,5,,5,

LESIZE,ALL,,,4
AMESH,1
ALLSEL,ALL
DL,1,1,ux,0
DL,1,1,uz,0
DL,1,1,roty,0
DL,2,1,ux,0
DL,2,1,roty,0
DL,3,1,uy,0
DL,3,1,rotx,0
DL,4,1,uy,0
DL,4,1,uz,0
DL,4,1,rotx,0
SFE,ALL,2,PRESS,,100
ALLSEL,ALL
FINI

/SOLUTION
SOLVE
FINISH

/POST1
SET,LAST
LAYER,1
SHELL,TOP
*SET,n1,node(5,5,0)
*GET,uz,node,n1,u,z
*STAT,uz
*GET,sx,node,n1,s,x
*STAT,sx
*GET,sy,node,n1,s,y
*STAT,sy
*SET,n2,node(2.5,2.5,0)
*GET,sxy,node,n2,s,xy
*STAT,sxy

*DIM,LABEL,CHAR,4,5
*DIM,VALUE,,4,3
LABEL(1,1) = 'CENTRAL ','SIGMAxx','SIGMAyy','TAUxy AT'
LABEL(1,2) = 'TRANSVER','AT THE C','AT THE C',' QUARTER'
LABEL(1,3) = 'SE DISPL','ENTRE OF ','ENTRE OF',' OF TOP '
LABEL(1,4) = 'ACEMENT',' TOP SHE',' TOP SHE','SHEET'
LABEL(1,5) = ' in','ET psi','ET psi',' psi'
*VFILL,VALUE(1,1),DATA,-0.123,34449,13350,-5067.5
*VFILL,VALUE(1,2),DATA,uz,sx,sy,sxy
*VFILL,VALUE(1,3),DATA,ABS((uz)/(-0.123)),ABS((sx)/(34449)),ABS((sy)/(13350)),ABS((sxy)/(-5067.5))

/NOPR
/COM
/OUT,vmr031-t3-281,vrt
/COM,------------------- VMr031-t3-281 RESULTS COMPARISON ---------------------
/COM,
/COM,                 |   TARGET   |   Mechanical APDL   |   RATIO
/COM,
/COM,USING SHELL281
/COM,
*VWRITE,LABEL(1,1),LABEL(1,2),LABEL(1,3),LABEL(1,4),LABEL(1,5),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,A8,A8,A8,A8'   ',F10.3,'  ',F12.3,'   ',1F10.3)
/COM,
```

```
/OUT
FINISH
*list,vmr031-t3-281,vrt
```

VMR038-2A 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr038-2a-182
/TITLE,vmr038-2a-182,J INTEGRAL VALUE FOR CENTERED CRACK PLATE WITH BISO MATERIAL
/COM, REFERENCE:" E.M.REMZI, NAFEMS, TWO DIMENSIONAL TEST CASES IN POST YIELD
/COM,             FRACTURE MECHANICS, REF: R0038
/COM,             CHAPTER 2.1 FROM REFERENCE ARTICLE
/COM,
/OUT,SCRATCH
/PREP7
A=25     ! CRACK LENGTH
B=100     ! WIDTH OF THE PLATE
H=200     ! HEIGHT OF THE PLATE

ET,1,PLANE182
KEYOPT,1,3,2   ! PLANE STRAIN

MP,EX,1,205000
MP,NUXY,1,0.3

TB,BISO,1,,
TBDATA,1,1000,2450  ! YIELD STRESS = 1000, TANGENT MODULUS = 2450

K,1,0,0,0
K,2,25,0,0
K,3,100,0,0
K,4,100,25,0
K,5,100,200,0
K,6,0,200,0
K,7,0,25,0

A,1,2,3,4,7
A,7,4,5,6

ESIZE,4.0
KSCON,2,2.5,1,8        ! WITH SINGULAR CRACK TIP ELEMENTS
AMESH,1
ESIZE,B/10
AMESH,2
ALLSEL,ALL

NSEL,S,LOC,Y,0
NSEL,R,LOC,X,25,100
D,ALL,UY,0    ! SYMMETRIC BOUNDARY CONDITION
ALLSEL,ALL

NSEL,S,LOC,X,0
D,ALL,UX,0    ! SYMMETRIC BOUNDARY CONDITION
ALLSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,CINT,ALL
CNVTOL,F,1,0.01   ! FORCE CONVERGENCE TOLERANCE
CNVTOL,U,1,0.01   ! DISPLACEMENT CONVERGENCE TOLERANCE
NLGEOM,ON    ! NON-LINEAR ANALYSIS
NSUBS,30,1000,30
TIME,1.0
NSEL,S,LOC,Y,200
D,ALL,UY,2    ! DISPLACEMENT CONTROL
NSEL,ALL
NSEL,S,LOC,Y,0
```

```
NSEL,R,LOC,X,25,25
CM,CRACK1,NODE   ! CRACK TIP NODE COMPONENT
ALLSEL,ALL
CINT,NEW,1
CINT,NAME,CRACK1
CINT,NCON,6    ! NUMBER OF COUNTOURS
CINT,SYMM,OFF   ! SYMMETRY TURNED OFF
CINT,NORM,0,2
ALLSEL,ALL
SOLVE
FINI

/POST1
SET,LAST
PRCINT,1
*GET,J1,CINT,1,CTIP,2,,1,,
*GET,J2,CINT,1,CTIP,2,,2,,
*GET,J3,CINT,1,CTIP,2,,3,,
*GET,J4,CINT,1,CTIP,2,,4,,
*GET,J5,CINT,1,CTIP,2,,5,,
*GET,J6,CINT,1,CTIP,2,,6,,
JC1 = (ABS(J1)+ABS(J2)+ABS(J3)+ABS(J4)+ABS(J5)+ABS(J6))/6
*STAT,JC1
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'JVALUE'
*VFILL,VALUE(1,1),DATA,1462
*VFILL,VALUE(1,2),DATA,JC1
*VFILL,VALUE(1,3),DATA,ABS(JC1/1462)
/OUT,vmr038-2a-182,vrt
/COM,
/COM,------------------- vmr038-2a-182 RESULTS COMPARISON --------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F15.4,'   ',F12.3)
/COM,-----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmr038-2a-182,vrt
```

VMR038-2A 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr038-2a-183
/TITLE,vmr038-2a-183,J INTEGRAL VALUE FOR CENTERED CRACK PLATE WITH BISO MATERIAL
/COM, REFERENCE:" E.M.REMZI, NAFEMS, TWO DIMENSIONAL TEST CASES IN POST YIELD
/COM,            FRACTURE MECHANICS, REF: R0038
/COM,            CHAPTER 2.1 FROM REFERENCE ARTICLE
/COM,
/OUT,SCRATCH
/PREP7
A=25     ! CRACK LENGTH
B=100     ! WIDTH OF THE PLATE
H=200     ! HEIGHT OF THE PLATE

ET,1,PLANE183
KEYOPT,1,3,2   ! PLANE STRAIN

MP,EX,1,205000
MP,NUXY,1,0.3

TB,BISO,1,,
TBDATA,1,1000,2450  ! YIELD STRESS = 1000, TANGENT MODULUS = 2450

K,1,0,0,0
```

```
K,2,25,0,0
K,3,100,0,0
K,4,100,25,0
K,5,100,200,0
K,6,0,200,0
K,7,0,25,0

A,1,2,3,4,7
A,7,4,5,6

ESIZE,4.0
KSCON,2,2.5,1,8        ! WITH SINGULAR CRACK TIP ELEMENTS
AMESH,1
ESIZE,B/10
AMESH,2
ALLSEL,ALL

NSEL,S,LOC,Y,0
NSEL,R,LOC,X,25,100
D,ALL,UY,0    ! SYMMETRIC BOUNDARY CONDITION
ALLSEL,ALL

NSEL,S,LOC,X,0
D,ALL,UX,0    ! SYMMETRIC BOUNDARY CONDITION
ALLSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,CINT,ALL
CNVTOL,F,1,0.01   ! FORCE CONVERGENCE TOLERANCE
CNVTOL,U,1,0.01   ! DISPLACEMENT CONVERGENCE TOLERANCE
NLGEOM,ON    ! NON-LINEAR ANALYSIS
NSUBS,30,1000,30
TIME,1.0
NSEL,S,LOC,Y,200
D,ALL,UY,2    ! DISPLACEMENT CONTROL
NSEL,ALL
NSEL,S,LOC,Y,0
NSEL,R,LOC,X,25,25
CM,CRACK1,NODE   ! CRACK TIP NODE COMPONENT
ALLSEL,ALL
CINT,NEW,1
CINT,NAME,CRACK1
CINT,NCON,6    ! NUMBER OF COUNTOURS
CINT,SYMM,OFF   ! SYMMETRY TURNED OFF
CINT,NORM,0,2
ALLSEL,ALL
SOLVE
FINI

/POST1
SET,LAST
PRCINT,1
*GET,J1,CINT,1,CTIP,2,,1,,
*GET,J2,CINT,1,CTIP,2,,2,,
*GET,J3,CINT,1,CTIP,2,,3,,
*GET,J4,CINT,1,CTIP,2,,4,,
*GET,J5,CINT,1,CTIP,2,,5,,
*GET,J6,CINT,1,CTIP,2,,6,,
JC1 = (ABS(J1)+ABS(J2)+ABS(J3)+ABS(J4)+ABS(J5)+ABS(J6))/6
*STAT,JC1
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'JVALUE'
*VFILL,VALUE(1,1),DATA,1462
*VFILL,VALUE(1,2),DATA,JC1
*VFILL,VALUE(1,3),DATA,ABS(JC1/1462)
/OUT,vmr038-2a-183,vrt
/COM,
/COM,------------------- vmr038-2a-183 RESULTS COMPARISON --------------
/COM,
```

```
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F12.4,'   ',F14.3)
/COM,-----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmr038-2a-183,vrt
```

VMR038-2B 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr038-2b-182
/TITLE,vmr038-2b-182,J INTEGRAL FOR CENTERED CRACK PLATE WITH ELASTIC-PERFECTLY PLASTIC MATERIAL
/COM      PLAIN STRAIN DISPLACEMENT CONTROL
/COM, REFERENCE : E.M.REMZI, NAFEMS, TWO DIMENSIONAL TEST CASES IN POST YIELD FRACTURE
/COM,              MECHANICS, REF: R00038
/COM,              CHAPTER 2.2 FROM REFERENCE ARTICLE
/OUT,SCRATCH
/PREP7
A=25     ! CRACK LENGTH
B=100     ! WIDTH OF THE PLATE
H=200     ! HEIGHT OF THE PLATE
ET,1,182    ! PLANE 182 ELEMENT
KEYOPT,1,3,2   ! PLANE STRAIN

MP,EX,1,205000
MP,NUXY,1,0.3
TB,BISO,1,,
TBDATA,1,1000,0

K,1,0,0,0
K,2,25,0,0
K,3,100,0,0
K,4,100,25,0
K,5,100,200,0
K,6,0,200,0
K,7,0,25,0

A,1,2,3,4,7
A,7,4,5,6

ESIZE,4
KSCON,2,2.5,1,8,,   ! SINGULAR CRACK TIP ELEMENTS
AMESH,1
ESIZE,B/10
AMESH,2
ALLSEL,ALL

NSEL,S,LOC,Y,0
NSEL,R,LOC,X,25,100
D,ALL,UY,0    ! SYMMETRY BOUNDARY CONDITION
ALLSEL,ALL

NSEL,S,LOC,X,0
D,ALL,UX,0    ! SYMMETRY BOUNDARY CONDITION
ALLSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,CINT,ALL
CNVTOL,F,1,0.01
CNVTOL,U,1,0.01
NLGEOM,ON
NSUBS,30,1000,30
TIME,1
```

```
NSEL,S,LOC,Y,200
D,ALL,UY,2
NSEL,ALL

NSEL,S,LOC,Y,0
NSEL,R,LOC,X,25,25
CM,CRACK1,NODE    ! CRACK TIP NODE COMPONENT
ALLSEL,ALL

CINT,NEW,1
CINT,NAME,CRACK1
CINT,NCON,6     ! NUMBER OF COUNTOURS AROUND CRACK TIP
CINT,SYMM,OFF    ! SYMMETRY TURNED OFF
CINT,NORM,0,2
ALLSEL,ALL
SOLVE
FINI

/POST1
SET,LAST
PRCINT,1
*GET,J1,CINT,1,CTIP,2,,1,,
*GET,J2,CINT,1,CTIP,2,,2,,
*GET,J3,CINT,1,CTIP,2,,3,,
*GET,J4,CINT,1,CTIP,2,,4,,
*GET,J5,CINT,1,CTIP,2,,5,,
*GET,J6,CINT,1,CTIP,2,,6,,
JC1 = (ABS(J1)+ABS(J2)+ABS(J3)+ABS(J4)+ABS(J5)+ABS(J6))/6
*STAT,JC1
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'J-VALUE'
*VFILL,VALUE(1,1),DATA,1468
*VFILL,VALUE(1,2),DATA,JC1
*VFILL,VALUE(1,3),DATA,ABS(JC1/1468)
/OUT,vmr038-2b-182,vrt
/COM, -----------------vmr038-2b-182 RESULTS COMPARISON -----------------
/COM,
/COM,            |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM, PLAIN STRAIN WITH DISPLACEMENT CONTROL
/COM, --------------------------------------
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM,
/COM,-----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmr038-2b-182,vrt
```

VMR038-2B 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr038-2b-183
/TITLE,vmr038-2b-183,J INTEGRAL FOR CENTERED CRACK PLATE WITH ELASTIC-PERFECTLY PLASTIC MATERIAL
/COM      PLAIN STRAIN LOAD CONTROL
/COM, REFERENCE : E.M.REMZI, NAFEMS, TWO DIMENSIONAL TEST CASES IN POST YIELD FRACTURE
/COM,             MECHANICS, REF: R00038
/COM,             CHAPTER 2.2 FROM REFERENCE ARTICLE
/COM,
/OUT,SCRATCH
/PREP7
A=25      ! CRACK LENGTH
B=100      ! WIDTH OF THE PLATE
H=200      ! HEIGHT OF THE PLATE
```

```
ET,1,183    ! PLANE 183 ELEMENT
KEYOPT,1,3,2   ! PLANE STRAIN

MP,EX,1,205000
MP,NUXY,1,0.3
TB,BISO,1,,
TBDATA,1,1000,0

K,1,0,0,0
K,2,25,0,0
K,3,100,0,0
K,4,100,25,0
K,5,100,200,0
K,6,0,200,0
K,7,0,25,0

A,1,2,3,4,7
A,7,4,5,6

ESIZE,1.5
KSCON,2,2.5,1,8,,   ! SINGULAR CRACK TIP ELEMENTS
AMESH,1
ESIZE,B/10
AMESH,2
ALLSEL,ALL

NSEL,S,LOC,Y,0
NSEL,R,LOC,X,25,100
D,ALL,UY,0    ! SYMMETRY BOUNDARY CONDITION
ALLSEL,ALL

NSEL,S,LOC,X,0
D,ALL,UX,0    ! SYMMETRY BOUNDARY CONDITION
ALLSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,CINT,ALL
CNVTOL,F,1,0.01
CNVTOL,U,1,0.01
NLGEOM,ON
NSUBS,30,1000,30
TIME,1

NSEL,S,LOC,Y,200
SF,ALL,PRES,-850   ! LOAD CONTROL
NSEL,ALL

NSEL,S,LOC,Y,0
NSEL,R,LOC,X,25,25
CM,CRACK1,NODE   ! CRACK TIP NODE COMPONENT
ALLSEL,ALL

CINT,NEW,1
CINT,NAME,CRACK1
CINT,NCON,6    ! NUMBER OF COUNTOURS AROUND CRACK TIP
CINT,SYMM,OFF   ! SYMMETRY TURNED OFF
CINT,NORM,0,2
ALLSEL,ALL
SOLVE
FINI

/POST1
SET,LAST
PRCINT,1
*GET,J1,CINT,1,CTIP,2,,1,,
*GET,J2,CINT,1,CTIP,2,,2,,
*GET,J3,CINT,1,CTIP,2,,3,,
JC1 = (ABS(J1)+ABS(J2)+ABS(J3))/3
*STAT,JC1
*DIM,LABEL,CHAR,1
```

```
*DIM,VALUE,,1,3
LABEL(1,1) = 'J-VALUE'
*VFILL,VALUE(1,1),DATA,198
*VFILL,VALUE(1,2),DATA,JC1
*VFILL,VALUE(1,3),DATA,ABS(JC1/198)
/OUT,vmr038-2b-183,vrt
/COM, -----------------vmr038-2b-183 RESULTS COMPARISON -----------------
/COM,
/COM,            |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM, PLAIN STRAIN WITH LOAD CONTROL
/COM, -------------------------------
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM,
/COM,-----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmr038-2b-183,vrt
```

VMR038-2E 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr038-2e-182
/TITLE,vmr038-2e-182,J INTEGRAL FOR CENTERED CRACK PLATE WITH ELASTIC-PERFECTLY PLASTIC MATERIAL
/COM      PLAIN STRESS DISPLACEMENT CONTROL
/COM, REFERENCE : E.M.REMZI, NAFEMS, TWO DIMENSIONAL TEST CASES IN POST YIELD FRACTURE
/COM,             MECHANICS, REF: R00038
/COM,             CHAPTER 2.5 FROM REFERENCE ARTICLE
/COM,
/OUT,SCRATCH
/PREP7
A=25     ! CRACK LENGTH
B=100     ! WIDTH OF THE PLATE
H=200     ! HEIGHT OF THE PLATE
ET,1,182    ! PLANE 182 ELEMENT
KEYOPT,1,3,0   ! PLANE STRESS

MP,EX,1,205000
MP,NUXY,1,0.3
TB,BISO,1,,
TBDATA,1,1000,0

K,1,0,0,0
K,2,25,0,0
K,3,100,0,0
K,4,100,25,0
K,5,100,200,0
K,6,0,200,0
K,7,0,25,0

A,1,2,3,4,7
A,7,4,5,6

ESIZE,2
KSCON,2,2.5,1,8,,   ! SINGULAR CRACK TIP ELEMENTS
AMESH,1
ESIZE,B/10
AMESH,2
ALLSEL,ALL

NSEL,S,LOC,Y,0
NSEL,R,LOC,X,25,100
D,ALL,UY,0    ! SYMMETRY BOUNDARY CONDITION
ALLSEL,ALL
```

```
NSEL,S,LOC,X,0
D,ALL,UX,0    ! SYMMETRY BOUNDARY CONDITION
ALLSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,CINT,ALL
CNVTOL,F,1,0.01
CNVTOL,U,1,0.01
NLGEOM,ON
NSUBS,1000,100000,100
NEQIT,100
TIME,1

NSEL,S,LOC,Y,200
D,ALL,UY,2.0   ! DISPLACEMENT CONTROL
NSEL,ALL

NSEL,S,LOC,Y,0
NSEL,R,LOC,X,25,25
CM,CRACK1,NODE   ! CRACK TIP NODE COMPONENT
ALLSEL,ALL

CINT,NEW,1
CINT,NAME,CRACK1
CINT,NCON,4    ! NUMBER OF COUNTOURS AROUND CRACK TIP
CINT,SYMM,OFF   ! SYMMETRY TURNED OFF
CINT,NORM,0,2
ALLSEL,ALL
SOLVE
FINI

/POST1
SET,LAST
PRCINT,1
*GET,J1,CINT,1,CTIP,2,,1,,
*GET,J2,CINT,1,CTIP,2,,2,,
*GET,J3,CINT,1,CTIP,2,,3,,
*GET,J4,CINT,1,CTIP,2,,4,,
JC1 = (ABS(J1)+ABS(J2)+ABS(J3)+ABS(J4))/4
*STAT,JC1
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'J-VALUE'
*VFILL,VALUE(1,1),DATA,1189
*VFILL,VALUE(1,2),DATA,JC1
*VFILL,VALUE(1,3),DATA,ABS(JC1/1189)
/OUT,vmr038-2e-182,vrt
/COM, -----------------vmr038-2e-182 RESULTS COMPARISON -----------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM, PLAIN STRAIN WITH LOAD CONTROL
/COM, --------------------------------
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM,
/COM,-----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmr038-2e-182,vrt
```

VMR038-2g 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
```

```
/VERIFY,vmr038-2g-182
/TITLE,vmr038-2g-182,CENTERED CRACK PLATE UNDER THERMAL LOADING WITH ELASTIC-PERFECTLY PLASTIC MATERIAL
/COM, REFERENCE : E.M.REMZI, NAFEMS, TWO DIMENSIONAL TEST CASES IN POST YIELD FRACTURE
/COM,             MECHANICS, REF: R00038
/COM,             CHAPTER 2.7 FROM REFERENCE ARTICLE
/COM,
/PREP7
A=25     ! CRACK LENGTH
B=100     ! WIDTH OF THE PLATE
H=200     ! HEIGHT OF THE PLATE
AF=1E-4                                 ! COEFFICIENT OF THERMAL EXPANISON
ET,1,PLANE182    ! PLANE 182 ELEMENT
KEYOPT,1,1,1
KEYOPT,1,3,2            ! PLANE STRAIN

MP,EX,1,205000
MP,NUXY,1,0.3
MP,ALPX,1,AF                            ! THERMAL MATERIAL PROPERTIES
MP,REFT,1,0                             ! REFERENCE TEMPERATURE
TB,BISO,1,,
TBDATA,1,1000,0

K,1,0,0,0
K,2,25,0,0
K,3,100,0,0
K,4,100,25,0
K,5,100,200,0
K,6,0,200,0
K,7,0,25,0

A,1,2,3,4,7
A,7,4,5,6

ESIZE,2.5
KSCON,2,2.5,1,8,,   ! SINGULAR CRACK TIP ELEMENTS
AMESH,1
ESIZE,8
AMESH,2
ALLSEL,ALL

NSEL,S,LOC,X,25,100
NSEL,R,LOC,Y,0
D,ALL,UY,0
ALLSEL

NSEL,S,LOC,X,0
D,ALL,UX,0
ALLSEL

FINI

/SOLU
ANTYPE,STATIC
OUTRES,CINT,ALL
CNVTOL,F,1,0.01
CNVTOL,U,1,0.01
NLGEOM,ON
NSUBS,20,1000,10
TIME,1

*GET,NN,NODE,0,COUNT
*DO,I,1,NN
  TT=0.01*NX(I)*NX(I)
  BF,I,TEMP,TT                  ! THERMAL LOADING
*ENDDO
ALLSEL

NSEL,S,LOC,Y,0
NSEL,R,LOC,X,25,25
CM,CRACK1,NODE   ! CRACK TIP NODE COMPONENT
ALLSEL,ALL
```

```
CINT,NEW,1
CINT,NAME,CRACK1
CINT,NCON,4   ! NUMBER OF COUNTOURS AROUND CRACK TIP
CINT,SYMM,OFF   ! SYMMETRY TURNED OFF
CINT,NORM,0,2
ALLSEL,ALL
SOLVE
FINI

/OUT,SCRATCH
/POST1
SET,LAST
PRCINT,1
*GET,J1,CINT,1,CTIP,2,,1,,
*GET,J2,CINT,1,CTIP,2,,2,,
*GET,J3,CINT,1,CTIP,2,,3,,
*GET,J4,CINT,1,CTIP,2,,4,,
JC1 = (ABS(J2)+ABS(J3)+ABS(J4))/3
*STAT,JC1
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'J-VALUE'
*VFILL,VALUE(1,1),DATA,105.8
*VFILL,VALUE(1,2),DATA,JC1
*VFILL,VALUE(1,3),DATA,ABS(JC1/105.8)
/OUT,vmr038-2g-182,vrt
/COM, -----------------vmr038-2g-182 RESULTS COMPARISON -----------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM, PLAIN STRAIN WITH LOAD CONTROL
/COM, --------------------------------
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM,
/COM,-----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmr038-2g-182,vrt
```

VMR038-3A 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr038-3a-182
/TITLE,vmr038-3a-182,J INTEGRAL FOR COMPACT TENSION SPECIMEN WITH BISO MATERIAL
/COM, REFERENCE: E.M.REMZI,NAFEMS,TWO DIMENSIONAL TEST CASES IN POST YIELD
/COM,            FRACTURE MECHANICS,R00038
/COM,            CHAPTER 3.1 FROM REFERENCE ARTICLE
/COM,
/OUT,SCRATCH
/PREP7
A = 29.78     ! CRACK LENGTH
L = 50     ! LENGTH OF THE PLATE
W = 30     ! WIDTH OF THE PLATE
B = 20.112

ET,1,PLANE182    ! PLANE 182 ELEMENT
KEYOPT,1,3,2    ! PLANE STRAIN

MP,EX,1,205000
MP,NUXY,1,0.3

TB,BISO,1
TBDATA,1,550,3044

K,1,0,0,0
```

```
K,2,29.78,0,0
K,3,50,0,0
K,4,50,15,0
K,5,50,30,0
K,6,0,30,0
K,7,0,20.112,0
K,8,0,15,0

A,1,2,3,4,5,6,7,8

KSCON,2,0.75,1,5,,
ESIZE,4
AMESH,1
ALLSEL,ALL

NSEL,S,LOC,X,29.78,50
NSEL,R,LOC,Y,0
D,ALL,UY,0
NSEL,ALL

NSEL,S,LOC,X,50
NSEL,R,LOC,Y,0
D,ALL,UX,0
ALLSEL,ALL

KSEL,S,,,7
NSLK,S
D,ALL,UY,1.05
NSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,CINT,ALL
CNVTOL,F,1,0.001
CNVTOL,U,1,0.001
NLGEOM,ON
NSUBS,10,1000,10
TIME,1.0

NSEL,S,LOC,X,29.78,29.78
NSEL,R,LOC,Y,0
CM,CRACK1,NODE
ALLSEL,ALL


CINT,NEW,1
CINT,NAME,CRACK1
CINT,NCON,4
CINT,SYMM,OFF
CINT,NORM,0,2
ALLSEL,ALL
SOLVE
FINI

/POST1
SET,LAST
N1=NODE(0,20.112,0)
*GET,RFORCE,NODE,N1,RF,FY
ALLSEL,ALL
/COM,
/COM, TOTAL REACTION FORCE AT POINT P IS 64970 N (FROM REFERENCE)
/COM, REACTION FORCE AT POINT P IS TOTAL LOAD/THICKNESS = 64970/25.2 = 2578 N
/COM,
PRCINT,1
*GET,J1,CINT,1,CTIP,2,,1,,
*GET,J2,CINT,1,CTIP,2,,2,,
*GET,J3,CINT,1,CTIP,2,,3,,
*GET,J4,CINT,1,CTIP,2,,4,,
JC1 = (ABS(J1)+ABS(J2)+ABS(J3)+ABS(J4))/4
*STAT,JC1
*DIM,LABEL,CHAR,1,2
```

```
*DIM,VALUE,,2,3
LABEL(1,1) = 'J1'
LABEL(1,2) = 'RF@P'
*VFILL,VALUE(1,1),DATA,230.8
*VFILL,VALUE(1,2),DATA,JC1
*VFILL,VALUE(1,3),DATA,ABS(JC1/230.8)
*VFILL,VALUE(2,1),DATA,2578
*VFILL,VALUE(2,2),DATA,RFORCE
*VFILL,VALUE(2,3),DATA,RFORCE/2578
/OUT,vmr038-3a-182,vrt
/COM,------------------- vmr038-3a-182 RESULTS COMPARISON --------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
/COM, AVERAGE J INTEGRAL VALUE
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM, REACTION FORCE AT POINT P
/COM,
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,-----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmr038-3a-182,vrt
```

VMR038-3A 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr038-3a-183
/TITLE,vmr038-3a-183,J INTEGRAL FOR COMPACT TENSION SPECIMEN WITH BISO MATERIAL
/COM, REFERENCE: E.M.REMZI,NAFEMS,TWO DIMENSIONAL TEST CASES IN POST YIELD
/COM,            FRACTURE MECHANICS,R00038
/COM,            CHAPTER 3.1 FROM REFERENCE ARTICLE
/COM,
/OUT,SCRATCH
/PREP7
A = 29.78      ! CRACK LENGTH
L = 50      ! LENGTH OF THE PLATE
W = 30      ! WIDTH OF THE PLATE
B = 20.112

ET,1,PLANE183     ! PLANE 183 ELEMENT
KEYOPT,1,3,2     ! PLANE STRAIN

MP,EX,1,205000
MP,NUXY,1,0.3

TB,BISO,1
TBDATA,1,550,3044

K,1,0,0,0
K,2,29.78,0,0
K,3,50,0,0
K,4,50,15,0
K,5,50,30,0
K,6,0,30,0
K,7,0,20.112,0
K,8,0,15,0

A,1,2,3,4,5,6,7,8

KSCON,2,0.75,1,5,,
ESIZE,4
AMESH,1
```

```
ALLSEL,ALL

NSEL,S,LOC,X,29.78,50
NSEL,R,LOC,Y,0
D,ALL,UY,0
NSEL,ALL

NSEL,S,LOC,X,50
NSEL,R,LOC,Y,0
D,ALL,UX,0
ALLSEL,ALL

KSEL,S,,,7
NSLK,S
D,ALL,UY,1.05
NSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,CINT,ALL
CNVTOL,F,1,0.001
CNVTOL,U,1,0.001
NLGEOM,ON
NSUBS,10,1000,10
TIME,1.0

NSEL,S,LOC,X,29.78,29.78
NSEL,R,LOC,Y,0
CM,CRACK1,NODE
ALLSEL,ALL


CINT,NEW,1
CINT,NAME,CRACK1
CINT,NCON,4
CINT,SYMM,OFF
CINT,NORM,0,2
ALLSEL,ALL
SOLVE
FINI

/POST1
SET,LAST
N1=NODE(0,20.112,0)
*GET,RFORCE,NODE,N1,RF,FY
ALLSEL,ALL
/COM,
/COM, TOTAL REACTION FORCE AT POINT P IS 64970 N (FROM REFERENCE)
/COM, REACTION FORCE AT POINT P IS TOTAL LOAD/THICKNESS = 64970/25.2 = 2578 N
/COM,
PRCINT,1
*GET,J1,CINT,1,CTIP,2,,1,,
*GET,J2,CINT,1,CTIP,2,,2,,
*GET,J3,CINT,1,CTIP,2,,3,,
*GET,J4,CINT,1,CTIP,2,,4,,
JC1 = (ABS(J1)+ABS(J2)+ABS(J3)+ABS(J4))/4
*STAT,JC1
*DIM,LABEL,CHAR,1,2
*DIM,VALUE,,2,3
LABEL(1,1) = 'J1'
LABEL(1,2) = 'RF@P'
*VFILL,VALUE(1,1),DATA,230.8
*VFILL,VALUE(1,2),DATA,JC1
*VFILL,VALUE(1,3),DATA,ABS(JC1/230.8)
*VFILL,VALUE(2,1),DATA,2578
*VFILL,VALUE(2,2),DATA,RFORCE
*VFILL,VALUE(2,3),DATA,RFORCE/2578
/OUT,vmr038-3a-183,vrt
/COM,------------------- vmr038-3a-183 RESULTS COMPARISON --------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
```

```
/COM,
/COM,
/COM, AVERAGE J INTEGRAL VALUE
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,
/COM, REACTION FORCE AT POINT P
/COM,
*VWRITE,LABEL(1,2),VALUE(2,1),VALUE(2,2),VALUE(2,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmr038-3a-183,vrt
```

VMR038-4A 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr038-4a-182
/TITLE,vmr038-4a-182,J INTEGRAL FOR 3 PT BEND SPECIMEN WITH POWER LAW HARDENING MATERIAL
/COM, REFERENCE: E.M.REMZI, NAFEMS, TWO DIMENSIONAL TEST CASES IN POST YIELD FRACTURE
/COM,            MECHANICS, REF: R00038
/COM,            CHAPTER 4.1 FROM REFERENCE ARTICLE
/COM,
/OUT,SCRATCH
/PREP7
ET,1,PLANE182
KEYOPT,1,1,1   ! UNIFROM REDUCED INTEGRATION FORMULATION
KEYOPT,1,3,2   ! PLANE STRAIN

A = 12.7    ! CRACK LENGTH
W = 25.4    ! WIDTH OF THE PLATE
L = 50.8    ! LENGTH OF THE PLATE

K,1,0,0,0
K,2,12.7,0,0
K,3,25.4,0,0
K,4,25.4,15,0
K,5,25.4,50.8,0
K,6,0,50.8,0
K,7,0,15,0
K,8,10,50.8,0
K,9,10,40.8,0
K,10,0,40.8,0

A,1,2,3,4,7
A,7,4,5,8,9,10
A,10,9,8,6


MP,EX,1,214800
MP,NUXY,1,0.3

TB,NLISO,1,,,POWER
TBDATA,1,275,0.1

KSCON,2,0.75,1,8,,
ESIZE,1.25
AMESH,1

ESIZE,6
AMESH,2
ALLSEL,ALL

ESIZE,5    ! REFINING THE MESH NEAR LOADING AREA
AMESH,3
ALLSEL,ALL
```

```
NUMMRG,NODE
NUMMRG,KP
ALLSEL,ALL

NSEL,S,LOC,X,12.7,25.4
NSEL,R,LOC,Y,0
D,ALL,UY,0
NSEL,ALL

NSEL,S,LOC,X,25.4,25.4
NSEL,R,LOC,Y,0
D,ALL,UX,0
NSEL,ALL

NSEL,S,LOC,X,0
NSEL,R,LOC,Y,50.8
D,ALL,UX,2    ! APPLIED DISPLACEMENTS
NSEL,ALL
ALLSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,CINT,ALL
NLGEOM,ON
NSUBS,10,1000,10
CNVTOL,F,1,0.001   ! FORCE CONVERGENCE
CNVTOL,U,1,0.001   ! DISPLACEMENT CONVERGENCE
TIME,1
NSEL,S,LOC,X,12.7,12.7
NSEL,R,LOC,Y,0
CM,CRACK1,NODE
ALLSEL,ALL
CINT,NEW,1
CINT,CTNC,CRACK1
CINT,NCON,10
CINT,SYMM,ON
CINT,NORM,0,2
ALLSEL,ALL
SOLVE
FINI

/POST1
SET,LAST
PRCINT,1
*GET,J1,CINT,1,CTIP,2,,1,,
*GET,J2,CINT,1,CTIP,2,,2,,
*GET,J3,CINT,1,CTIP,2,,3,,
*GET,J4,CINT,1,CTIP,2,,4,,
*GET,J5,CINT,1,CTIP,2,,5,,
*GET,J6,CINT,1,CTIP,2,,6,,
*GET,J7,CINT,1,CTIP,2,,7,,
*GET,J8,CINT,1,CTIP,2,,8,,
*GET,J9,CINT,1,CTIP,2,,9,,
*GET,J10,CINT,1,CTIP,2,,10,,
JC1 = (ABS(J1)+ABS(J2)+ABS(J3)+ABS(J4)+ABS(J5)+ABS(J6)+ABS(J7)+ABS(J8)+ABS(J9)+ABS(J10))/10
*STAT,JC1
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'J1 '
*VFILL,VALUE(1,1),DATA,203.8
*VFILL,VALUE(1,2),DATA,JC1
*VFILL,VALUE(1,3),DATA,ABS(JC1/203.8)
/OUT,vmr038-4a-182,vrt
/COM,
/COM, --------------------vmr038-4a-182 RESULTS COMPARISON------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
```

```
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,-------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmr038-4a-182,vrt
```

VMR038-4A 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr038-4a-183
/TITLE,vmr038-4a-183,J INTEGRAL FOR 3 PT BEND SPECIMEN WITH POWER LAW HARDENING MATERIAL
/COM, REFERENCE: E.M.REMZI, NAFEMS, TWO DIMENSIONAL TEST CASES IN POST YIELD FRACTURE
/COM,            MECHANICS, REF: R00038
/COM,       CHAPTER 4.1 FROM REFERENCE ARTICLE
/COM,
/OUT,SCRATCH
/PREP7
ET,1,PLANE183
KEYOPT,1,3,2   ! PLANE STRAIN

A = 12.7    ! CRACK LENGTH
W = 25.4    ! WIDTH OF THE PLATE
L = 50.8    ! LENGTH OF THE PLATE

K,1,0,0,0
K,2,12.7,0,0
K,3,25.4,0,0
K,4,25.4,15,0
K,5,25.4,50.8,0
K,6,0,50.8,0
K,7,0,15,0
K,8,10,50.8,0
K,9,10,40.8,0
K,10,0,40.8,0

A,1,2,3,4,7
A,7,4,5,8,9,10
A,10,9,8,6


MP,EX,1,214800
MP,NUXY,1,0.3

TB,NLISO,1,,,POWER
TBDATA,1,275,0.1

KSCON,2,0.75,1,8,,
ESIZE,1.25
AMESH,1

ESIZE,6
AMESH,2
ALLSEL,ALL

ESIZE,5    ! REFINING THE MESH NEAR LOADING AREA
AMESH,3
ALLSEL,ALL

NUMMRG,NODE
NUMMRG,KP
ALLSEL,ALL

NSEL,S,LOC,X,12.7,25.4
NSEL,R,LOC,Y,0
D,ALL,UY,0
NSEL,ALL

NSEL,S,LOC,X,25.4,25.4
```

```
NSEL,R,LOC,Y,0
D,ALL,UX,0
NSEL,ALL

NSEL,S,LOC,X,0
NSEL,R,LOC,Y,50.8
D,ALL,UX,2    ! APPLIED DISPLACEMENTS
NSEL,ALL
ALLSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,CINT,ALL
NLGEOM,ON
NSUBS,10,1000,10
CNVTOL,F,1,0.001   ! FORCE CONVERGENCE
CNVTOL,U,1,0.001   ! DISPLACEMENT CONVERGENCE
TIME,1
NSEL,S,LOC,X,12.7,12.7
NSEL,R,LOC,Y,0
CM,CRACK1,NODE
ALLSEL,ALL
CINT,NEW,1
CINT,CTNC,CRACK1
CINT,NCON,10
CINT,SYMM,ON
CINT,NORM,0,2
ALLSEL,ALL
SOLVE
FINI


/POST1
SET,LAST
PRCINT,1
*GET,J1,CINT,1,CTIP,2,,1,,
*GET,J2,CINT,1,CTIP,2,,2,,
*GET,J3,CINT,1,CTIP,2,,3,,
*GET,J4,CINT,1,CTIP,2,,4,,
*GET,J5,CINT,1,CTIP,2,,5,,
*GET,J6,CINT,1,CTIP,2,,6,,
*GET,J7,CINT,1,CTIP,2,,7,,
*GET,J8,CINT,1,CTIP,2,,8,,
*GET,J9,CINT,1,CTIP,2,,9,,
*GET,J10,CINT,1,CTIP,2,,10,,
JC1 = (ABS(J1)+ABS(J2)+ABS(J3)+ABS(J4)+ABS(J5)+ABS(J6)+ABS(J7)+ABS(J8)+ABS(J9)+ABS(J10))/10
*STAT,JC1
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'J-VALUE '
*VFILL,VALUE(1,1),DATA,203.8
*VFILL,VALUE(1,2),DATA,JC1
*VFILL,VALUE(1,3),DATA,ABS(JC1/203.8)
/OUT,vmr038-4a-183,vrt
/COM,
/COM, --------------------vmr038-4a-183 RESULTS COMPARISON------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,----------------------------------------------------------------
/OUT,
FINISH
*LIST,vmr038-4a-183,vrt
```

VMLSB2-LE8 208 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmlsb2-le8-208
/TITLE,vmlsb2-le8-208,AXISYMMETRIC SHELL WITH PRESSURE LOADING
/COM, REFERENCE: NAFEMS BENCHMARKS,REPORT:LSB2,1990-06-15/2
/COM, ORIGINIAL TEST NUMBER: LE8
/PREP7
ET,1,SHELL208    ! SHELL 208 ELEMENT
KEYOPT,1,3,2    ! INCLUDE EXTRA INTERNAL NODES
SECTYPE,1,SHELL
SECDATA,0.01,1,0,3

MP,EX,1,210E9
MP,NUXY,1,0.3

K,1,0,0.5,0
K,2,0.25,0.5,0
K,3,0.25,0,0
K,4,0.1875,0.5,0
K,5,0.1875,0.5625,0
K,6,0.1508,0.5505,0
K,7,0,0.5+0.25,0

LARC,1,6,7,0.25
LARC,6,5,4,0.0625
LARC,5,2,4,0.0625
L,2,3

KDELE,7
KDELE,4

LESIZE,1,,,16
LESIZE,2,,,8
LESIZE,3,,,10
LESIZE,4,,,8

LMESH,ALL
ALLSEL,ALL

NSEL,S,LOC,X,0.25
NSEL,R,LOC,Y,0
D,ALL,UY,0
NSEL,ALL

NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0.5
D,ALL,UX,0
D,ALL,ROTZ,0
ALLSEL,ALL

SFE,ALL,2,PRES,0,1E6   ! UNIFORM INTERNAL PRESSURE
ALLSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
NSUBS,10,10,10
OUTRES,ALL,ALL
TIME,1
SOLVE
FINI

/POST1
SET,LAST
*GET,SZ_HOOP,NODE,2,S,Z   ! HOOP STRESS FROM Mechanical APDL IN PA
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'HOOP_STRESS'
```

```
*VFILL,VALUE(1,1),DATA,94.55
*VFILL,VALUE(1,2),DATA,(SZ_HOOP/1000000)
*VFILL,VALUE(1,3),DATA,((SZ_HOOP/1000000)/(94.55))
/OUT,vmlsb2-le8-208,vrt
/COM,------------------- vmlsb2-le8-208 RESULTS COMPARISON --------------
/COM,
/COM,            |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,-----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmlsb2-le8-208,vrt
```

VMLSB2-LE8 209 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmlsb2-le8-209
/TITLE,vmlsb2-le8-209,AXISYMMETRIC SHELL WITH PRESSURE LOADING
/COM, REFERENCE: NAFEMS BENCHMARKS,REPORT: LSB2,1990-06-15/2
/COM, ORIGINIAL TEST NUMBER: LE8
/PREP7
ET,1,SHELL209    ! SHELL 209 ELEMENT
SECTYPE,1,SHELL
SECDATA,0.01,1,0,3

MP,EX,1,210E9
MP,NUXY,1,0.3

K,1,0,0.5,0
K,2,0.25,0.5,0
K,3,0.25,0,0
K,4,0.1875,0.5,0
K,5,0.1875,0.5625,0
K,6,0.1508,0.5505,0
K,7,0,0.5+0.25,0

LARC,1,6,7,0.25
LARC,6,5,4,0.0625
LARC,5,2,4,0.0625
L,2,3

KDELE,7
KDELE,4

LESIZE,1,,,16
LESIZE,2,,,8
LESIZE,3,,,10
LESIZE,4,,,8

LMESH,ALL
ALLSEL,ALL

NSEL,S,LOC,X,0.25
NSEL,R,LOC,Y,0
D,ALL,UY,0
NSEL,ALL

NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0.5
D,ALL,UX,0
D,ALL,ROTZ,0
ALLSEL,ALL

SFE,ALL,2,PRES,0,1E6   ! UNIFORM INTERNAL PRESSURE
ALLSEL,ALL
```

```
FINI

/SOLU
ANTYPE,STATIC
NSUBS,10,10,10
OUTRES,ALL,ALL
TIME,1
SOLVE
FINI

/POST1
SET,LAST
*GET,SZ_HOOP,NODE,2,S,Z   ! HOOP STRESS FROM Mechanical APDL IN PA
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'HOOP_STRESS'
*VFILL,VALUE(1,1),DATA,94.55
*VFILL,VALUE(1,2),DATA,(SZ_HOOP/1000000)
*VFILL,VALUE(1,3),DATA,((SZ_HOOP/1000000)/(94.55))
/OUT,vmlsb2-le8-209,vrt
/COM,------------------- vmlsb2-le8-209 RESULTS COMPARISON --------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,-----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmlsb2-le8-209,vrt
```

VMLSB2-LE9 208 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmlsb2-le9-208
/TITLE,vmlsb2-le9-208,AXISYMMETRIC BRANCHED SHELL WITH PRESSURE LOADING
/COM, REFERENCE: NAFEMS BENCHMARKS,REPORT: LSB2,1989-01-01/1
/COM, ORIGINAL TEST NUMBER: LE9
/PREP7
ET,1,SHELL208
KEYOPT,1,3,2   ! INCLUDE EXTRA INTERNAL NODE
KEYOPT,1,8,2   ! STORE DATA FOR ALL LAYERS
SECTYPE,1,SHELL
SECDATA,0.01,1,0
MP,EX,1,210E9
MP,NUXY,1,0.3
K,1,0.70710,0,0
K,2,0.70710,0.875,0
K,3,0.70710,1,0
K,4,0.70710,1.125,0
K,5,0.70710,2,0
K,6,0,0.70710,0
K,7,0.60874,0.91374,0
K,8,0,1.70710,0

L,5,4
L,4,3
LARC,3,7,8,1
LARC,7,6,8,1
L,3,2
L,2,1

KDELE,8

LESIZE,1,,,8
LESIZE,2,,,8
LESIZE,3,,,8
```

```
LESIZE,4,,,10
LESIZE,5,,,8
LESIZE,6,,,8
LMESH,ALL
ALLSEL,ALL

NSEL,S,LOC,X,0.70710
NSEL,R,LOC,Y,0
D,ALL,ALL,0
ALLSEL,ALL

LSEL,S,LINE,,3,4,1
LSEL,A,LINE,,1,2,1
NSLL,S,1
ESLN,S
SFE,ALL,2,PRES,0,1E6
ALLSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,ALL,ALL
NSUBS,10,10,10
TIME,1
SOLVE
FINI

/POST1
SET,LAST
/GRAPHICS,POWER
/SHOW,vmfebsta-le9-208
ESEL,S,ELEM,,16
PLESOL,S,Y
*GET,SYY_MIN,PLNSOL,0,MIN
ESEL,ALL
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'AXIAL-STRESS'
*VFILL,VALUE(1,1),DATA,-319.9
*VFILL,VALUE(1,2),DATA,(SYY_MIN/1000000)
*VFILL,VALUE(1,3),DATA,((SYY_MIN/1000000)/(-319.9))
/OUT,vmlsb2-le9-208,vrt
/COM,-------------------vmlsb2-le9-208 RESULTS COMPARISON --------------
/COM,
/COM,            |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,-----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmlsb2-le9-208,vrt
```

VMLSB2-LE9 209 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmlsb2-le9-209
/TITLE,vmlsb2-le9-209,AXISYMMETRIC BRANCHED SHELL WITH PRESSURE LOADING
/COM, REFERENCE: NAFEMS BENCHMARK,REPORT: LSB2,1989-01-01/1
/COM, ORIGINAL TEST NUMBER: LE9
/PREP7
ET,1,SHELL209
KEYOPT,1,8,2
SECTYPE,1,SHELL
SECDATA,0.01,1,0
MP,EX,1,210E9
MP,NUXY,1,0.3
```

```
K,1,0.70710,0,0
K,2,0.70710,0.875,0
K,3,0.70710,1,0
K,4,0.70710,1.125,0
K,5,0.70710,2,0
K,6,0,0.70710,0
K,7,0.60874,0.91374,0
K,8,0,1.70710,0

L,5,4
L,4,3
LARC,3,7,8,1
LARC,7,6,8,1
L,3,2
L,2,1

KDELE,8

LESIZE,1,,,8
LESIZE,2,,,8
LESIZE,3,,,8
LESIZE,4,,,10
LESIZE,5,,,8
LESIZE,6,,,8
LMESH,ALL
ALLSEL,ALL

NSEL,S,LOC,X,0.70710
NSEL,R,LOC,Y,0
D,ALL,ALL,0
ALLSEL,ALL

LSEL,S,LINE,,3,4,1
LSEL,A,LINE,,1,2,1
NSLL,S,1
ESLN,S
SFE,ALL,2,PRES,0,1E6
ALLSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,ALL,ALL
NSUBS,10,10,10
TIME,1
SOLVE
FINI

/POST1
SET,LAST
/GRAPHICS,POWER
/SHOW,vmfebsta-le9-209
ESEL,S,ELEM,,16
PLESOL,S,Y
*GET,SYY_MIN,PLNSOL,0,MIN
ESEL,ALL
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'AXIAL-STRESS'
*VFILL,VALUE(1,1),DATA,-319.9
*VFILL,VALUE(1,2),DATA,(SYY_MIN/1000000)
*VFILL,VALUE(1,3),DATA,((SYY_MIN/1000000)/(-319.9))
/OUT,vmlsb2-le9-209,vrt
/COM,-------------------vmlsb2-le9-209 RESULTS COMPARISON --------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,-----------------------------------------------------------------------
/OUT,
```

```
FINISH
*LIST,vmlsb2-le9-209,vrt
```

VMLSB2-LE11 185 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmlsb2-le11-185
/TITLE,vmlsb2-le11-185,TAPERED CYLINDER WITH TEMPERATURE LOADING
/COM, REFERENCE: NAFEMS BENCHMARKS,REPORT:LSB2,1990-06-15/2
/COM, ORIGINIAL TEST NUMBER: LE11
/OUT,SCRATCH
/PREP7
ET,1,SOLID185   ! SOLID 185 ELEMENT
KEYOPT,1,2,2   ! ENCHANCED STRAIN FORMULATION

MP,EX,1,210E9
MP,NUXY,1,0.3
MP,ALPX,1,2.3E-4
MP,ALPZ,1,2.3E-4
MP,ALPY,1,2.3E-4

K,1,1.39,0,0
K,2,1.21,0,-0.707
K,3,0,0,0
K,4,1,0,0
K,5,1,0,-1.39
K,6,1,0,-1.79
K,7,0.70710,0,-1.79
K,8,0.70710,0,-0.70710

LARC,4,8,3,1
LARC,1,2,3,1.4

L,4,1
L,2,5
L,5,6
L,6,7
L,7,8

AL,1,3,2,4,5,6,7

K,10,0,0,-5E3
VROTATE,1,,,,,,3,10,90,1

KDELE,3
KDELE,10

LESIZE,1,,,8
LESIZE,3,,,4
LESIZE,2,,,6
LESIZE,7,,,6
LESIZE,4,,,4
LESIZE,5,,,2
LESIZE,6,,,2

VSWEEP,1,1,9
ALLSEL,ALL

ASEL,S,AREA,,1
NSLA,S,1
D,ALL,UY,0
ALLSEL,ALL

ASEL,S,AREA,,9
NSLA,S,1
D,ALL,UX,0
ALLSEL,ALL
```

```
ASEL,S,AREA,,4,8,4
NSLA,S,1
D,ALL,UZ,0
ALLSEL,ALL

*GET,NNODE,NODE,0,COUNT  ! GET THE NUMBER OF NODES
*DO,I,1,NNODE,1   ! DO OPERATION FROM 1 TO MAXIMUM NODE NUMBER
*GET,NXX,NODE,I,LOC,X  ! GET THE X LOCATION OF NODE
*GET,NYY,NODE,I,LOC,Y  ! GET THE Y LOCATION OF NODE
*GET,NZZ,NODE,I,LOC,Z  ! GET THE Z LOCATION OF NODE
TN1 = SQRT((NXX**2)+(NYY**2))
TN  = TN1-NZZ   ! NEGATIVE SIGN SINCE THE GEOMETRY IS MODELED IN NEGATIVE Z AXIS
BF,I,TEMP,TN
*ENDDO
ALLSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,ALL,ALL
NSUBS,10,10,10
TIME,1
SOLVE
FINI

/POST1
SET,LAST
N1 = NODE(1,0,0)
*GET,SZZ,NODE,N1,S,Z
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'DIRECT_STRESS'
*VFILL,VALUE(1,1),DATA,-105
*VFILL,VALUE(1,2),DATA,(SZZ/1000000)
*VFILL,VALUE(1,3),DATA,((SZZ/1000000)/(-105))
/OUT,vmlsb2-le11-185,vrt
/COM,------------------- vmlsb2-le11-185 RESULTS COMPARISON --------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,-----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmlsb2-le11-185,vrt
```

VMLSB2-LE11 186 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmlsb2-le11-186
/TITLE,vmlsb2-le11-186,TAPERED CYLINDER WITH TEMPERATURE LOADING
/COM, REFERENCE:NAFEMS BENCHMARK,REPORT:LSB2,1990-06-15/2
/COM, ORIGINIAL TEST NUMBER: LE11
/OUT,SCRATCH
/PREP7
ET,1,SOLID186   ! SOLID 186 ELEMENT
KEYOPT,1,2,1

MP,EX,1,210E9
MP,NUXY,1,0.3
MP,ALPX,1,2.3E-4
MP,ALPZ,1,2.3E-4
MP,ALPY,1,2.3E-4

K,1,1.39,0,0
K,2,1.21,0,-0.707
```

```
K,3,0,0,0
K,4,1,0,0
K,5,1,0,-1.39
K,6,1,0,-1.79
K,7,0.70710,0,-1.79
K,8,0.70710,0,-0.70710

LARC,4,8,3,1
LARC,1,2,3,1.4

L,4,1
L,2,5
L,5,6
L,6,7
L,7,8

AL,1,3,2,4,5,6,7

K,10,0,0,-5E3
VROTATE,1,,,,,,3,10,90,1

KDELE,3
KDELE,10

LESIZE,1,,,8
LESIZE,3,,,4
LESIZE,2,,,6
LESIZE,7,,,6
LESIZE,4,,,4
LESIZE,5,,,2
LESIZE,6,,,2

VSWEEP,1,1,9
ALLSEL,ALL

ASEL,S,AREA,,1
NSLA,S,1
D,ALL,UY,0
ALLSEL,ALL

ASEL,S,AREA,,9
NSLA,S,1
D,ALL,UX,0
ALLSEL,ALL

ASEL,S,AREA,,4,8,4
NSLA,S,1
D,ALL,UZ,0
ALLSEL,ALL

*GET,NNODE,NODE,0,COUNT  ! GET THE NUMBER OF NODES
*DO,I,1,NNODE,1   ! DO OPERATION FROM 1 TO MAXIMUM NODE NUMBER
*GET,NXX,NODE,I,LOC,X  ! GET THE X LOCATION OF NODE
*GET,NYY,NODE,I,LOC,Y  ! GET THE Y LOCATION OF NODE
*GET,NZZ,NODE,I,LOC,Z  ! GET THE Z LOCATION OF NODE
TN1 = SQRT((NXX**2)+(NYY**2))
TN  = TN1-NZZ   ! NEGATIVE SIGN SINCE THE GEOMETRY IS MODELED IN NEGATIVE Z AXIS
BF,I,TEMP,TN
*ENDDO
ALLSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,ALL,ALL
NSUBS,10,10,10
TIME,1
SOLVE
FINI

/POST1
SET,LAST
```

```
N1 = NODE(1,0,0)
*GET,SZZ,NODE,N1,S,Z
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'DIRECT_STRESS'
*VFILL,VALUE(1,1),DATA,-105
*VFILL,VALUE(1,2),DATA,(SZZ/1000000)
*VFILL,VALUE(1,3),DATA,((SZZ/1000000)/(-105))
/OUT,vmlsb2-le11-186,vrt
/COM,------------------- vmlsb2-le11-186 RESULTS COMPARISON --------------
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,-----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmlsb2-le11-186,vrt
```

VM-R049-1A 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr1a-181
/TITLE,vmr049-cr1a-181,CONSTANT-LOAD CREEP BENCHMARK
/COM, REFERENCE: TEST CR-1A FROM NAFEMS REPORT 0049.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,0
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
ET,1,181,,,
R,1,1,1,1,1,
E,1,2,3,4
E,4,3,5,6
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,,,4
D,ALL,UY,
NSEL,ALL
D,ALL,ROTX
D,ALL,ROTY
D,4,UZ,0
FINISH

*DO,I,1,2,1

*IF,I,EQ,2,THEN
```

```
/PREP7
TB,HILL,1
TBDATA,1, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0
*ENDIF

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,100,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

*IF,I,EQ,1,THEN
/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/COLOR,CURVE,RED,1
/YRANGE,-5,10
PLVAR,2,3
FINISH

/POST1
SET,1,1
*GET,S1,NODE,3,EPCR,X
R1=1.00
SET,2,2
*GET,S2,NODE,3,EPCR,X
R2=S2/2
SET,2,4
*GET,S3,NODE,3,EPCR,X
R3=S3/4
SET,2,6
*GET,S4,NODE,3,EPCR,X
R4=S4/6
SET,2,8
*GET,S5,NODE,3,EPCR,X
R5=S5/8
SET,2,10
*GET,S6,NODE,3,EPCR,X
R6=S6/10

*DIM,VALUE,,6,6
*DIM,LABEL,CHAR,10
LABEL(1) = '0','200','400','600','800','1000'
*VFILL,VALUE(1,1),DATA,0,2,4,6,8,10
*VFILL,VALUE(1,2),DATA,S1,S2,S3,S4,S5,S6
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6

/POST1
SET,1,1
*GET,S1_Y,NODE,3,EPCR,Y
R7=1.00
SET,2,2
*GET,S2_Y,NODE,3,EPCR,Y
R8=S2_Y/(-1.0)
```

```
SET,2,4
*GET,S3_Y,NODE,3,EPCR,Y
R9=S3_Y/(-2.0)
SET,2,6
*GET,S4_Y,NODE,3,EPCR,Y
R10=S4_Y/(-3.0)
SET,2,8
*GET,S5_Y,NODE,3,EPCR,Y
R11=S5_Y/(-4.0)
SET,2,10
*GET,S6_Y,NODE,3,EPCR,Y
R12=S6_Y/(-5.0)
LABEL(1) = '0','200','400','600','800','1000'
*VFILL,VALUE(1,4),DATA,0,-1,-2,-3,-4,-5
*VFILL,VALUE(1,5),DATA,S1_Y,S2_Y,S3_Y,S4_Y,S5_Y,S6_Y
*VFILL,VALUE(1,6),DATA,R7,R8,R9,R10,R11,R12
*ENDIF

*IF,I,EQ,2,THEN
/COM,
/COM,  ANISOTROPIC CREEP MODELED AS ISOTROPIC /COM,

/POST26
ESOL,3,1,,EPCR,X
ESOL,4,1,,EPCR,Y
PRVAR,2
/AXLAB,X,TIME
/AXLAB,Y,ANISOTROPIC CREEP STRAIN
/COLOR,CURVE,BLUE,1
/YRANGE,-5,10
PLVAR,3,4
FINISH

/POST1
SET,1,1
*GET,S11,NODE,3,EPCR,X
R11=1.00
SET,2,2
*GET,S22,NODE,3,EPCR,X
R22=S22/2
SET,2,4
*GET,S33,NODE,3,EPCR,X
R33=S33/4
SET,2,6
*GET,S44,NODE,3,EPCR,X
R44=S44/6
SET,2,8
*GET,S55,NODE,3,EPCR,X
R55=S55/8
SET,2,10
*GET,S66,NODE,3,EPCR,X
R66=S66/10

*DIM,VALUE2,,6,6
*VFILL,VALUE2(1,1),DATA,0,2,4,6,8,10
*VFILL,VALUE2(1,2),DATA,S11,S22,S33,S44,S55,S66
*VFILL,VALUE2(1,3),DATA,R11,R22,R33,R44,R55,R66

/POST1
SET,1,1
*GET,S11_Y,NODE,3,EPCR,Y
R77=1.00
SET,2,2
*GET,S22_Y,NODE,3,EPCR,Y
R88=S22_Y/(-1.0)
SET,2,4
*GET,S33_Y,NODE,3,EPCR,Y
R99=S33_Y/(-2.0)
SET,2,6
*GET,S44_Y,NODE,3,EPCR,Y
R100=S44_Y/(-3.0)
SET,2,8
```

```
*GET,S55_Y,NODE,3,EPCR,Y
R111=S55_Y/(-4.0)
SET,2,10
*GET,S66_Y,NODE,3,EPCR,Y
R122=S66_Y/(-5.0)
LABEL(1) = '0','200','400','600','800','1000'
*VFILL,VALUE2(1,4),DATA,0,-1,-2,-3,-4,-5
*VFILL,VALUE2(1,5),DATA,S11_Y,S22_Y,S33_Y,S44_Y,S55_Y,S66_Y
*VFILL,VALUE2(1,6),DATA,R77,R88,R99,R100,R111,R122
*ENDIF
*ENDDO
/COM,
/COM,
/COM,------------- vmr049-cr1a-181 ISOTROPIC RESULTS COMPARISON --------------
/COM,
/COM, vmr049-cr1a-181.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS.  THE RESULTS DISPLAYED ARE INCREMENTED /COM, FOR THIS PURPOSE.
/COM,
/COM,
/COM,|  TIME   |  TARGET X  |  Mechanical APDL  |  RATIO  |  TARGET Y  |  Mechanical APDL  | RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3), VALUE(1,4),VALUE(1,5), VALUE(1,6)
(1X,A8,'   ',F8.3,'   ',F8.3,'   ',F15.3,'   ',1F10.3,'   ',F8.3,'   ',F14.3,'   ')
/COM,
/COM,
/COM,------------ vmr049-cr1a-181 ANISOTROPIC RESULTS COMPARISON -------------
/COM,
/COM,
/COM,|  TIME   |  TARGET X  |  Mechanical APDL  |  RATIO  |  TARGET Y  |  Mechanical APDL  | RATIO
/COM,
*VWRITE,LABEL(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3), VALUE2(1,4),VALUE2(1,5), VALUE2(1,6)
(1X,A8,'   ',F8.3,'   ',F8.3,'   ',F15.3,'   ',1F10.3,'   ',F8.3,'   ',F14.3,'   ')
FINISH
/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR2X ',' ECR2Y '
*VFILL,VALUE1(1,1),DATA,S6,S6_Y
*VFILL,VALUE1(1,2),DATA,R6,R12
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr1a-181'

/OUT,vmr049-cr1a-181,vrt
/COM
/COM,------------------- vmr049-cr1a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F12.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F12.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr1a-181,vrt
```

VM-R049-1A 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr1a-182
/TITLE,vmr049-cr1a-182,CONSTANT-LOAD CREEP BENCHMARK
/COM, REFERENCE: TEST CR-1A FROM NAFEMS REPORT 0049.

/PREP7
```

```
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,0
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
ET,1,182
KEYOPT,1,1,1
KEYOPT,1,3,0
E,1,2,3,4
E,4,3,5,6
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,,,4
D,ALL,UY,
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,100,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

*DO,I,1,2,1

*IF,I,EQ,2,THEN
/PREP7
TB,HILL,1
TBDATA,1, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0
*ENDIF

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
```

```
/OUT
RATE, ON, ON
DELT,100,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

*IF,I,EQ,1,THEN
/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/COLOR,CURVE,RED,1
/YRANGE,-5,10
PLVAR,2,3
FINISH

/POST1
SET,1,1
*GET,S1,NODE,3,EPCR,X
R1=1.00
SET,2,2
*GET,S2,NODE,3,EPCR,X
R2=S2/2
SET,2,4
*GET,S3,NODE,3,EPCR,X
R3=S3/4
SET,2,6
*GET,S4,NODE,3,EPCR,X
R4=S4/6
SET,2,8
*GET,S5,NODE,3,EPCR,X
R5=S5/8
SET,2,10
*GET,S6,NODE,3,EPCR,X
R6=S6/10

*DIM,VALUE,,6,6
*DIM,LABEL,CHAR,10
LABEL(1) = '0','200','400','600','800','1000'
*VFILL,VALUE(1,1),DATA,0,2,4,6,8,10
*VFILL,VALUE(1,2),DATA,S1,S2,S3,S4,S5,S6
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6

/POST1
SET,1,1
*GET,S1_Y,NODE,3,EPCR,Y
R7=1.00
SET,2,2
*GET,S2_Y,NODE,3,EPCR,Y
R8=S2_Y/(-1.0)
SET,2,4
*GET,S3_Y,NODE,3,EPCR,Y
R9=S3_Y/(-2.0)
SET,2,6
*GET,S4_Y,NODE,3,EPCR,Y
R10=S4_Y/(-3.0)
SET,2,8
*GET,S5_Y,NODE,3,EPCR,Y
R11=S5_Y/(-4.0)
SET,2,10
*GET,S6_Y,NODE,3,EPCR,Y
R12=S6_Y/(-5.0)
LABEL(1) = '0','200','400','600','800','1000'
*VFILL,VALUE(1,4),DATA,0,-1,-2,-3,-4,-5
*VFILL,VALUE(1,5),DATA,S1_Y,S2_Y,S3_Y,S4_Y,S5_Y,S6_Y
```

```
*VFILL,VALUE(1,6),DATA,R7,R8,R9,R10,R11,R12
*ENDIF

*IF,I,EQ,2,THEN
/COM,
/COM,  ANISOTROPIC CREEP MODELED AS ISOTROPIC
/COM,

/POST26
ESOL,3,1,,EPCR,X
ESOL,4,1,,EPCR,Y
PRVAR,3,4
/AXLAB,X,TIME
/AXLAB,Y, ANISOTROPIC CREEP STRAIN
/COLOR,CURVE,BLUE,1
/YRANGE,-5,10
PLVAR,3,4
FINISH

/POST1
SET,1,1
*GET,S11,NODE,3,EPCR,X
R11=1.00
SET,2,2
*GET,S22,NODE,3,EPCR,X
R22=S22/2
SET,2,4
*GET,S33,NODE,3,EPCR,X
R33=S33/4
SET,2,6
*GET,S44,NODE,3,EPCR,X
R44=S44/6
SET,2,8
*GET,S55,NODE,3,EPCR,X
R55=S55/8
SET,2,10
*GET,S66,NODE,3,EPCR,X
R66=S66/10

*DIM,VALUE2,,6,6
*VFILL,VALUE2(1,1),DATA,0,2,4,6,8,10
*VFILL,VALUE2(1,2),DATA,S11,S22,S33,S44,S55,S66
*VFILL,VALUE2(1,3),DATA,R11,R22,R33,R44,R55,R66

/POST1
SET,1,1
*GET,S11_Y,NODE,3,EPCR,Y
R77=1.00
SET,2,2
*GET,S22_Y,NODE,3,EPCR,Y
R88=S22_Y/(-1.0)
SET,2,4
*GET,S33_Y,NODE,3,EPCR,Y
R99=S33_Y/(-2.0)
SET,2,6
*GET,S44_Y,NODE,3,EPCR,Y
R100=S44_Y/(-3.0)
SET,2,8
*GET,S55_Y,NODE,3,EPCR,Y
R111=S55_Y/(-4.0)
SET,2,10
*GET,S66_Y,NODE,3,EPCR,Y
R122=S66_Y/(-5.0)
LABEL(1) = '0','200','400','600','800','1000'
*VFILL,VALUE2(1,4),DATA,0,-1,-2,-3,-4,-5
*VFILL,VALUE2(1,5),DATA,S11_Y,S22_Y,S33_Y,S44_Y,S55_Y,S66_Y
*VFILL,VALUE2(1,6),DATA,R77,R88,R99,R100,R111,R122
*ENDIF
*ENDDO
/COM,
/COM,
/COM,------------- vmr049-cr1a-182 ISOTROPIC RESULTS COMPARISON --------------
```

```
/COM,
/COM, vmr049-cr1a-182.grph RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS.  THE RESULTS DISPLAYED ARE INCREMENTED
/COM, FOR THIS PURPOSE.
/COM,
/COM,
/COM,|  TIME   |  TARGET X  |  Mechanical APDL   |  RATIO  |  TARGET Y  |  Mechanical APDL   | RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3), VALUE(1,4),VALUE(1,5), VALUE(1,6)
(1X,A8,'   ',F8.3,'   ',F8.3,'   ',F14.3,'   ',1F12.3,'   ',F8.3,'   ',F14.3,'   ')
/COM,
/COM,
/COM,------------ vmr049-cr1a-182 ANISOTROPIC RESULTS COMPARISON -------------
/COM,
/COM,
/COM,|  TIME   |  TARGET X  |  Mechanical APDL   |  RATIO  |  TARGET Y  |  Mechanical APDL   | RATIO
/COM,
*VWRITE,LABEL(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3), VALUE2(1,4),VALUE2(1,5), VALUE2(1,6)
(1X,A8,'   ',F8.3,'   ',F8.3,'   ',F14.3,'   ',1F12.3,'   ',F8.3,'   ',F14.3,'   ')
FINISH

/POST26
/COM,ESOL,2,1,,EPCR,X
/COM,ESOL,3,1,,EPCR,Y
/COM,PRVAR,2,3
/COM,PLVAR,2,3
/COM,*GET,RES1X,VARI,2,RTIME,1000
/COM,*GET,RES1Y,VARI,3,RTIME,1000

*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR2X ',' ECR2Y '
*VFILL,VALUE1(1,1),DATA,S66,S66_Y
*VFILL,VALUE1(1,2),DATA,R66,R122
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr1a-182'

/OUT,vmr049-cr1a-182,vrt
/COM
/COM,------------------- vmr049-cr1a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F12.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F12.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr1a-182,vrt
```

VM-R049-1A 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr1a-183
/TITLE,vmr049-cr1a-183,CONSTANT-LOAD CREEP BENCHMARK
/COM, REFERENCE: TEST CR-1A FROM NAFEMS REPORT 0049.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
```

```
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,0
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183
KEYOPT,1,3,0
E,1,2,3,4,5,6,7,8
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,,,8
D,ALL,UY,
NSEL,ALL

*DO,I,1,2,1

*IF,I,EQ,2,THEN
/PREP7
TB,HILL,1
TBDATA,1, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0
*ENDIF

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,100,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

*IF,I,EQ,1,THEN
/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/COLOR,CURVE,RED,1
/YRANGE,-5,10
PLVAR,2,3
FINISH

/POST1
SET,1,1
*GET,S1,NODE,3,EPCR,X
```

```
R1=1.00
SET,2,2
*GET,S2,NODE,3,EPCR,X
R2=S2/2
SET,2,4
*GET,S3,NODE,3,EPCR,X
R3=S3/4
SET,2,6
*GET,S4,NODE,3,EPCR,X
R4=S4/6
SET,2,8
*GET,S5,NODE,3,EPCR,X
R5=S5/8
SET,2,10
*GET,S6,NODE,3,EPCR,X
R6=S6/10

*DIM,VALUE,,6,6
*DIM,LABEL,CHAR,10
LABEL(1) = '0','200','400','600','800','1000'
*VFILL,VALUE(1,1),DATA,0,2,4,6,8,10
*VFILL,VALUE(1,2),DATA,S1,S2,S3,S4,S5,S6
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6

/POST1
SET,1,1
*GET,S1_Y,NODE,3,EPCR,Y
R7=1.00
SET,2,2
*GET,S2_Y,NODE,3,EPCR,Y
R8=S2_Y/(-1.0)
SET,2,4
*GET,S3_Y,NODE,3,EPCR,Y
R9=S3_Y/(-2.0)
SET,2,6
*GET,S4_Y,NODE,3,EPCR,Y
R10=S4_Y/(-3.0)
SET,2,8
*GET,S5_Y,NODE,3,EPCR,Y
R11=S5_Y/(-4.0)
SET,2,10
*GET,S6_Y,NODE,3,EPCR,Y
R12=S6_Y/(-5.0)
LABEL(1) = '0','200','400','600','800','1000'
*VFILL,VALUE(1,4),DATA,0,-1,-2,-3,-4,-5
*VFILL,VALUE(1,5),DATA,S1_Y,S2_Y,S3_Y,S4_Y,S5_Y,S6_Y
*VFILL,VALUE(1,6),DATA,R7,R8,R9,R10,R11,R12
*ENDIF

*IF,I,EQ,2,THEN
/COM,
/COM,  ANISOTROPIC CREEP MODELED AS ISOTROPIC
/COM,

/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,ANISOTROPIC CREEP STRAIN
/COLOR,CURVE,BLUE,1
/YRANGE,-5,10
PLVAR,2,3
FINISH

/POST1
SET,1,1
*GET,S11,NODE,3,EPCR,X
R11=1.00
SET,2,2
*GET,S22,NODE,3,EPCR,X
R22=S22/2
```

```
SET,2,4
*GET,S33,NODE,3,EPCR,X
R33=S33/4
SET,2,6
*GET,S44,NODE,3,EPCR,X
R44=S44/6
SET,2,8
*GET,S55,NODE,3,EPCR,X
R55=S55/8
SET,2,10
*GET,S66,NODE,3,EPCR,X
R66=S66/10

*DIM,VALUE2,,6,6
*VFILL,VALUE2(1,1),DATA,0,2,4,6,8,10
*VFILL,VALUE2(1,2),DATA,S11,S22,S33,S44,S55,S66
*VFILL,VALUE2(1,3),DATA,R11,R22,R33,R44,R55,R66

/POST1
SET,1,1
*GET,S11_Y,NODE,3,EPCR,Y
R77=1.00
SET,2,2
*GET,S22_Y,NODE,3,EPCR,Y
R88=S22_Y/(-1.0)
SET,2,4
*GET,S33_Y,NODE,3,EPCR,Y
R99=S33_Y/(-2.0)
SET,2,6
*GET,S44_Y,NODE,3,EPCR,Y
R100=S44_Y/(-3.0)
SET,2,8
*GET,S55_Y,NODE,3,EPCR,Y
R111=S55_Y/(-4.0)
SET,2,10
*GET,S66_Y,NODE,3,EPCR,Y
R122=S66_Y/(-5.0)
LABEL(1) = '0','200','400','600','800','1000'
*VFILL,VALUE2(1,4),DATA,0,-1,-2,-3,-4,-5
*VFILL,VALUE2(1,5),DATA,S11_Y,S22_Y,S33_Y,S44_Y,S55_Y,S66_Y
*VFILL,VALUE2(1,6),DATA,R77,R88,R99,R100,R111,R122
*ENDIF
*ENDDO
/COM,
/COM,
/COM,------------- vmr049-cr1a-183 ISOTROPIC RESULTS COMPARISON --------------
/COM,
/COM, vmr049-cr1a-183.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS.  THE RESULTS DISPLAYED ARE INCREMENTED
/COM, FOR THIS PURPOSE.
/COM,
/COM,
/COM,|  TIME  |  TARGET X  |  Mechanical APDL  |  RATIO  |  TARGET Y  |  Mechanical APDL  | RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3), VALUE(1,4),VALUE(1,5), VALUE(1,6)
(1X,A8,'   ',F8.3,'   ',F8.3,'   ',F14.3,'   ',1F10.3,'   ',F8.3,'   ',F14.3,'   ')
/COM,
/COM,
/COM,------------ vmr049-cr1a-183 ANISOTROPIC RESULTS COMPARISON -------------
/COM,
/COM,
/COM,|  TIME  |  TARGET X  |  Mechanical APDL  |  RATIO  |  TARGET Y  |  Mechanical APDL  | RATIO
/COM,
*VWRITE,LABEL(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3), VALUE2(1,4),VALUE2(1,5), VALUE2(1,6)
(1X,A8,'   ',F8.3,'   ',F8.3,'   ',F14.3,'   ',1F10.3,'   ',F8.3,'   ',F14.3,'   ')
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR2X ',' ECR2Y '
*VFILL,VALUE1(1,1),DATA,S6,S6_Y
```

```
*VFILL,VALUE1(1,2),DATA,R6,R12
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr1a-183'

/OUT,vmr049-cr1a-183,vrt
/COM
/COM,------------------- vmr049-cr1a RESULTS COMPARISON ---------------------
/COM,
/COM,             |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr1a-183,vrt
```

VM-R049-1A 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr1a-281
/TITLE,vmr049-cr1a-281,CONSTANT-LOAD CREEP BENCHMARK
/COM, REFERENCE: TEST CR-1A FROM NAFEMS REPORT 0049.
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,3.125E-14
*SET,C2,5
*SET,C3,0
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,0
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
N,7,50,0
N,8,100,25
N,9,50,50
N,10,0,25
N,11,100,75
N,12,50,100
N,13,0,75
ET,1,SHELL281,,,
R,1,1,1,1,1,
E,1,2,3,4,7,8,9,10
E,4,3,5,6,9,11,12,13
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,,,4
D,ALL,UY,
NSEL,ALL
D,ALL,ROTX
```

```
D,ALL,ROTY
D,9,UZ,0
FINISH
*DO,I,1,2,1
*IF,I,EQ,2,THEN
/PREP7
TB,HILL,1
TBDATA,1, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0
*ENDIF
/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,100,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH
*IF,I,EQ,1,THEN
/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
/COLOR,CURVE,RED,1
/YRANGE,-5,10
PLVAR,2,3
FINISH
/POST1
SET,1,1
*GET,S1,NODE,3,EPCR,X
R1=1.00
SET,2,2
*GET,S2,NODE,3,EPCR,X
R2=S2/2
SET,2,4
*GET,S3,NODE,3,EPCR,X
R3=S3/4
SET,2,6
*GET,S4,NODE,3,EPCR,X
R4=S4/6
SET,2,8
*GET,S5,NODE,3,EPCR,X
R5=S5/8
SET,2,10
*GET,S6,NODE,3,EPCR,X
R6=S6/10
*DIM,VALUE,,6,6
*DIM,LABEL,CHAR,10
LABEL(1) = '0','200','400','600','800','1000'
*VFILL,VALUE(1,1),DATA,0,2,4,6,8,10
*VFILL,VALUE(1,2),DATA,S1,S2,S3,S4,S5,S6
*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6
/POST1
SET,1,1
*GET,S1_Y,NODE,3,EPCR,Y
R7=1.00
SET,2,2
*GET,S2_Y,NODE,3,EPCR,Y
R8=S2_Y/(-1.0)
```

```
SET,2,4
*GET,S3_Y,NODE,3,EPCR,Y
R9=S3_Y/(-2.0)
SET,2,6
*GET,S4_Y,NODE,3,EPCR,Y
R10=S4_Y/(-3.0)
SET,2,8
*GET,S5_Y,NODE,3,EPCR,Y
R11=S5_Y/(-4.0)
SET,2,10
*GET,S6_Y,NODE,3,EPCR,Y
R12=S6_Y/(-5.0)
LABEL(1) = '0','200','400','600','800','1000'
*VFILL,VALUE(1,4),DATA,0,-1,-2,-3,-4,-5
*VFILL,VALUE(1,5),DATA,S1_Y,S2_Y,S3_Y,S4_Y,S5_Y,S6_Y
*VFILL,VALUE(1,6),DATA,R7,R8,R9,R10,R11,R12
*ENDIF
*IF,I,EQ,2,THEN
/COM,
/COM,  ANISOTROPIC CREEP MODELED AS ISOTROPIC /COM,
/POST26
ESOL,3,1,,EPCR,X
ESOL,4,1,,EPCR,Y
PRVAR,2
/AXLAB,X,TIME
/AXLAB,Y,ANISOTROPIC CREEP STRAIN
/COLOR,CURVE,BLUE,1
/YRANGE,-5,10
PLVAR,3,4
FINISH
/POST1
SET,1,1
*GET,S11,NODE,3,EPCR,X
R11=1.00
SET,2,2
*GET,S22,NODE,3,EPCR,X
R22=S22/2
SET,2,4
*GET,S33,NODE,3,EPCR,X
R33=S33/4
SET,2,6
*GET,S44,NODE,3,EPCR,X
R44=S44/6
SET,2,8
*GET,S55,NODE,3,EPCR,X
R55=S55/8
SET,2,10
*GET,S66,NODE,3,EPCR,X
R66=S66/10
*DIM,VALUE2,,6,6
*VFILL,VALUE2(1,1),DATA,0,2,4,6,8,10
*VFILL,VALUE2(1,2),DATA,S11,S22,S33,S44,S55,S66
*VFILL,VALUE2(1,3),DATA,R11,R22,R33,R44,R55,R66
SET,1,1
*GET,S11_Y,NODE,3,EPCR,Y
R77=1.00
SET,2,2
*GET,S22_Y,NODE,3,EPCR,Y
R88=S22_Y/(-1.0)
SET,2,4
*GET,S33_Y,NODE,3,EPCR,Y
R99=S33_Y/(-2.0)
SET,2,6
*GET,S44_Y,NODE,3,EPCR,Y
R100=S44_Y/(-3.0)
SET,2,8
*GET,S55_Y,NODE,3,EPCR,Y
R111=S55_Y/(-4.0)
SET,2,10
*GET,S66_Y,NODE,3,EPCR,Y
R122=S66_Y/(-5.0)
LABEL(1) = '0','200','400','600','800','1000'
```

```
*VFILL,VALUE2(1,4),DATA,0,-1,-2,-3,-4,-5
*VFILL,VALUE2(1,5),DATA,S11_Y,S22_Y,S33_Y,S44_Y,S55_Y,S66_Y
*VFILL,VALUE2(1,6),DATA,R77,R88,R99,R100,R111,R122
*ENDIF
*ENDDO
/COM,
/COM,
/COM,------------- vmr049-cr1a-281 ISOTROPIC RESULTS COMPARISON --------------
/COM,
/COM, vmr049-cr1a-281.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS.  THE RESULTS DISPLAYED ARE INCREMENTED /COM, FOR THIS PURPOSE.
/COM,
/COM,
/COM,|  TIME  |  TARGET X  |  Mechanical APDL  |  RATIO  |  TARGET Y  |  Mechanical APDL  | RATIO
/COM,
*VWRITE,LABEL(1), VALUE(1,1), VALUE(1,2), VALUE(1,3), VALUE(1,4),VALUE(1,5), VALUE(1,6)
(1X,A8,'   ',F8.3,'   ',F8.3,'   ',F14.3,'   ',1F14.3,'   ',F8.3,'   ',F10.3,'   ')
/COM,
/COM,
/COM,------------ vmr049-cr1a-281 ANISOTROPIC RESULTS COMPARISON -------------
/COM,
/COM,
/COM,|  TIME  |  TARGET X  |  Mechanical APDL  |  RATIO  |  TARGET Y  |  Mechanical APDL  | RATIO
/COM,
*VWRITE,LABEL(1), VALUE2(1,1), VALUE2(1,2), VALUE2(1,3), VALUE2(1,4),VALUE2(1,5), VALUE2(1,6)
(1X,A8,'   ',F8.3,'   ',F8.3,'   ',F14.3,'   ',1F14.3,'   ',F8.3,'   ',F10.3,'   ')
FINISH
/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR2X ',' ECR2Y '
*VFILL,VALUE1(1,1),DATA,S6,S6_Y
*VFILL,VALUE1(1,2),DATA,R6,R12
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr1a-281'
/OUT,vmr049-cr1a-281,vrt
/COM
/COM,------------------- vmr049-cr1a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr049-cr1a-281,vrt
/OUT,SCRATCH
```

VM-R049-1B 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr1b-181
/TITLE,vmr049-cr1b-181,CONSTANT-LOAD CREEP BENCHMARK
/COM, REFERENCE: TEST CR-1B FROM NAFEMS REPORT R0049.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
```

```
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
ET,1,181,,,
R,1,1,1,1,1,
E,1,2,3,4
E,4,3,5,6
NSEL,S,LOC,X,
D,ALL,UX,
D,ALL,ROTX
NSEL,ALL
NSEL,S,,,4
D,ALL,UY,
D,ALL,ROTY
NSEL,ALL
D,ALL,ROTZ
D,ALL,UZ

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
SOLVE
RATE, ON, ON
DELT,100,99,101
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
PLVAR,2,3
FINISH

/POST1
SET,,,,,,,1
*GET,S1,NODE,3,EPCR,X
*GET,S1_Y,NODE,3,EPCR,Y
R1=1.00
R7=1.00
SET,,,,,,,3
*GET,S2,NODE,3,EPCR,X
*GET,S2_Y,NODE,3,EPCR,Y
R2=S2/0.854E-1
R8=S2_Y/(-0.427E-1)
SET,,,,,,,5
*GET,S3,NODE,3,EPCR,X
*GET,S3_Y,NODE,3,EPCR,Y
R3=S3/0.1396
R9=S3_Y/(-0.698E-1)
SET,,,,,,,7
*GET,S4,NODE,3,EPCR,X
```

```
*GET,S4_Y,NODE,3,EPCR,Y
R4=S4/0.183
R10=S4_Y/(-0.9133E-1)
SET,,,,,,,9
*GET,S5,NODE,3,EPCR,X
*GET,S5_Y,NODE,3,EPCR,Y
R5=S5/0.219
R11=S5_Y/(-0.1097)
SET,,,,,,,11
*GET,S6,NODE,3,EPCR,X
*GET,S6_Y,NODE,3,EPCR,Y
R6=S6/0.251
R12=S6_Y/(-0.125)
*DIM,VALUE,,6,4
*DIM,LABEL,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,RATIO,,6,4
LABEL(1) = '0','200','400','600','800','1000'
TARGETX(1) = '0.50E-6','0.0854','0.1396','0.183','0.219','0.251'
TARGETY(1) = '-0.25E-6','-0.0427','-0.0698','-0.09133','-0.1097','-0.125'
*VFILL,VALUE(1,1),DATA,S1,S2,S3,S4,S5,S6
*VFILL,VALUE(1,2),DATA,R1,R2,R3,R4,R5,R6
*VFILL,VALUE(1,3),DATA,S1_Y,S2_Y,S3_Y,S4_Y,S5_Y,S6_Y
*VFILL,VALUE(1,4),DATA,R7,R8,R9,R10,R11,R12
/COM
/COM
/COM,--------- vmr049-cr1b-181 RESULTS COMPARISON-----------
/COM,
/COM, vmr049-cr1b-181.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 100,FIGURE 3.7(B). THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE
/COM,
/COM,-------- CREEP COMPONENT IN X DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),TARGETX(1), VALUE(1,1), VALUE(1,2)
(1X,A6,'   ',1X,A9,'   ',F14.5,'   ',F12.3,'   ')
/COM,
/COM,-------- CREEP COMPONENT IN Y DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),TARGETY(1), VALUE(1,3), VALUE(1,4)
(1X,A6,'   ',1X,A9,'   ',F14.5,'   ',F12.3,'   ')
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR2X ',' ECR2Y '
*VFILL,VALUE1(1,1),DATA,S6,S6_Y
*VFILL,VALUE1(1,2),DATA,R6,R12
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr1b-181'

/OUT,vmr049-cr1b-181,vrt
/COM
/COM,------------------- vmr049-cr1b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE181
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT
```

```
FINISH
*LIST,vmr049-cr1b-181,vrt
```

VM-R049-1B 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr1b-182
/TITLE,vmr049-cr1b-182,CONSTANT-LOAD CREEP BENCHMARK
/COM, REFERENCE: TEST CR-1B FROM NAFEMS REPORT R0049.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
ET,1,182
KEYOPT,1,1,1
KEYOPT,1,3,0
E,1,2,3,4
E,4,3,5,6
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,,,4
D,ALL,UY,
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
SOLVE
RATE, ON, ON
DELT,100,99,101
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
PLVAR,2,3
FINISH
```

```
/POST1
SET,,,,,,,1
*GET,S1,NODE,3,EPCR,X
*GET,S1_Y,NODE,3,EPCR,Y
R1=1.00
R7=1.00
SET,,,,,,,3
*GET,S2,NODE,3,EPCR,X
*GET,S2_Y,NODE,3,EPCR,Y
R2=S2/0.854E-1
R8=S2_Y/(-0.427E-1)
SET,,,,,,,5
*GET,S3,NODE,3,EPCR,X
*GET,S3_Y,NODE,3,EPCR,Y
R3=S3/0.1396
R9=S3_Y/(-0.698E-1)
SET,,,,,,,7
*GET,S4,NODE,3,EPCR,X
*GET,S4_Y,NODE,3,EPCR,Y
R4=S4/0.183
R10=S4_Y/(-0.9133E-1)
SET,,,,,,,9
*GET,S5,NODE,3,EPCR,X
*GET,S5_Y,NODE,3,EPCR,Y
R5=S5/0.219
R11=S5_Y/(-0.1097)
SET,,,,,,,11
*GET,S6,NODE,3,EPCR,X
*GET,S6_Y,NODE,3,EPCR,Y
R6=S6/0.251
R12=S6_Y/(-0.125)
*DIM,VALUE,,6,4
*DIM,LABEL,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,RATIO,,6,4
LABEL(1) = '0','200','400','600','800','1000'
TARGETX(1) = '0.50E-6','0.0854','0.1396','0.183','0.219','0.251'
TARGETY(1) = '-0.25E-6','-0.0427','-0.0698','-0.09133','-0.1097','-0.125'
*VFILL,VALUE(1,1),DATA,S1,S2,S3,S4,S5,S6
*VFILL,VALUE(1,2),DATA,R1,R2,R3,R4,R5,R6
*VFILL,VALUE(1,3),DATA,S1_Y,S2_Y,S3_Y,S4_Y,S5_Y,S6_Y
*VFILL,VALUE(1,4),DATA,R7,R8,R9,R10,R11,R12
/COM
/COM
/COM,--------- vmr049-cr1b-182 RESULTS COMPARISON-----------
/COM,
/COM, vmr049-cr1b-182.grph RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 100,FIGURE 3.7(B). THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE
/COM,
/COM,-------- CREEP COMPONENT IN X DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),TARGETX(1), VALUE(1,1), VALUE(1,2)
(1X,A6,'   ',1X,A9,'   ',F14.5,'   ',F12.3,'   ')
/COM,
/COM,-------- CREEP COMPONENT IN Y DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),TARGETY(1), VALUE(1,3), VALUE(1,4)
(1X,A6,'   ',1X,A9,'   ',F14.5,'   ',F12.3,'   ')
FINISH

/POST26
/COM,ESOL,2,1,,EPCR,X
/COM,ESOL,3,1,,EPCR,Y
/COM,PRVAR,2,3
/COM,PLVAR,2,3
```

```
/COM,*GET,RES1X,VARI,2,RTIME,1000
/COM,*GET,RES1Y,VARI,3,RTIME,1000

*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR2X ',' ECR2Y '
*VFILL,VALUE1(1,1),DATA,S6,S6_Y
*VFILL,VALUE1(1,2),DATA,R6,R12
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr1b-182'

/OUT,vmr049-cr1b-182,vrt
/COM
/COM,------------------- vmr049-cr1b RESULTS COMPARISON ---------------------
/COM,
/COM,             |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'       ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'       ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr1b-182,vrt
```

VM-R049-1B 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr1b-183
/TITLE,vmr049-cr1b-183,CONSTANT-LOAD CREEP BENCHMARK
/COM, REFERENCE: TEST CR-1B FROM NAFEMS REPORT R0049.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183
KEYOPT,1,3,0
E,1,2,3,4,5,6,7,8
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,,,8
D,ALL,UY,
```

```
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUT,SCRATCH
SOLVE
RATE, ON, ON
DELT,100,99,101
TIME,1000
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
PLVAR,2,3
FINISH

/POST1
SET,,,,,,,1
*GET,S1,NODE,3,EPCR,X
*GET,S1_Y,NODE,3,EPCR,Y
R1=1.00
R7=1.00
SET,,,,,,,3
*GET,S2,NODE,3,EPCR,X
*GET,S2_Y,NODE,3,EPCR,Y
R2=S2/0.854E-1
R8=S2_Y/(-0.427E-1)
SET,,,,,,,5
*GET,S3,NODE,3,EPCR,X
*GET,S3_Y,NODE,3,EPCR,Y
R3=S3/0.1396
R9=S3_Y/(-0.698E-1)
SET,,,,,,,7
*GET,S4,NODE,3,EPCR,X
*GET,S4_Y,NODE,3,EPCR,Y
R4=S4/0.183
R10=S4_Y/(-0.9133E-1)
SET,,,,,,,9
*GET,S5,NODE,3,EPCR,X
*GET,S5_Y,NODE,3,EPCR,Y
R5=S5/0.219
R11=S5_Y/(-0.1097)
SET,,,,,,,11
*GET,S6,NODE,3,EPCR,X
*GET,S6_Y,NODE,3,EPCR,Y
R6=S6/0.251
R12=S6_Y/(-0.125)
*DIM,VALUE,,6,4
*DIM,LABEL,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,RATIO,,6,4
LABEL(1) = '0','200','400','600','800','1000'
TARGETX(1) = '0.50E-6','0.0854','0.1396','0.183','0.219','0.251'
TARGETY(1) = '-0.25E-6','-0.0427','-0.0698','-0.09133','-0.1097','-0.125'
*VFILL,VALUE(1,1),DATA,S1,S2,S3,S4,S5,S6
*VFILL,VALUE(1,2),DATA,R1,R2,R3,R4,R5,R6
*VFILL,VALUE(1,3),DATA,S1_Y,S2_Y,S3_Y,S4_Y,S5_Y,S6_Y
*VFILL,VALUE(1,4),DATA,R7,R8,R9,R10,R11,R12
/COM
```

```
/COM
/COM,--------- vmr049-cr1b-183 RESULTS COMPARISON-----------
/COM,
/COM, vmr049-cr1b-183.grph RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 100,FIGURE 3.7(B). THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE
/COM,
/COM,-------- CREEP COMPONENT IN X DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),TARGETX(1), VALUE(1,1), VALUE(1,2)
(1X,A6,'   ',1X,A9,'   ',F14.5,'   ',F12.3,'   ')
/COM,
/COM,-------- CREEP COMPONENT IN Y DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),TARGETY(1), VALUE(1,3), VALUE(1,4)
(1X,A6,'   ',1X,A9,'   ',F14.5,'   ',F12.3,'   ')
FINISH

/POST26
/COM,ESOL,2,1,,EPCR,X
/COM,ESOL,3,1,,EPCR,Y
/COM,PRVAR,2,3
/COM,PLVAR,2,3
/COM,*GET,RES1X,VARI,2,RTIME,1000
/COM,*GET,RES1Y,VARI,3,RTIME,1000

*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR2X ',' ECR2Y '
*VFILL,VALUE1(1,1),DATA,S6,S6_Y
*VFILL,VALUE1(1,2),DATA,R6,R12
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr1b-183'

/OUT,vmr049-cr1b-183,vrt
/COM
/COM,------------------- vmr049-cr1b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr1b-183,vrt
```

VM-R049-1B 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr1b-281
/TITLE,vmr049-cr1b-281,CONSTANT-LOAD CREEP BENCHMARK
/COM, REFERENCE: TEST CR-1B FROM NAFEMS REPORT R0049.
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
```

```
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
N,7,50,0
N,8,100,25
N,9,50,50
N,10,0,25
N,11,100,75
N,12,50,100
N,13,0,75
ET,1,SHELL281,,,
R,1,1,1,1,1,
E,1,2,3,4,7,8,9,10
E,4,3,5,6,9,11,12,13
NSEL,S,LOC,X,
D,ALL,UX,
D,ALL,ROTX
NSEL,ALL
NSEL,S,,,4
D,ALL,UY,
D,ALL,ROTY
NSEL,ALL
D,ALL,ROTZ
D,ALL,UZ
/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUT,SCRATCH
SOLVE
RATE, ON, ON
DELT,100,99,101
TIME,1000
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH
/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
PLVAR,2,3
FINISH
/POST1
SET,,,,,,,1
*GET,S1,NODE,3,EPCR,X
*GET,S1_Y,NODE,3,EPCR,Y
R1=1.00
R7=1.00
SET,,,,,,,3
*GET,S2,NODE,3,EPCR,X
*GET,S2_Y,NODE,3,EPCR,Y
R2=S2/0.854E-1
R8=S2_Y/(-0.427E-1)
SET,,,,,,,5
```

```
*GET,S3,NODE,3,EPCR,X
*GET,S3_Y,NODE,3,EPCR,Y
R3=S3/0.1396
R9=S3_Y/(-0.698E-1)
SET,,,,,,,7
*GET,S4,NODE,3,EPCR,X
*GET,S4_Y,NODE,3,EPCR,Y
R4=S4/0.183
R10=S4_Y/(-0.9133E-1)
SET,,,,,,,9
*GET,S5,NODE,3,EPCR,X
*GET,S5_Y,NODE,3,EPCR,Y
R5=S5/0.219
R11=S5_Y/(-0.1097)
SET,,,,,,,11
*GET,S6,NODE,3,EPCR,X
*GET,S6_Y,NODE,3,EPCR,Y
R6=S6/0.251
R12=S6_Y/(-0.125)
*DIM,VALUE,,6,4
*DIM,LABEL,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,RATIO,,6,4
LABEL(1) = '0','200','400','600','800','1000'
TARGETX(1) = '0.50E-6','0.0854','0.1396','0.183','0.219','0.251'
TARGETY(1) = '-0.25E-6','-0.0427','-0.0698','-0.09133','-0.1097','-0.125'
*VFILL,VALUE(1,1),DATA,S1,S2,S3,S4,S5,S6
*VFILL,VALUE(1,2),DATA,R1,R2,R3,R4,R5,R6
*VFILL,VALUE(1,3),DATA,S1_Y,S2_Y,S3_Y,S4_Y,S5_Y,S6_Y
*VFILL,VALUE(1,4),DATA,R7,R8,R9,R10,R11,R12
/COM
/COM
/COM,--------- vmr049-cr1b-281 RESULTS COMPARISON-----------
/COM,
/COM, vmr049-cr1b-281.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 100,FIGURE 3.7(B). THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE
/COM,
/COM,-------- CREEP COMPONENT IN X DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),TARGETX(1), VALUE(1,1), VALUE(1,2)
(1X,A6,'   ',1X,A9,'   ',F14.5,'   ',F12.3,'   ')
/COM,
/COM,-------- CREEP COMPONENT IN Y DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),TARGETY(1), VALUE(1,3), VALUE(1,4)
(1X,A6,'   ',1X,A9,'   ',F14.5,'   ',F12.3,'   ')
FINISH
/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR2X ',' ECR2Y '
*VFILL,VALUE1(1,1),DATA,S6,S6_Y
*VFILL,VALUE1(1,2),DATA,R6,R12
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr1b-281'
/OUT,vmr049-cr1b-281,vrt
/COM
/COM,------------------- vmr049-cr1b RESULTS COMPARISON --------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F12.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F12.4,'      ',F9.4,'     ',A7,A8)
```

```
/COM,
/COM,---------------------------------------------------------------
/OUT
FINISH
*LIST,vmr049-cr1b-281,vrt
```

VM-R049-1C 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr1c-181
/TITLE,vmr049-cr1c-181,CONSTANT-LOAD CREEP BENCHMARK
/COM, REFERENCE: TEST CR-1C FROM NAFEMS R0049.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,0.5E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
*SET,C5,1E-16
*SET,C6,5
*SET,C7,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,11
TBDATA,1,C1,C2,C3,C4,C5,C6,C6
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
ET,1,181
R,1,1,1,1,1,
E,1,2,3,4
E,4,3,5,6
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,,,4
D,ALL,UY,
NSEL,ALL
D,ALL,UZ
D,ALL,ROTZ
FINISH

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-100
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUT,SCRATCH
SOLVE
RATE, ON, ON
DELT,100,99,101
TIME,1000
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH
```

```
/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
PLVAR,2,3
FINISH

/POST1
SET,,,,,,,1
*GET,S1,NODE,3,EPCR,X
*GET,S1_Y,NODE,3,EPCR,Y
R1=1.00
R7=1.00
SET,,,,,,,3
*GET,S2,NODE,3,EPCR,X
*GET,S2_Y,NODE,3,EPCR,Y
R2=S2/0.1614E-2
R8=S2_Y/(-0.807E-3)
SET,,,,,,,5
*GET,S3,NODE,3,EPCR,X
*GET,S3_Y,NODE,3,EPCR,Y
R3=S3/0.2407E-2
R9=S3_Y/(-0.1203E-2)
SET,,,,,,,7
*GET,S4,NODE,3,EPCR,X
*GET,S4_Y,NODE,3,EPCR,Y
R4=S4/0.3055E-2
R10=S4_Y/(-0.15275E-2)
SET,,,,,,,9
*GET,S5,NODE,3,EPCR,X
*GET,S5_Y,NODE,3,EPCR,Y
R5=S5/0.36339E-2
R11=S5_Y/(-0.18172E-2)
SET,,,,,,,11
*GET,S6,NODE,3,EPCR,X
*GET,S6_Y,NODE,3,EPCR,Y
R6=S6/0.41475E-2
R12=S6_Y/(-0.2074E-2)
*DIM,VALUE,,6,4
*DIM,LABEL,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,RATIO,,6,4
LABEL(1) = '0','200','400','600','800','1000'
TARGETX(1) = '0.100E-7','0.001614','0.002407','0.003055','0.0036339','0.0041475'
TARGETY(1) = '-0.50E-8','-0.000807','-0.001203','-0.001528','-0.001817','-0.002074'
*VFILL,VALUE(1,1),DATA,S1,S2,S3,S4,S5,S6
*VFILL,VALUE(1,2),DATA,R1,R2,R3,R4,R5,R6
*VFILL,VALUE(1,3),DATA,S1_Y,S2_Y,S3_Y,S4_Y,S5_Y,S6_Y
*VFILL,VALUE(1,4),DATA,R7,R8,R9,R10,R11,R12
/COM
/COM
/COM,--------- vmr049-cr1c-181 RESULTS COMPARISON-----------
/COM,
/COM, vmr049-cr1c-181.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 100 ,FIGURE 3.7C. THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE
/COM,
/COM,-------- CREEP COMPONENT IN X DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),TARGETX(1), VALUE(1,1), VALUE(1,2)
(1X,A6,'   ',1X,A8,'   ',F14.5,'   ',F12.3,'   ')
/COM,
/COM,-------- CREEP COMPONENT IN Y DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
```

```
*VWRITE,LABEL(1),TARGETY(1), VALUE(1,3), VALUE(1,4)
(1X,A6,'   ',1X,A8,'   ',F14.5,'   ',F12.3,'   ')
FINISH

/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR11X ',' ECR11Y '
*VFILL,VALUE1(1,1),DATA,S6,S6_Y
*VFILL,VALUE1(1,2),DATA,R6,R12
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr1c-181'

/OUT,vmr049-cr1c-181,vrt
/COM
/COM,------------------- vmr049-cr1c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE181
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr1c-181,vrt
```

VM-R049-1C 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr1c-182
/TITLE,vmr049-cr1c-182,CONSTANT LOAD CREEP BENCHMARK
/COM, REFERENCE: TEST CR-1C FROM NAFEMS R0049.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,0.5E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
*SET,C5,1E-16
*SET,C6,5
*SET,C7,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,11
TBDATA,1,C1,C2,C3,C4,C5,C6,C6
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
ET,1,182
KEYOPT,1,1,0
KEYOPT,1,3,0
E,1,2,3,4
E,4,3,5,6
```

```
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,,,4
D,ALL,UY,
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-100
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
SOLVE
RATE, ON, ON
DELT,100,99,101
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH


/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
PLVAR,2,3
*GET,RES1X,VARI,2,RTIME,1000
*GET,RES1Y,VARI,3,RTIME,1000

*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR11X ',' ECR11Y '
*VFILL,VALUE1(1,1),DATA,4.2691,-4.2691
*VFILL,VALUE1(1,1),DATA,RES1X,RES1Y
*VFILL,VALUE1(1,2),DATA,ABS(RES1X/0.0041475),ABS(RES1Y/(-0.002074))
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr1c-182'

/OUT,vmr049-cr1c-182,vrt
/COM
/COM,------------------- vmr049-cr1c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr1c-182,vrt
```

VM-R049-1C 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr1c-183
/TITLE,vmr049-cr1c-183,CONSTANT-LOAD CREEP BENCHMARK
/COM, REFERENCE: TEST CR-1C FROM NAFEMS R0049.

/PREP7
```

```
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,0.5E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
*SET,C5,1E-16
*SET,C6,5
*SET,C7,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,11
TBDATA,1,C1,C2,C3,C4,C5,C6,C6
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183
KEYOPT,1,3,0
E,1,2,3,4,5,6,7,8
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,,,8
D,ALL,UY,
NSEL,ALL

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-100
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8

SOLVE
RATE, ON, ON
DELT,100,99,101
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
PLVAR,2,3
FINISH

/POST1
SET,,,,,,,1
*GET,S1,NODE,3,EPCR,X
*GET,S1_Y,NODE,3,EPCR,Y
R1=S1/0.100E-7
R7=S1_Y/(-0.500E-8)
SET,,,,,,,3
*GET,S2,NODE,3,EPCR,X
*GET,S2_Y,NODE,3,EPCR,Y
```

```
R2=S2/0.1614E-2
R8=S2_Y/(-0.807E-3)
SET,,,,,,,5
*GET,S3,NODE,3,EPCR,X
*GET,S3_Y,NODE,3,EPCR,Y
R3=S3/0.2407E-2
R9=S3_Y/(-0.1203E-2)
SET,,,,,,,7
*GET,S4,NODE,3,EPCR,X
*GET,S4_Y,NODE,3,EPCR,Y
R4=S4/0.3055E-2
R10=S4_Y/(-0.15275E-2)
SET,,,,,,,9
*GET,S5,NODE,3,EPCR,X
*GET,S5_Y,NODE,3,EPCR,Y
R5=S5/0.36339E-2
R11=S5_Y/(-0.18172E-2)
SET,,,,,,,11
*GET,S6,NODE,3,EPCR,X
*GET,S6_Y,NODE,3,EPCR,Y
R6=S6/0.41475E-2
R12=S6_Y/(-0.2074E-2)
*DIM,VALUE,,6,4
*DIM,LABEL,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,RATIO,,6,4
LABEL(1) = '0','200','400','600','800','1000'
TARGETX(1) = '0.100E-7','0.001614','0.002407','0.003055','0.0036339','0.0041475'
TARGETY(1) = '-0.50E-8','-0.000807','-0.001203','-0.001528','-0.001817','-0.002074'
*VFILL,VALUE(1,1),DATA,S1,S2,S3,S4,S5,S6
*VFILL,VALUE(1,2),DATA,R1,R2,R3,R4,R5,R6
*VFILL,VALUE(1,3),DATA,S1_Y,S2_Y,S3_Y,S4_Y,S5_Y,S6_Y
*VFILL,VALUE(1,4),DATA,R7,R8,R9,R10,R11,R12
/COM
/COM
/COM,--------- vmr049-cr1c-183 RESULTS COMPARISON-----------
/COM,
/COM, vmr049-cr1c-183.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 100 ,FIGURE 3.7C. THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE
/COM,
/COM,-------- CREEP COMPONENT IN X DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),TARGETX(1), VALUE(1,1), VALUE(1,2)
(1X,A6,'   ',1X,A8,'   ',F14.5,'   ',F12.3,'   ')
/COM,
/COM,-------- CREEP COMPONENT IN Y DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),TARGETY(1), VALUE(1,3), VALUE(1,4)
(1X,A6,'   ',1X,A8,'   ',F14.5,'   ',F12.3,'   ')
FINISH

/POST26
/COM,ESOL,2,1,,EPCR,X
/COM,ESOL,3,1,,EPCR,Y
/COM,PRVAR,2,3
/COM,PLVAR,2,3
/COM,*GET,RES1X,VARI,2,RTIME,1000
/COM,*GET,RES1Y,VARI,3,RTIME,1000

*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR11X ',' ECR11Y '
*VFILL,VALUE1(1,1),DATA,S6,S6_Y
*VFILL,VALUE1(1,2),DATA,R6,R12
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr1c-183'
```

```
/OUT,vmr049-cr1c-183,vrt
/COM
/COM,------------------- vmr049-cr1c RESULTS COMPARISON ---------------------
/COM,
/COM,             |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'       ',F14.4,'       ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'       ',F14.4,'       ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr1c-183,vrt
```

VM-R049-1C 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr1c-281
/TITLE,vmr049-cr1c-281,CONSTANT-LOAD CREEP BENCHMARK
/COM, REFERENCE: TEST CR-1C FROM NAFEMS R0049.
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,0.5E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
*SET,C5,1E-16
*SET,C6,5
*SET,C7,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,11
TBDATA,1,C1,C2,C3,C4,C5,C6,C6
SAVE
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
N,7,50,0
N,8,100,25
N,9,50,50
N,10,0,25
N,11,100,75
N,12,50,100
N,13,0,75
ET,1,SHELL281
R,1,1,1,1,1,
E,1,2,3,4,7,8,9,10
E,4,3,5,6,9,11,12,13
NSEL,ALL
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,,,4
D,ALL,UY,
NSEL,ALL
```

```
D,ALL,UZ
D,ALL,ROTZ
FINISH
/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-100
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
SOLVE
RATE, ON, ON
DELT,100,99,101
TIME,1000
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH
/POST26
ESOL,2,1,,EPCR,X
ESOL,3,1,,EPCR,Y
PRVAR,2,3
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN
PLVAR,2,3
FINISH
/POST1
SET,,,,,,,1
*GET,S1,NODE,3,EPCR,X
*GET,S1_Y,NODE,3,EPCR,Y
R1=1.00
R7=1.00
SET,,,,,,,3
*GET,S2,NODE,3,EPCR,X
*GET,S2_Y,NODE,3,EPCR,Y
R2=S2/0.1614E-2
R8=S2_Y/(-0.807E-3)
SET,,,,,,,5
*GET,S3,NODE,3,EPCR,X
*GET,S3_Y,NODE,3,EPCR,Y
R3=S3/0.2407E-2
R9=S3_Y/(-0.1203E-2)
SET,,,,,,,7
*GET,S4,NODE,3,EPCR,X
*GET,S4_Y,NODE,3,EPCR,Y
R4=S4/0.3055E-2
R10=S4_Y/(-0.15275E-2)
SET,,,,,,,9
*GET,S5,NODE,3,EPCR,X
*GET,S5_Y,NODE,3,EPCR,Y
R5=S5/0.36339E-2
R11=S5_Y/(-0.18172E-2)
SET,,,,,,,11
*GET,S6,NODE,3,EPCR,X
*GET,S6_Y,NODE,3,EPCR,Y
R6=S6/0.41475E-2
R12=S6_Y/(-0.2074E-2)
*DIM,VALUE,,6,4
*DIM,LABEL,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,RATIO,,6,4
LABEL(1) = '0','200','400','600','800','1000'
TARGETX(1) = '0.100E-7','0.001614','0.002407','0.003055','0.0036339','0.0041475'
TARGETY(1) = '-0.50E-8','-0.000807','-0.001203','-0.001528','-0.001817','-0.002074'
*VFILL,VALUE(1,1),DATA,S1,S2,S3,S4,S5,S6
*VFILL,VALUE(1,2),DATA,R1,R2,R3,R4,R5,R6
*VFILL,VALUE(1,3),DATA,S1_Y,S2_Y,S3_Y,S4_Y,S5_Y,S6_Y
*VFILL,VALUE(1,4),DATA,R7,R8,R9,R10,R11,R12
/COM
/COM,--------- vmr049-cr1c-281 RESULTS COMPARISON-----------
```

```
/COM,
/COM, vmr049-cr1c-281.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 100 ,FIGURE 3.7C. THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE
/COM,
/COM,-------- CREEP COMPONENT IN X DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),TARGETX(1), VALUE(1,1), VALUE(1,2)
(1X,A6,'   ',1X,A8,'   ',F14.5,'   ',F12.3,'   ')
/COM,
/COM,-------- CREEP COMPONENT IN Y DIRECTION ---------
/COM,
/COM,| TIME |   TARGET  |    Mechanical APDL   |    RATIO
/COM,
*VWRITE,LABEL(1),TARGETY(1), VALUE(1,3), VALUE(1,4)
(1X,A6,'   ',1X,A8,'   ',F14.5,'   ',F12.3,'   ')
FINISH
/POST26
*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' ECR11X ',' ECR11Y '
*VFILL,VALUE1(1,1),DATA,S6,S6_Y
*VFILL,VALUE1(1,2),DATA,R6,R12
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr1c-281'
/OUT,vmr049-cr1c-281,vrt
/COM
/COM,------------------- vmr049-cr1c RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,---------------------------------------------------------------
/OUT
FINISH
*LIST,vmr049-cr1c-281,vrt
```

VM-R049-2 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr2-181
/TITLE,vmr049-cr2-181,CONSTANT-DISPLACEMENT CREEP BENCHMARK
/COM, REFERENCE: TEST CR-2A FROM NAFEMS REPORT 0049.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (TIME HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5.0
*SET,C3,-0.5
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (STRAIN HARDENING)!***
*SET,C1,1.5625E-14
```

```
*SET,C2,5
*SET,C3,-0.5
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3
SAVE
/PREP7
N,1
N,2,100
N,3,100,100
N,4,0,100
ET,1,181,,,
R,1,1,1,1,1,
E,1,2,3,4
NSEL,ALL
D,ALL,UZ,
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,S,LOC,Y,100
D,ALL,UY,0.1
NSEL,ALL
*DO,I,1,2
*STATUS,I

/PREP7
*IF,I,EQ,1,THEN
MAT,1
*ELSEIF,I,EQ,2,THEN
MPCHG,2,ALL
*ENDIF
FINI

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE

/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
```

```
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH

OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

/POST26
*IF,I,EQ,1,THEN
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,5
/GROPT,DIVY,6
/XRANGE,0,1000
/YRANGE,0,300
ESOL,2,1,,S,EQV,TIMEHARD
PRVAR,2
/COLOR,CURVE,BMAG,1
/AXLAB,X,TIME
/AXLAB,Y,STRESS
PLVAR,2
/NOERASE

/POST1
SET,1,1
*GET,SH1,NODE,3,S,X
R1=SH1/285.714
SET,6,19
*GET,SH2,NODE,3,S,X
R2=SH2/46.612
SET,6,39
*GET,SH3,NODE,3,S,X
R3=SH3/42.206
SET,6,59
*GET,SH4,NODE,3,S,X
R4=SH4/39.893
SET,6,79
*GET,SH5,NODE,3,S,X
R5=SH5/38.353
SET,6,99
*GET,SH6,NODE,3,S,X
R6=SH6/37.211
*DIM,VALUE,,6,3
*DIM,LABEL,CHAR,10
*DIM,TARGET,CHAR,10
*DIM,RATIO,,6,4
LABEL(1) = '0','200.0','400.0','600.0','800.0','1000'
TARGET(1) = '285.714','46.612','42.206','39.893','38.353','37.211'
*VFILL,VALUE(1,1),DATA,SH1,SH2,SH3,SH4,SH5,SH6
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6

*ELSEIF,I,EQ,2,THEN
ESOL,3,1,,S,EQV,STRAINHA
PRVAR,3
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/YRANGE,0,300
/COLOR,CURVE,BLUE,1
```

```
PLVAR,3

/POST1
SET,1,1
*GET,SH1_1,NODE,3,S,X
R7=SH1_1/285.714
SET,6,19
*GET,SH2_1,NODE,3,S,X
R8=SH2_1/62.014
SET,6,39
*GET,SH3_1,NODE,3,S,X
R9=SH3_1/57.251
SET,6,59
*GET,SH4_1,NODE,3,S,X
R10=SH4_1/54.690
SET,6,79
*GET,SH5_1,NODE,3,S,X
R11=SH5_1/52.959
SET,6,99
*GET,SH6_1,NODE,3,S,X
R12=SH6_1/51.661
*DIM,VALUE1,,6,3
*DIM,LABEL1,CHAR,10
*DIM,TARGET1,CHAR,10
*DIM,RATIO1,,6,3
LABEL1(1) = '0','200.0','400.0','600.0','800.0','1000'
TARGET1(1) = '285.714','62.014','57.251','54.690','52.959','51.661'
*VFILL,VALUE1(1,1),DATA,SH1_1,SH2_1,SH3_1,SH4_1,SH5_1,SH6_1
*VFILL,RATIO1(1,1),DATA,R7,R8,R9,R10,R11,R12
/COM
/COM,--------- vmr049-cr2-181 STRESS RESULTS COMPARISON (TIME HARDENING)-----------
/COM,
/COM, COMPARE NUMERICAL VALUES LISTED BELOW WITH FIGURE 3.10(A)
/COM, ON PAGE 103 AS NO NUMERICAL RESULTS ARE PRESENTED.
/COM,
/COM,|   TIME   |   TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,LABEL(1), TARGET(1), VALUE(1,1), RATIO(1,1)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',1F12.3)
/COM,
/COM,
/COM,--------- vmr049-cr2-181 STRESS RESULTS COMPARISON (STRAIN HARDENING)-----------
/COM,
/COM,|   TIME   |   TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,LABEL(1), TARGET1(1), VALUE1(1,1), RATIO1(1,1)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',1F12.3)
*ENDIF
*ENDDO
FINISH

/POST26
*DIM,LABEL2,CHAR,2
*DIM,VALUE2,,2,3
LABEL2(1) = ' S6 ',' S7 '
*VFILL,VALUE2(1,1),DATA,SH6,SH6_1
*VFILL,VALUE2(1,2),DATA,R6,R12
*DIM,LABEL3,CHAR,2
LABEL3(1) = 'vmr049-','cr2-181'

/OUT,vmr049-cr2-181,vrt
/COM
/COM,------------------- vmr049-cr2 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL2(1),VALUE2(1,1),VALUE2(1,2),LABEL3(1),LABEL3(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL2(2),VALUE2(2,1),VALUE2(2,2),LABEL3(1),LABEL3(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
```

```
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr2-181,vrt
```

VM-R049-2 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr2-182
/TITLE,vmr049-cr2-182,CONSTANT-DISPLACEMENT CREEP BENCHMARK
/COM TEST CASE REFERENCED FROM R0049 NAFEMS MANUAL,
/COM TEST CR-2:  CONSTANT-DISPLACEMENT CREEP BENCHMARK

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (TIME HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5.0
*SET,C3,-0.5
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (STRAIN HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3
N,1
N,2,100
N,3,100,100
N,4,0,100
ET,1,182,1,,
E,1,2,3,4
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,S,LOC,Y,100
D,ALL,UY,0.1
NSEL,ALL
*DO,I,1,2
*STATUS,I
/PREP7
*IF,I,EQ,1,THEN
MAT,1
*ELSEIF,I,EQ,2,THEN
MPCHG,2,ALL
*ENDIF
FINISH

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
```

```
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

/POST26

*IF,I,EQ,1,THEN
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,5
/GROPT,DIVY,6
/XRANGE,0,1000
/YRANGE,0,300
ESOL,2,1,,S,EQV,TIMEHARD
PRVAR,2
/COLOR,CURVE,BMAG,1
/AXLAB,X,TIME
/AXLAB,Y,STRESS
PLVAR,2

/POST1
SET,1,1
*GET,SH1,NODE,3,S,X
R1=SH1/285.714
SET,6,19
*GET,SH2,NODE,3,S,X
R2=SH2/46.612
```

```
SET,6,39
*GET,SH3,NODE,3,S,X
R3=SH3/42.206
SET,6,59
*GET,SH4,NODE,3,S,X
R4=SH4/39.893
SET,6,79
*GET,SH5,NODE,3,S,X
R5=SH5/38.353
SET,6,99
*GET,SH6,NODE,3,S,X
R6=SH6/37.211
*DIM,VALUE1,,6,3
*DIM,VALUE2,,6,3
*DIM,LABEL,CHAR,10
*DIM,TARGET,CHAR,10
LABEL(1) = '0','200', '400', '600', '800', '1000'
TARGET(1) = '285.714','46.612','42.206','39.353','38.353','37.211'
*VFILL,VALUE1(1,1),DATA,SH1,SH2,SH3,SH4,SH5,SH6
*VFILL,VALUE2(1,1),DATA,R1,R2,R3,R4,R5,R6

*ELSEIF,I,EQ,2,THEN
/NOERASE
/GROPT,DIVX,5
/GROPT,DIVY,6
/XRANGE,0,1000
/YRANGE,0,300
ESOL,3,1,,S,EQV,STRAINHARDENING
PRVAR,3
/COLOR,CURVE,GREE,1
/AXLAB,X,TIME
/AXLAB,Y,STRESS
PLVAR,3

/POST1
SET,1,1
*GET,S1,NODE,3,S,X
R10=S1/285.714
SET,6,19
*GET,S2,NODE,3,S,X
R11=S2/62.014
SET,6,39
*GET,S3,NODE,3,S,X
R12=S3/57.251
SET,6,59
*GET,S4,NODE,3,S,X
R13=S4/54.690
SET,6,79
*GET,S5,NODE,3,S,X
R14=S5/52.959
SET,6,99
*GET,S6,NODE,3,S,X
R15=S6/51.661
*DIM,VALUE3,,6,3
*DIM,VALUE4,,6,3
*DIM,LABEL2,CHAR,10
*DIM,TARGET2,CHAR,10
LABEL2(1) = '0','200', '400', '600', '800', '1000'
TARGET2(1) = '285.714','62.014','57.251','54.690','52.959','51.661'
*VFILL,VALUE3(1,1),DATA,S1,S2,S3,S4,S5,S6
*VFILL,VALUE4(1,1),DATA,R10,R11,R12,R13,R14,R15
/COM
/COM
/COM,--------- vmr049-cr2-182 TIME HARDENING COMPARISON -----------
/COM,
/COM COMPARE NUMERICAL VALUES LISTED
/COM BELOW WITH GRAPH OF FIGURE
/COM 3.10A ON PAGE 103 AS NO NUMERICAL
/COM RESULTS ARE PRESENTED.
/COM,
/COM,|   TIME   |  TARGET |  Mechanical APDL  |  RATIO |
/COM,
```

```
*VWRITE,LABEL(1),TARGET(1),VALUE1(1,1),VALUE2(1,1)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',1F12.3,'   ')
/COM,
/COM,
/COM,--------- vmr049-cr2-182 STRAIN HARDENING COMPARISON ---------
/COM,
/COM,|   TIME    |  TARGET |  Mechanical APDL   |  RATIO |
/COM,
*VWRITE,LABEL2(1),TARGET2(1), VALUE3(1,1), VALUE4(1,1)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',1F12.3,'   ')
*ENDIF
*ENDDO
FINISH

/POST26
*DIM,LABEL3,CHAR,2
*DIM,VALUE5,,2,3
LABEL3(1) = ' S6 ',' S7 '
*VFILL,VALUE5(1,1),DATA,SH6,S6
*VFILL,VALUE5(1,2),DATA,R6,R15
*DIM,LABEL4,CHAR,2
LABEL4(1) = 'vmr049-','cr2-182'

/OUT,vmr049-cr2-182,vrt
/COM
/COM,------------------- vmr049-cr2 RESULTS COMPARISON ---------------------
/COM,
/COM,           |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL3(1),VALUE5(1,1),VALUE5(1,2),LABEL4(1),LABEL4(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL3(2),VALUE5(2,1),VALUE5(2,2),LABEL4(1),LABEL4(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr2-182,vrt
```

VM-R049-2 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr2-183
/TITLE,vmr049-cr2-183,CONSTANT-DISPLACEMENT CREEP BENCHMARK
/COM, REFERENCE: TEST CR-2A FROM NAFEMS REPORT 0049.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (TIME HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5.0
*SET,C3,-0.5
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (STRAIN HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
MP,EX,2,200E3
```

```
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3
SAVE
N,1
N,2,100
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183,,,
E,1,2,3,4,5,6,7,8
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,S,LOC,Y,100
D,ALL,UY,0.1
NSEL,ALL
*DO,I,1,2
*STATUS,I

/PREP7
*IF,I,EQ,1,THEN
MAT,1
*ELSEIF,I,EQ,2,THEN
MPCHG,2,ALL
*ENDIF
FINI

/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE

/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
```

```
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME, 1000
/OUT,SCRATCH
OUTRES,ALL,ALL
OUTPR,ALL,LAST
SOLVE
/OUT
FINISH

/POST26
*IF,I,EQ,1,THEN
ESOL,2,1,,S,EQV,TIMEHARD
PRVAR,2
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/YRANGE,0,400
PLVAR,2
/NOERASE

/POST1
SET,1,1
*GET,SH1,NODE,3,S,X
R1=SH1/285.714
SET,6,19
*GET,SH2,NODE,3,S,X
R2=SH2/46.612
SET,6,39
*GET,SH3,NODE,3,S,X
R3=SH3/42.206
SET,6,59
*GET,SH4,NODE,3,S,X
R4=SH4/39.893
SET,6,79
*GET,SH5,NODE,3,S,X
R5=SH5/38.353
SET,6,99
*GET,SH6,NODE,3,S,X
R6=SH6/37.211
*DIM,VALUE,,6,3
*DIM,LABEL,CHAR,10
*DIM,TARGET,CHAR,10
*DIM,RATIO,,6,4
LABEL(1) = '0','200.0','400.0','600.0','800.0','1000'
TARGET(1) = '285.714','46.612','42.206','39.893','38.353','37.211'
*VFILL,VALUE(1,1),DATA,SH1,SH2,SH3,SH4,SH5,SH6
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6

*ELSEIF,I,EQ,2,THEN
ESOL,3,1,,S,EQV,STRAINHA
PRVAR,3
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/COLOR,CURVE,BLUE,1
/YRANGE,0,400
PLVAR,3

/POST1
SET,1,1
*GET,SH1_1,NODE,3,S,X
R7=SH1_1/285.714
SET,6,19
*GET,SH2_1,NODE,3,S,X
R8=SH2_1/62.014
SET,6,39
*GET,SH3_1,NODE,3,S,X
R9=SH3_1/57.251
SET,6,59
*GET,SH4_1,NODE,3,S,X
R10=SH4_1/54.690
SET,6,79
```

```
*GET,SH5_1,NODE,3,S,X
R11=SH5_1/52.959
SET,6,99
*GET,SH6_1,NODE,3,S,X
R12=SH6_1/51.661
*DIM,VALUE1,,6,3
*DIM,LABEL1,CHAR,10
*DIM,TARGET1,CHAR,10
*DIM,RATIO1,,6,3
LABEL1(1) = '0','200.0','400.0','600.0','800.0','1000'
TARGET1(1) = '285.714','62.014','57.251','54.690','52.959','51.661'
*VFILL,VALUE1(1,1),DATA,SH1_1,SH2_1,SH3_1,SH4_1,SH5_1,SH6_1
*VFILL,RATIO1(1,1),DATA,R7,R8,R9,R10,R11,R12
/COM
/COM,--------- vmr049-cr2-183 STRESS RESULTS COMPARISON (TIME HARDENING)-----------
/COM,
/COM, COMPARE NUMERICAL VALUES LISTED BELOW WITH FIGURE 3.10(A)
/COM, ON PAGE 103 AS NO NUMERICAL RESULTS ARE PRESENTED.
/COM,
/COM,|   TIME    |   TARGET   |  Mechanical APDL   |  RATIO
/COM,
*VWRITE,LABEL(1), TARGET(1), VALUE(1,1), RATIO(1,1)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',1F12.3)
/COM,
/COM,
/COM,--------- vmr049-cr2-183 STRESS RESULTS COMPARISON (STRAIN HARDENING)-----------
/COM,
/COM,|   TIME    |   TARGET   |  Mechanical APDL   |  RATIO
/COM,
*VWRITE,LABEL(1), TARGET1(1), VALUE1(1,1), RATIO1(1,1)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',1F12.3)
*ENDIF
*ENDDO
FINISH


/POST26
*DIM,LABEL3,CHAR,2
*DIM,VALUE2,,2,3
LABEL3(1) = ' S6 ',' S7 '
*VFILL,VALUE2(1,1),DATA,SH6,SH6_1
*VFILL,VALUE2(1,2),DATA,R6,R12
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr2-183'

/OUT,vmr049-cr2-183,vrt
/COM
/COM,------------------- vmr049-cr2 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL3(1),VALUE2(1,1),VALUE2(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.3,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL3(2),VALUE2(2,1),VALUE2(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.3,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,---------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr2-183,vrt
```

VM-R049-2 185 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr2-185
/TITLE,vmr049-cr2-185,CONSTANT-DISPLACEMENT CREEP BENCHMARK
```

```
/COM,REFERENCE: COMPARISON IS MADE GRAPHICLY WITH THE SOLUTION
/COM,OF THE TEST CR-2C FROM THE NAFEMS REPORT

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS
*SET,C1,3.125E-14
*SET,C2,5.0
*SET,C3,0.0
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,0.2000E+06
MP,EY,1,0.2000E+06
MP,EZ,1,0.2000E+06
MP,GXY,1,0.7692E+05
MP,GYZ,1,0.7692E+05
MP,GXZ,1,0.7692E+05
MP,NUXY,1,0.3000E+00
MP,NUYZ,1,0.3000E+00
MP,NUXZ,1,0.3000E+00
MP,DENS,1,0.0000E+00
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
ET,1,SOLID185
KEYOPT,1,1,0
KEYOPT,1,2,0
KEYOPT,1,4,0
KEYOPT,1,5,0
KEYOPT,1,6,0
BLOCK,0,100,0,100,0,100,
ESIZE,50
VMESH,1
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Z,100
D,ALL,UZ
NSEL,S,LOC,X,100
D,ALL,UX,0.3
NSEL,S,LOC,Y,100
D,ALL,UY,0.2
NSEL,S,LOC,Z
D,ALL,UZ,-0.1
NSEL,ALL
FINISH

/SOLU
RATE, OFF
SOLCONTROL,ON
DELT,1.0E-10,1E-11,1E-9
TIME, 1.0E-10
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT

/SOLU
RATE, ON, ON
SOLCONTROL,ON
DELT,1E-1,1E-1,100
TIME, 1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH
```

```
/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/GROPT,ASCAL,ON
/GROPT,AXDV,ON
/GROPT,AXNM,ON
/GROPT,AXNSC,ON
/GROPT,DIG1,5
/GROPT,DIG2,3
ESOL,2,1,,S,X
ESOL,3,1,,S,Y
ESOL,4,1,,S,Z
PRVAR,2,3,4
PLVAR,2,3,4

/POST1
SET,,,,,,,1
*GET,S1,NODE,4,S,X
R1=S1/1153.846
SET,,,,,,,14
*GET,S2,NODE,4,S,X
R2=S2/1016.393
SET,,,,,,,16
*GET,S3,NODE,4,S,X
R3=S3/1013.616
SET,,,,,,,18
*GET,S4,NODE,4,S,X
R4=S4/1011.562
SET,,,,,,,20
*GET,S5,NODE,4,S,X
R5=S5/1009.958
SET,,,,,,,22
*GET,S6,NODE,4,S,X
R6=S6/1009.05
*DIM,VALUE,,6,4
*DIM,RATIO,,6,4
*DIM,LABEL,CHAR,10
*DIM,TARGET,CHAR,10
LABEL(1) = '0','200','400','600','800','1000'
TARGET(1) = '1153.846','1016.393','1013.616','1011.562','1009.958','1009.05'
*VFILL,VALUE(1,1),DATA,S1,S2,S3,S4,S5,S6
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6
SET,,,,,,,1
*GET,S1_Y,NODE,4,S,Y
R7=S1_Y/1000.000
SET,,,,,,,14
*GET,S2_Y,NODE,4,S,Y
R8=S2_Y/1000.000
SET,,,,,,,16
*GET,S3_Y,NODE,4,S,Y
R9=S3_Y/1000.000
SET,,,,,,,18
*GET,S4_Y,NODE,4,S,Y
R10=S4_Y/1000.000
SET,,,,,,,20
*GET,S5_Y,NODE,4,S,Y
R11=S5_Y/1000.000
SET,,,,,,,22
*GET,S6_Y,NODE,4,S,Y
R12=S6_Y/1000.000
*DIM,TARGET2,CHAR,10
*VFILL,VALUE(1,2),DATA,S1_Y,S2_Y,S3_Y,S4_Y,S5_Y,S6_Y
*VFILL,RATIO(1,2),DATA,R7,R8,R9,R10,R11,R12
TARGET2(1)='1000.000','1000.000','1000.000','1000.000','1000.000','1000.000'
```

```
SET,,,,,,,1
*GET,S1_Z,NODE,4,S,Z
R13=S1_Z/846.154
SET,,,,,,,14
*GET,S2_Z,NODE,4,S,Z
R14=S2_Z/983.608
SET,,,,,,,16
*GET,S3_Z,NODE,4,S,Z
R15=S3_Z/985.942
SET,,,,,,,18
*GET,S4_Z,NODE,4,S,Z
R16=S4_Z/988.439
SET,,,,,,,20
*GET,S5_Z,NODE,4,S,Z
R17=S5_Z/990.043
SET,,,,,,,22
*GET,S6_Z,NODE,4,S,Z
R18=S6_Z/990.950
*DIM,TARGET3,CHAR,10
*VFILL,VALUE(1,3),DATA,S1_Z,S2_Z,S3_Z,S4_Z,S5_Z,S6_Z
*VFILL,RATIO(1,3),DATA,R13,R14,R15,R16,R17,R18
TARGET3(1)='846.154','983.608','985.942','988.439','990.043','990.950'
/COM
/COM---------- VMR049-CR2-185 RESULTS COMPARISON -------------
/COM
/COM COMPARE NUMERICAL VALUES LISTED
/COM BELOW WITH GRAPH OF FIGURE
/COM 3.10C ON PAGE 103 AS NO NUMERICAL
/COM,RESULTS ARE PRESENTED
/COM
/COM
/COM,--------- VMR049-CR2-185 STRESS RESULTS IN X DIRECTION -----------
/COM,
/COM,|   TIME   |  TARGET  |  Mechanical APDL  | RATIO
/COM,
*VWRITE,LABEL(1), TARGET(1), VALUE(1,1), RATIO(1,1)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,--------- VMR049-CR2-185 RESULTS IN Y DIRECTION -----------
/COM,
/COM,|   TIME   |  TARGET  |  Mechanical APDL  | RATIO
/COM,
*VWRITE,LABEL(1), TARGET2(1), VALUE(1,2), RATIO(1,2)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,--------- VMR049-CR2-185 STRESS RESULTS IN Z DIRECTION -----------
/COM,
/COM,|   TIME   |  TARGET  |  Mechanical APDL  | RATIO
/COM,
*VWRITE,LABEL(1), TARGET3(1), VALUE(1,3), RATIO(1,3)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',F12.3,'   ')
FINISH

/POST26
*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' S6X ',' S6Y ',' S6Z'
*VFILL,VALUE1(1,1),DATA,S6,S6_Y,S6_Z
*VFILL,VALUE1(1,2),DATA,R6,R12,R18
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr2-185'

/OUT,vmr049-cr2-185,vrt
/COM
/COM,------------------- vmr049-cr2 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID185
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.3,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
```

```
(1X,A8,'      ',F14.3,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.3,'     ',F10.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr2-185,vrt
```

VM-R049-2 187 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr2-187
/TITLE,vmr049-cr2-187,CONSTANT-DISPLACEMENT CREEP BENCHMARK
/COM,REFERENCE:COMPARISON IS MADE GRAPHICLY WITH THE SOLUTION OF
/COM THE TEST CR-2C FROM THE NAFEMS REPORT RO049

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS !***
*SET,C1,3.125E-14
*SET,C2,5.0
*SET,C3,0.0
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,0.2000E+06
MP,EY,1,0.2000E+06
MP,EZ,1,0.2000E+06
MP,GXY,1,0.7692E+05
MP,GYZ,1,0.7692E+05
MP,GXZ,1,0.7692E+05
MP,NUXY,1,0.3000E+00
MP,NUYZ,1,0.3000E+00
MP,NUXZ,1,0.3000E+00
MP,DENS,1,0.0000E+00
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
ET,1,SOLID187
BLOCK,0,100,0,100,0,100,
/VIEW, 1 ,1,1,1
/ANG, 1

ESIZE,100
VMESH,1
NSEL,ALL
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Z,100
D,ALL,UZ
NSEL,S,LOC,X,100
D,ALL,UX,0.3
NSEL,S,LOC,Y,100
D,ALL,UY,0.2
NSEL,S,LOC,Z
D,ALL,UZ,-0.1
NSEL,ALL
FINISH

/SOLU
RATE, OFF
SOLCONTROL,ON
DELT,1.0E-10,1E-11,1E-9
```

```
TIME, 1.0E-10
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT

/SOLU
RATE, ON, ON
SOLCONTROL,ON
DELT,1,1,100
TIME, 1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/GROPT,ASCAL,ON
/GROPT,AXDV,ON
/GROPT,AXNM,ON
/GROPT,AXNSC,ON
/GROPT,DIG1,5
/GROPT,DIG2,3
ESOL,2,1,,S,X
ESOL,3,1,,S,Y
ESOL,4,1,,S,Z
PRVAR,2,3,4
PLVAR,2,3,4
FINISH

/POST1
SET,,,,,,,1
*GET,S1,NODE,4,S,X
R1=S1/1153.846
SET,,,,,,,14
*GET,S2,NODE,4,S,X
R2=S2/1016.393
SET,,,,,,,16
*GET,S3,NODE,4,S,X
R3=S3/1013.616
SET,,,,,,,18
*GET,S4,NODE,4,S,X
R4=S4/1011.562
SET,,,,,,,20
*GET,S5,NODE,4,S,X
R5=S5/1009.957
SET,,,,,,,22
*GET,S6,NODE,4,S,X
R6=S6/1009.05
*DIM,VALUE,,6,4
*DIM,TARGET,CHAR,10
*DIM,RATIO,,6,4
*DIM,LABEL,CHAR,10
LABEL(1) = '0','200','400','600','800','1000'
TARGET(1) ='1153.846','1016.393','1013.616','1011.562','1009.957','1009.05'
*VFILL,VALUE(1,1),DATA,S1,S2,S3,S4,S5,S6
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6
SET,,,,,,,1
*GET,S1_Y,NODE,4,S,Y
R7=S1_Y/1000.000
SET,,,,,,,14
```

```
*GET,S2_Y,NODE,4,S,Y
R8=S2_Y/1000.000
SET,,,,,,,16
*GET,S3_Y,NODE,4,S,Y
R9=S3_Y/1000.000
SET,,,,,,,18
*GET,S4_Y,NODE,4,S,Y
R10=S4_Y/1000.000
SET,,,,,,,20
*GET,S5_Y,NODE,4,S,Y
R11=S5_Y/1000.000
SET,,,,,,,22
*GET,S6_Y,NODE,4,S,Y
R12=S6_Y/1000.000
*VFILL,VALUE(1,2),DATA,S1_Y,S2_Y,S3_Y,S4_Y,S5_Y,S6_Y
*VFILL,RATIO(1,2),DATA,R6,R7,R8,R9,R10,R11,R12
*DIM,TARGET2,CHAR,10
TARGET2(1)='1000.000','1000.000','1000.000','1000.000','1000.000','1000.000'
SET,,,,,,,1
*GET,S1_Z,NODE,4,S,Z
R13=S1_Z/846.154
SET,,,,,,,14
*GET,S2_Z,NODE,4,S,Z
R14=S2_Z/983.608
SET,,,,,,,16
*GET,S3_Z,NODE,4,S,Z
R15=S3_Z/985.942
SET,,,,,,,18
*GET,S4_Z,NODE,4,S,Z
R16=S4_Z/988.439
SET,,,,,,,20
*GET,S5_Z,NODE,4,S,Z
R17=S5_Z/990.043
SET,,,,,,,22
*GET,S6_Z,NODE,4,S,Z
R18=S6_Z/990.95
*DIM,TARGET3,CHAR,10
*VFILL,VALUE(1,3),DATA,S1_Z,S2_Z,S3_Z,S4_Z,S5_Z,S6_Z
*VFILL,RATIO(1,3),DATA,R13,R14,R15,R16,R17,R18
TARGET3(1)='846.154','983.608','985.942','988.439','990.043','990.95'
/COM
/COM NAFEMS RESULTS
/COM COMPARE NUMERICAL VALUES LISTED
/COM BELOW WITH GRAPH OF FIGURE
/COM 3.10C ON PAGE 103 AS NO NUMERICAL RESULTS
/COM ARE PRESENTED
/COM
/COM,--------- vmr049-cr2-187 STRESS RESULTS IN X DIRECTION -----------
/COM,
/COM,|   TIME   |  TARGET  |  Mechanical APDL  | RATIO
/COM,
*VWRITE,LABEL(1), TARGET(1), VALUE(1,1), RATIO(1,3)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,--------- vmr049-cr2-187 STRESS RESULTS IN Y DIRECTION -----------
/COM,
/COM,|   TIME   |  TARGET  |  Mechanical APDL  | RATIO
/COM,
*VWRITE,LABEL(1), TARGET2(1), VALUE(1,2), RATIO(1,3)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,--------- vmr049-cr2-187 STRESS RESULTS IN Z DIRECTION -----------
/COM,
/COM,|   TIME   |  TARGET  |  Mechanical APDL  | RATIO
/COM,
*VWRITE,LABEL(1), TARGET3(1), VALUE(1,3), RATIO(1,3)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',F12.3,'   ')
FINISH


/POST26
*DIM,LABEL1,CHAR,3
```

```
*DIM,VALUE1,,3,3
LABEL1(1) = ' S6X ',' S6Y ',' S6Z '
*GET,S6,NODE,4,S,X
*GET,S6_Y,NODE,4,S,Y

*VFILL,VALUE1(1,1),DATA,S6,S6_Y,S6_Z
*VFILL,VALUE1(1,2),DATA,R6,R12,R18
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr2-187'

/OUT,vmr049-cr2-187,vrt
/COM
/COM,------------------- vmr049-cr2 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID187
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.3,'      ',F10.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.3,'      ',F10.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.3,'      ',F10.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr2-187,vrt
```

VM-R049-2 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr2-281
/TITLE,vmr049-cr2-281,CONSTANT-DISPLACEMENT CREEP BENCHMARK
/COM, REFERENCE: TEST CR-2A FROM NAFEMS REPORT 0049.
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (TIME HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5.0
*SET,C3,-0.5
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,1000
C***   ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS (STRAIN HARDENING)!***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3
SAVE
/PREP7
N,1
N,2,100
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
```

```
N,8,0,50
ET,1,SHELL281,,,
R,1,1,1,1,1,
E,1,2,3,4,5,6,7,8
NSEL,ALL
D,ALL,UZ,
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
D,8,ROTY,0
NSEL,S,LOC,X,100
D,ALL,UX,0.1
NSEL,S,LOC,Y,100
D,ALL,UY,0.1
NSEL,ALL
*DO,I,1,2
*STATUS,I
/PREP7
*IF,I,EQ,1,THEN
MAT,1
*ELSEIF,I,EQ,2,THEN
MPCHG,2,ALL
*ENDIF
FINI
/SOLU
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,0.10,0.099,0.10
TIME, 0.10
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,1.0,0.99,1.0
TIME, 1.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,5.0,4.99,5.0
TIME, 5.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON
DELT,10.0,9.99,10.0
TIME, 10.0
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,10,1,100
AUTOS,OFF
TIME,1000
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH
/POST26
```

```
*IF,I,EQ,1,THEN
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,5
/GROPT,DIVY,6
/XRANGE,0,1000
/YRANGE,0,300
ESOL,2,1,,S,EQV,TIMEHARD
PRVAR,2
/COLOR,CURVE,BMAG,1
/AXLAB,X,TIME
/AXLAB,Y,STRESS
PLVAR,2
/NOERASE
/POST1
SET,1,1
*GET,SH1,NODE,3,S,X
R1=SH1/285.714
SET,6,19
*GET,SH2,NODE,3,S,X
R2=SH2/46.612
SET,6,39
*GET,SH3,NODE,3,S,X
R3=SH3/42.206
SET,6,59
*GET,SH4,NODE,3,S,X
R4=SH4/39.893
SET,6,79
*GET,SH5,NODE,3,S,X
R5=SH5/38.353
SET,6,99
*GET,SH6,NODE,3,S,X
R6=SH6/37.211
*DIM,VALUE,,6,3
*DIM,LABEL,CHAR,10
*DIM,TARGET,CHAR,10
*DIM,RATIO,,6,4
LABEL(1) = '0','200.0','400.0','600.0','800.0','1000'
TARGET(1) = '285.714','46.612','42.206','39.893','38.353','37.211'
*VFILL,VALUE(1,1),DATA,SH1,SH2,SH3,SH4,SH5,SH6
*VFILL,RATIO(1,1),DATA,R1,R2,R3,R4,R5,R6
*ELSEIF,I,EQ,2,THEN
ESOL,3,1,,S,EQV,STRAINHA
PRVAR,3
/AXLAB,X,TIME
/AXLAB,Y,STRESS
/YRANGE,0,300
/COLOR,CURVE,BLUE,1
PLVAR,3
/POST1
SET,1,1
*GET,SH1_1,NODE,3,S,X
R7=SH1_1/285.714
SET,6,19
*GET,SH2_1,NODE,3,S,X
R8=SH2_1/62.014
SET,6,39
*GET,SH3_1,NODE,3,S,X
R9=SH3_1/57.251
SET,6,59
*GET,SH4_1,NODE,3,S,X
R10=SH4_1/54.690
SET,6,79
*GET,SH5_1,NODE,3,S,X
```

```
R11=SH5_1/52.959
SET,6,99
*GET,SH6_1,NODE,3,S,X
R12=SH6_1/51.661
*DIM,VALUE1,,6,3
*DIM,LABEL1,CHAR,10
*DIM,TARGET1,CHAR,10
*DIM,RATIO1,,6,3
LABEL1(1) = '0','200.0','400.0','600.0','800.0','1000'
TARGET1(1) = '285.714','62.014','57.251','54.690','52.959','51.661'
*VFILL,VALUE1(1,1),DATA,SH1_1,SH2_1,SH3_1,SH4_1,SH5_1,SH6_1
*VFILL,RATIO1(1,1),DATA,R7,R8,R9,R10,R11,R12
/COM
/COM,--------- vmr049-cr2-281 STRESS RESULTS COMPARISON (TIME HARDENING)-----------
/COM,
/COM, COMPARE NUMERICAL VALUES LISTED BELOW WITH FIGURE 3.10(A)
/COM, ON PAGE 103 AS NO NUMERICAL RESULTS ARE PRESENTED.
/COM,
/COM,|   TIME    |   TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,LABEL(1), TARGET(1), VALUE(1,1), RATIO(1,1)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',1F12.3)
/COM,
/COM,
/COM,--------- vmr049-cr2-281 STRESS RESULTS COMPARISON (STRAIN HARDENING)-----------
/COM,
/COM,|   TIME    |   TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,LABEL(1), TARGET1(1), VALUE1(1,1), RATIO1(1,1)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',1F12.3)
*ENDIF
*ENDDO
FINISH
/POST26
*DIM,LABEL2,CHAR,2
*DIM,VALUE2,,2,3
LABEL2(1) = ' S6 ',' S7 '
*VFILL,VALUE2(1,1),DATA,SH6,SH6_1
*VFILL,VALUE2(1,2),DATA,R6,R12
*DIM,LABEL3,CHAR,2
LABEL3(1) = 'vmr049-','cr2-281'
/OUT,vmr049-cr2-281,vrt
/COM
/COM,------------------- vmr049-cr2 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL2(1),VALUE2(1,1),VALUE2(1,2),LABEL3(1),LABEL3(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL2(2),VALUE2(2,1),VALUE2(2,2),LABEL3(1),LABEL3(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr049-cr2-281,vrt
```

VM-R049-3 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr3-181
/TITLE,vmr049-cr3-181,VARIABLE-LOAD UNIAXIAL CREEP BENCHMARK
/COM,THE COMPARISON IS MADE GRAPHICALLY WITH THE RESULTS OF THE
/COM,TEST CR-3A FROM NAFEMS REPORT.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
```

```
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(STRAIN HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** ELASTIC CONSTANT
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
ET,1,181,,,
R,1,1,1,1,1,
E,1,2,3,4
E,4,3,5,6
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,,,4
D,ALL,UY,
NSEL,ALL
D,ALL,UZ
D,ALL,ROTX
D,ALL,ROTY
D,ALL,ROTZ

*DO,I,1,2
*STATUS,I

/PREP7
*IF,I,EQ,1,THEN
MAT,1
*ELSEIF,I,EQ,2,THEN
MPCHG,2,ALL
*ENDIF
FINISH

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,1E-2,1E-2,1
TIME,100
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
```

```
/OUT

/SOLU
SFDELE,ALL,ALL
NSEL,S,LOC,X,100
SF,ALL,PRES,-250
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME,100.00000001
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,1,1,10
TIME,200
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

*IF,I,EQ,1,THEN
/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,4
/GROPT,DIVY,7
/XRANGE,0,200
/YRANGE,0,0.35
ESOL,2,1,,EPCR,X,TIMEHARDENING
/COLOR,CURVE,GREE,1
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN (XX)
PLVAR,2
PRVAR,2

/POST1
SET,,,,,,,1
*GET,S1,NODE,3,EPCR,X
R1=1.000
SET,,,,,,,62
*GET,S2,NODE,3,EPCR,X
R2=S2/0.068
SET,,,,,,,112
*GET,S3,NODE,3,EPCR,X
R3=S3/0.097
SET,,,,,,,123
*GET,S4,NODE,3,EPCR,X
R4=S4/0.166
SET,,,,,,,128
*GET,S5,NODE,3,EPCR,X
R5=S5/0.221
*DIM,VALUE,,5,3
*DIM,VALUE2,,5,3
*DIM,LABEL,CHAR,10
*DIM,TARGET,CHAR,10
LABEL(1) = '0','50','100','150','200'
TARGET(1) = '0.000','0.068','0.097','0.166','0.221'
*VFILL,VALUE(1,1),DATA,S1,S2,S3,S4,S5
*VFILL,VALUE2(1,1),DATA,R1,R2,R3,R4,R5

*ELSEIF,I,EQ,2,THEN
```

```
/POST26
/NOERASE
/AXLAB,X,
/AXLAB,Y,
/GROPT,DIVX,4
/GROPT,DIVY,7
/XRANGE,0,200
/YRANGE,0,0.35
ESOL,3,1,,EPCR,X,STRAINHARDENING
/COLOR,CURVE,BMAG,1
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN (XX)
PLVAR,3
PRVAR,3

/POST1
SET,,,,,,,1
*GET,S1_2,NODE,3,EPCR,X
R6=1.000
SET,,,,,,,62
*GET,S2_2,NODE,3,EPCR,X
R7=S2_2/0.070
SET,,,,,,,112
*GET,S3_2,NODE,3,EPCR,X
R8=S3_2/0.099
SET,,,,,,,123
*GET,S4_2,NODE,3,EPCR,X
R9=S4_2/0.236
SET,,,,,,,128
*GET,S5_2,NODE,3,EPCR,X
R10=S5_2/0.315
*DIM,VALUE3,,5,3
*DIM,VALUE4,,5,3
*DIM,LABEL2,CHAR,10
*DIM,TARGET2,CHAR,10
*VFILL,VALUE3(1,1),DATA,S1_2,S2_2,S3_2,S4_2,S5_2
*VFILL,VALUE4(1,1),DATA,R6,R7,R8,R9,R10
LABEL2(1) = '0','50','100','150','200'
TARGET2(1) = '0.000','0.070','0.099','0.236','0.315'
*ENDIF
FINISH
*ENDDO
/COM
/COM
/COM
/COM,--------- vmr049-cr3-181 TIME HARDENING COMPARISON-----------
/COM
/COM  COMPARE NUMERICAL VALUES LISTED
/COM  BELOW WITH GRAPH OF FIGURE 3.12A ON
/COM  PAGE 105 AS NO NUMERICAL RESULTS ARE
/COM  PRESENTED.
/COM
/COM,| TIME |  TARGET |  Mechanical APDL  |  RATIO |
/COM,
*VWRITE,LABEL(1),TARGET(1),VALUE(1,1),VALUE2(1,1)
(1X,A6,'   ',1X,A6,'   ',F14.3,'   ',1F12.3,'   ')
/COM
/COM
/COM,--------- vmr049-cr3-181 STRAIN HARDENING COMPARISON-----------
/COM,
/COM,| TIME |  TARGET |  Mechanical APDL  |  RATIO |
/COM,
*VWRITE,LABEL2(1),TARGET2(1),VALUE3(1,1),VALUE4(1,1)
(1X,A6,'   ',1X,A6,'   ',F14.3,'   ',1F12.3,'   ')
FINISH

/POST26
*DIM,LABEL3,CHAR,2
*DIM,VALUE5,,2,3
LABEL3(1) = ' S2 ',' S7 '
*VFILL,VALUE5(1,1),DATA,S5,S5_2
*VFILL,VALUE5(1,2),DATA,R5,R10
```

```
*DIM,LABEL4,CHAR,2
LABEL4(1) = 'vmr049-','cr3-181'

/OUT,vmr049-cr3-181,vrt
/COM
/COM,------------------- vmr049-cr3 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL3(1),VALUE5(1,1),VALUE5(1,2),LABEL4(1),LABEL4(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL3(2),VALUE5(2,1),VALUE5(2,2),LABEL4(1),LABEL4(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr3-181,vrt
```

VM-R049-3 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr3-182
/TITLE,vmr049-cr3-182,VARIABLE-LOAD UNIAXIAL CREEP BENCHMARK
/COM,THE COMPARISON IS MADE GRAPHICALLY WITH THE RESULTS OF THE TEST CR-3A
/COM,FROM NAFEMS REPORT R0049.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(STRAIN HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** ELASTIC CONSTANT
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
ET,1,182
KEYOPT,1,1,1
KEYOPT,1,3,0
E,1,2,3,4
E,4,3,5,6
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
```

```
NSEL,S,,,4
D,ALL,UY,
NSEL,ALL
*DO,I,1,2
*STATUS,I

/PREP7
*IF,I,EQ,1,THEN
MAT,1
*ELSEIF,I,EQ,2,THEN
MPCHG,2,ALL
*ENDIF
FINISH

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,1E-2,1E-2,1
TIME,100
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT

/SOLU
SFDELE,ALL,ALL
NSEL,S,LOC,X,100
SF,ALL,PRES,-250
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME,100.00000001
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,1,1,10
TIME,200
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH

*IF,I,EQ,1,THEN

/POST1
SET,,,,,,,1
*GET,S1,NODE,3,EPCR,X
R1=1.000
SET,,,,,,,62
*GET,S2,NODE,3,EPCR,X
R2=S2/0.068
SET,,,,,,,112
*GET,S3,NODE,3,EPCR,X
R3=S3/0.097
SET,,,,,,,123
*GET,S4,NODE,3,EPCR,X
R4=S4/0.166
SET,,,,,,,128
*GET,S5,NODE,3,EPCR,X
R5=S5/0.221
```

```
*DIM,VALUE,,5,3
*DIM,VALUE2,,5,3
*DIM,LABEL,CHAR,10
*DIM,TARGET,CHAR,10
LABEL(1) = '0','50','100','150','200'
TARGET(1) = '0.000','0.068','0.097','0.166','0.221'
*VFILL,VALUE(1,1),DATA,S1,S2,S3,S4,S5
*VFILL,VALUE2(1,1),DATA,R1,R2,R3,R4,R5

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,4
/GROPT,DIVY,7
/XRANGE,0,200
/YRANGE,0,0.35
ESOL,2,1,,EPCR,X,TIMEHARDENING
PRVAR,2
/COLOR,CURVE,GREE,1
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN(XX)
PLVAR,2

*ELSEIF,I,EQ,2,THEN
/POST1
SET,,,,,,,1
*GET,S1_2,NODE,3,EPCR,X
R6=1.000
SET,,,,,,,62
*GET,S2_2,NODE,3,EPCR,X
R7=S2_2/0.070
SET,,,,,,,112
*GET,S3_2,NODE,3,EPCR,X
R8=S3_2/0.099
SET,,,,,,,123
*GET,S4_2,NODE,3,EPCR,X
R9=S4_2/0.236
SET,,,,,,,128
*GET,S5_2,NODE,3,EPCR,X
R10=S5_2/0.315
*DIM,VALUE3,,5,3
*DIM,VALUE4,,5,3
*DIM,LABEL2,CHAR,10
*DIM,TARGET2,CHAR,10
*VFILL,VALUE3(1,1),DATA,S1_2,S2_2,S3_2,S4_2,S5_2
*VFILL,VALUE4(1,1),DATA,R6,R7,R8,R9,R10
LABEL2(1) = '0','50','100','150','200'
TARGET2(1) = '0.000','0.070','0.099','0.236','0.315'

/POST26
/NOERASE
/AXLAB,X,
/AXLAB,Y,
/GROPT,DIVX,4
/GROPT,DIVY,7
/XRANGE,0,200
/YRANGE,0,0.35
ESOL,3,1,,EPCR,X,STRAINHARDENING
/COLOR,CURVE,BMAG,1
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN(XX)
PLVAR,3
PRVAR,3
*ENDIF
```

```
*ENDDO
/COM
/COM
/COM
/COM,--------- vmr049-cr3-182 TIME HARDENING COMPARISON-----------
/COM
/COM  COMPARE NUMERICAL VALUES LISTED
/COM  BELOW WITH GRAPH OF FIGURE 3.12A ON
/COM  PAGE 105 AS NO NUMERICAL RESULTS ARE
/COM  PRESENTED.
/COM
/COM,| TIME |  TARGET |  Mechanical APDL  |  RATIO |
/COM,
*VWRITE,LABEL(1),TARGET(1),VALUE(1,1),VALUE2(1,1)
(1X,A6,'   ',1X,A6,'   ',F14.3,'   ',1F12.3,'   ')
/COM
/COM
/COM,--------- vmr049-cr3-182 STRAIN HARDENING COMPARISON-----------
/COM,
/COM,| TIME |  TARGET |  Mechanical APDL  |  RATIO |
/COM,
*VWRITE,LABEL2(1),TARGET2(1),VALUE3(1,1),VALUE4(1,1)
(1X,A6,'   ',1X,A6,'   ',F14.3,'   ',1F12.3,'   ')
FINISH


/POST26
*DIM,LABEL3,CHAR,2
*DIM,VALUE5,,2,3
LABEL3(1) = ' S2 ',' S7 '
*VFILL,VALUE5(1,1),DATA,S5,S5_2
*VFILL,VALUE5(1,2),DATA,R5,R10
*DIM,LABEL4,CHAR,2
LABEL4(1) = 'vmr049-','cr3-182'

/OUT,vmr049-cr3-182,vrt
/COM
/COM,------------------- vmr049-cr3 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL3(1),VALUE5(1,1),VALUE5(1,2),LABEL4(1),LABEL4(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL3(2),VALUE5(2,1),VALUE5(2,2),LABEL4(1),LABEL4(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr3-182,vrt
```

VM-R049-3 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr3-183
/TITLE,vmr049-cr3-183,VARIABLE-LOAD UNIAXIAL CREEP BENCHMARK
/COM,THE COMPARISON IS MADE GRAPHICALLY WITH THE RESULTS OF THE TEST CR-3A
/COM,FROM NAFEMS REPORT R0049.

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** TIME PARAMETER
```

```
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(STRAIN HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** ELASTIC CONSTANT
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,100
N,4,0,100
N,5,50,0
N,6,100,50
N,7,50,100
N,8,0,50
ET,1,183
KEYOPT,1,3,0
E,1,2,3,4,5,6,7,8
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,,,8
D,ALL,UY,
NSEL,ALL
*DO,I,1,2
*STATUS,I

/PREP7
*IF,I,EQ,1,THEN
MAT,1
*ELSEIF,I,EQ,2,THEN
MPCHG,2,ALL
*ENDIF
FINISH

/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,1E-2,1E-2,1
TIME,100
/OUTPUT,SCRATCH
OUTRES,ALL,-10
SOLVE
/OUT

/SOLU
SFDELE,ALL,ALL
NSEL,S,LOC,X,100
SF,ALL,PRES,-250
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
```

```
TIME,100.00000001
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,1,1,10
TIME,200
/OUTPUT,SCRATCH
OUTRES,ALL,-10
SOLVE
/OUT
FINISH


*IF,I,EQ,1,THEN

/POST1
SET,,,,,,,1
*GET,S1,NODE,3,EPCR,X
R1=1.000
SET,,,,,,,6
*GET,S2,NODE,3,EPCR,X
R2=S2/0.068
SET,,,,,,,11
*GET,S3,NODE,3,EPCR,X
R3=S3/0.097
SET,,,,,,,17
*GET,S4,NODE,3,EPCR,X
R4=S4/0.166
SET,,,,,,,22
*GET,S5,NODE,3,EPCR,X
R5=S5/0.221
*DIM,VALUE,,5,3
*DIM,VALUE2,,5,3
*DIM,LABEL,CHAR,10
*DIM,TARGET,CHAR,10
LABEL(1) = '0','50','100','150','200'
TARGET(1) = '0.000','0.068','0.097','0.166','0.221'
*VFILL,VALUE(1,1),DATA,S1,S2,S3,S4,S5
*VFILL,VALUE2(1,1),DATA,R1,R2,R3,R4,R5

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,4
/GROPT,DIVY,7
/XRANGE,0,200
/YRANGE,0,0.35
ESOL,2,1,,EPCR,X,TIMEHARDENING
PRVAR,2
/COLOR,CURVE,GREE,1
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN (XX)
PLVAR,2

*ELSEIF,I,EQ,2,THEN
/POST1
SET,,,,,,,1
*GET,S1_2,NODE,3,EPCR,X
R6=1.000
SET,,,,,,,6
*GET,S2_2,NODE,3,EPCR,X
R7=S2_2/0.070
```

```
SET,,,,,,,11
*GET,S3_2,NODE,3,EPCR,X
R8=S3_2/0.099
SET,,,,,,,17
*GET,S4_2,NODE,3,EPCR,X
R9=S4_2/0.236
SET,,,,,,,22
*GET,S5_2,NODE,3,EPCR,X
R10=S5_2/0.315
*DIM,VALUE3,,5,3
*DIM,VALUE4,,5,3
*DIM,LABEL2,CHAR,10
*DIM,TARGET2,CHAR,10
*VFILL,VALUE3(1,1),DATA,S1_2,S2_2,S3_2,S4_2,S5_2
*VFILL,VALUE4(1,1),DATA,R6,R7,R8,R9,R10
LABEL2(1) = '0','50','100','150','200'
TARGET2(1) = '0.000','0.070','0.099','0.236','0.315'

/POST26
/NOERASE
/GROPT,DIVX,4
/GROPT,DIVY,7
/XRANGE,0,200
/YRANGE,0,0.35
ESOL,3,1,,EPCR,X,STRAINHARDENING
/COLOR,CURVE,BMAG,1
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN (XX)
PLVAR,3
PRVAR,3
*ENDIF
*ENDDO
/COM
/COM
/COM,--------- vmr049-cr3-183 TIME HARDENING COMPARISON-----------
/COM,
/COM  NAFEMS RESULTS
/COM
/COM  COMPARE NUMERICAL VALUES LISTED
/COM  BELOW WITH GRAPH OF FIGURE 3.12A ON
/COM  PAGE 105 AS NO NUMERICAL RESULTS ARE
/COM  PRESENTED.
/COM
/COM,|   TIME   |  TARGET |  Mechanical APDL  |  RATIO |
/COM,
*VWRITE,LABEL(1),TARGET(1),VALUE(1,1),VALUE2(1,1)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',1F12.2,'   ')
/COM
/COM
/COM,--------- vmr049-cr3-183 STRAIN HARDENING COMPARISON-----------
/COM,
/COM,|   TIME   |  TARGET |  Mechanical APDL  |  RATIO |
/COM,
*VWRITE,LABEL2(1),TARGET2(1),VALUE3(1,1),VALUE4(1,1)
(1X,A8,'   ',1X,A8,'   ',F14.3,'   ',1F12.2,'   ')
FINISH

/POST26
*DIM,LABEL3,CHAR,2
*DIM,VALUE5,,2,3
LABEL3(1) = ' S2 ',' S7 '
*VFILL,VALUE5(1,1),DATA,S5,S5_2
*VFILL,VALUE5(1,2),DATA,R5,R10
*DIM,LABEL4,CHAR,2
LABEL4(1) = 'vmr049-','cr3-183'

/OUT,vmr049-cr3-183,vrt
/COM
/COM,------------------- vmr049-cr3 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
```

```
/COM, PLANE183
*VWRITE,LABEL3(1),VALUE5(1,1),VALUE5(1,2),LABEL4(1),LABEL4(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL3(2),VALUE5(2,1),VALUE5(2,2),LABEL4(1),LABEL4(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr3-183,vrt
```

VM-R049-3 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr3-281
/TITLE,vmr049-cr3-281,VARIABLE-LOAD UNIAXIAL CREEP BENCHMARK
/COM,THE COMPARISON IS MADE GRAPHICALLY WITH THE RESULTS OF THE
/COM,TEST CR-3A FROM NAFEMS REPORT.
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(TIME HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,200
C*** ELASTIC CONSTANT
MP,EX,1,200E3
MP,NUXY,1,0.3
TUNIF,HOT
TOFF,1E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4
C*** PARAMETRIC INPUT FOR CREEP CONSTANT !(STRAIN HARDENING)***
*SET,C1,1.5625E-14
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** ELASTIC CONSTANT
MP,EX,2,200E3
MP,NUXY,2,0.3
TB,CREEP,2,,,7
TBDATA,1,C1,C2,C3,C4
N,1,0,0,0
N,2,100,0
N,3,100,50
N,4,0,50
N,5,100,100
N,6,0,100
N,7,50,0
N,8,100,25
N,9,50,50
N,10,0,25
N,11,100,75
N,12,50,100
N,13,0,75
ET,1,SHELL281,,,
R,1,1,1,1,1,
E,1,2,3,4,7,8,9,10
E,4,3,5,6,9,11,12,13
NSEL,S,LOC,X,
D,ALL,UX,
NSEL,ALL
NSEL,S,,,4
D,ALL,UY,
NSEL,ALL
D,ALL,UZ
```

```
D,ALL,ROTX
D,ALL,ROTY
D,ALL,ROTZ
*DO,I,1,2
*STATUS,I
/PREP7
*IF,I,EQ,1,THEN
MAT,1
*ELSEIF,I,EQ,2,THEN
MPCHG,2,ALL
*ENDIF
FINISH
/SOLU
NSEL,S,LOC,X,100
SF,ALL,PRES,-200
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,1E-2,1E-2,1
TIME,100
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
/SOLU
SFDELE,ALL,ALL
NSEL,S,LOC,X,100
SF,ALL,PRES,-250
NSEL,ALL
RATE, OFF
DELT,1.0E-8,1.0E-9,1.0E-8
TIME,100.00000001
/OUTPUT,SCRATCH
OUTRES,ALL,LAST
SOLVE
/OUT
RATE, ON, ON
DELT,1,1,10
TIME,200
/OUTPUT,SCRATCH
OUTRES,ALL,ALL
SOLVE
/OUT
FINISH
*IF,I,EQ,1,THEN
/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,DIVX,4
/GROPT,DIVY,7
/XRANGE,0,200
/YRANGE,0,0.35
ESOL,2,1,,EPCR,X,TIMEHARDENING
/COLOR,CURVE,GREE,1
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN (XX)
PLVAR,2
PRVAR,2
```

```
/POST1
SET,,,,,,,1
*GET,S1,NODE,3,EPCR,X
R1=1.000
SET,,,,,,,62
*GET,S2,NODE,3,EPCR,X
R2=S2/0.068
SET,,,,,,,112
*GET,S3,NODE,3,EPCR,X
R3=S3/0.097
SET,,,,,,,123
*GET,S4,NODE,3,EPCR,X
R4=S4/0.166
SET,,,,,,,128
*GET,S5,NODE,3,EPCR,X
R5=S5/0.221
*DIM,VALUE,,5,3
*DIM,VALUE2,,5,3
*DIM,LABEL,CHAR,10
*DIM,TARGET,CHAR,10
LABEL(1) = '0','50','100','150','200'
TARGET(1) = '0.000','0.068','0.097','0.166','0.221'
*VFILL,VALUE(1,1),DATA,S1,S2,S3,S4,S5
*VFILL,VALUE2(1,1),DATA,R1,R2,R3,R4,R5
*ELSEIF,I,EQ,2,THEN
/POST26
/NOERASE
/AXLAB,X,
/AXLAB,Y,
/GROPT,DIVX,4
/GROPT,DIVY,7
/XRANGE,0,200
/YRANGE,0,0.35
ESOL,3,1,,EPCR,X,STRAINHARDENING
/COLOR,CURVE,BMAG,1
/AXLAB,X,TIME
/AXLAB,Y,CREEP STRAIN (XX)
PLVAR,3
PRVAR,3
/POST1
SET,,,,,,,1
*GET,S1_2,NODE,3,EPCR,X
R6=1.000
SET,,,,,,,62
*GET,S2_2,NODE,3,EPCR,X
R7=S2_2/0.070
SET,,,,,,,112
*GET,S3_2,NODE,3,EPCR,X
R8=S3_2/0.099
SET,,,,,,,123
*GET,S4_2,NODE,3,EPCR,X
R9=S4_2/0.236
SET,,,,,,,128
*GET,S5_2,NODE,3,EPCR,X
R10=S5_2/0.315
*DIM,VALUE3,,5,3
*DIM,VALUE4,,5,3
*DIM,LABEL2,CHAR,10
*DIM,TARGET2,CHAR,10
*VFILL,VALUE3(1,1),DATA,S1_2,S2_2,S3_2,S4_2,S5_2
*VFILL,VALUE4(1,1),DATA,R6,R7,R8,R9,R10
LABEL2(1) = '0','50','100','150','200'
TARGET2(1) = '0.000','0.070','0.099','0.236','0.315'
*ENDIF
FINISH
*ENDDO
/COM
/COM
/COM
/COM,--------- vmr049-cr3-281 TIME HARDENING COMPARISON-----------
/COM
/COM  COMPARE NUMERICAL VALUES LISTED
```

```
/COM  BELOW WITH GRAPH OF FIGURE 3.12A ON
/COM  PAGE 105 AS NO NUMERICAL RESULTS ARE
/COM  PRESENTED.
/COM
/COM,| TIME |  TARGET |  Mechanical APDL  |  RATIO |
/COM,
*VWRITE,LABEL(1),TARGET(1),VALUE(1,1),VALUE2(1,1)
(1X,A6,'   ',1X,A6,'   ',F14.3,'   ',1F12.3,'   ')
/COM
/COM
/COM,--------- vmr049-cr3-281 STRAIN HARDENING COMPARISON-----------
/COM,
/COM,| TIME |  TARGET |  Mechanical APDL  |  RATIO |
/COM,
*VWRITE,LABEL2(1),TARGET2(1),VALUE3(1,1),VALUE4(1,1)
(1X,A6,'   ',1X,A6,'   ',F14.3,'   ',1F12.3,'   ')
FINISH
/POST26
*DIM,LABEL3,CHAR,2
*DIM,VALUE5,,2,3
LABEL3(1) = ' S2 ',' S7 '
*VFILL,VALUE5(1,1),DATA,S5,S5_2
*VFILL,VALUE5(1,2),DATA,R5,R10
*DIM,LABEL4,CHAR,2
LABEL4(1) = 'vmr049-','cr3-281'
/OUT,vmr049-cr3-281,vrt
/COM
/COM,------------------- vmr049-cr3 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL3(1),VALUE5(1,1),VALUE5(1,2),LABEL4(1),LABEL4(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL3(2),VALUE5(2,1),VALUE5(2,2),LABEL4(1),LABEL4(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr049-cr3-281,vrt
```

VM-R049-4 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr4-182
/TITLE,vmr049-cr4-182,PRESSURISED CYLINDER CREEP BENCHMARK
/COM,NAFEMS REPORT R0049, TEST:  CR-4
/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS !***
*SET,C1,3.125E-14
*SET,C2,5.0
*SET,C3,0.0
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,100
C***   ELASTIC CONSTANT
MP,EX,,0.2000E+06
MP,EY,,0.2000E+06
MP,EZ,,0.2000E+06
MP,GXY,,0.7692E+05
MP,GYZ,,0.7692E+05
MP,GXZ,,0.7692E+05
MP,NUXY,,0.3000E+00
MP,NUYZ,,0.3000E+00
MP,NUXZ,,0.3000E+00
MP,DENS,,0.0000E+00
TB,CREEP,1,,,6
```

```
TBDATA,1,C1,C2,C3,C4
N,1,100
N,9,200
FILL,1,9,7,2,1,1,
N,10,100,12.5
N,18,200,12.5
FILL,10,18,7,11,1,1,
N,19,100,25
N,27,200,25
FILL,19,27,7,20,1,1,
ET,1,182,1,,1
E,1,2,11,10
EGEN,8,1,1
EN,9,10,11,20,19
EGEN,8,1,9
NSEL,ALL
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
NSEL,S,LOC,Y,25
D,ALL,UY
NSEL,ALL
FINI

/SOLU
RATE, OFF
SOLCONTROL,ON
ERESX,ON
NSEL,S,LOC,X,100
SF,ALL,PRES,200
NSEL,ALL
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUT,SCRATCH
SOLVE
/OUT
/SOLU
RATE, ON, ON
SOLCONTROL,ON
ERESX,OFF
NSUBST,1000,10000,100
TIME, 100
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT

/POST1
SET,FIRST
FLST,2,2,1
FITEM,2,1
FITEM,2,9
PATH,PATH,2,30,20,
PPATH,P51X,1
PDEF,STAT
AVPRIN,0,0,
PDEF,SXELASTI,S,X,AVG
*DIM,SXELAS,ARRAY,21,1
*DO,JJ,1,21,5
*GET,SXELAS(JJ,1),PATH,0,ITEM,SXELASTI,PATHPT,JJ
*ENDDO
V1=SXELAS(1,1)
V2=SXELAS(6,1)
V3=SXELAS(11,1)
V4=SXELAS(16,1)
V5=SXELAS(21,1)
*DIM,SXELAST,,5,1
*VFILL,SXELAST,DATA,V1,V2,V3,V4,V5
R1=SXELAS(1,1)/(-194.074)
R2=SXELAS(6,1)/(-100.337)
R3=SXELAS(11,1)/(-50.123)
```

```
R4=SXELAS(16,1)/(-19.487)
R5=SXELAS(21,1)/(.635)
AVPRIN,0,0,
PDEF,SZELASTI,S,Z,AVG
*DIM,SZELAS,ARRAY,21,1
*DO,JJ,1,21,5
*GET,SZELAS(JJ,1),PATH,0,ITEM,SZELASTI,PATHPT,JJ
*ENDDO
V6=SZELAS(1,1)
V7=SZELAS(6,1)
V8=SZELAS(11,1)
V9=SZELAS(16,1)
V10=SZELAS(21,1)
*DIM,SZELAST,,5,1
*VFILL,SZELAST,DATA,V6,V7,V8,V9,V10
R6=SZELAS(1,1)/(327.407)
R7=SZELAS(6,1)/(233.670)
R8=SZELAS(11,1)/(183.457)
R9=SZELAS(16,1)/(152.821)
R10=SZELAS(21,1)/(132.698)
/AXLAB,X,RADIUS
/AXLAB,Y,STRESS
/XRANGE,0,100
/YRANGE,-250,500
/COLOR,CURVE,RED,1
PLPATH,SXELASTI
/NOERASE
/COLOR,CURVE,BLUE,1
PLPATH,SZELASTI
PRPATH,SXELASTI,SZELASTI
/NOERASE
SET,LAST
PDEF,SXSTEADY,S,X,AVG
AVPRIN,0,0,
PDEF,SZSTEADY,S,Z,AVG
/COLOR,CURVE,GREE,1
PLPATH,SXSTEADY
/COLOR,CURVE,YELL,1
PLPATH,SZSTEADY
PRPATH,SXSTEADY,SZSTEADY
*DIM,SXSTEA,ARRAY,21,1
*DO,JJ,1,21,5
*GET,SXSTEA(JJ,1),PATH,0,ITEM,SXSTEADY,PATHPT,JJ
*ENDDO
V11=SXSTEA(1,1)
V12=SXSTEA(6,1)
V13=SXSTEA(11,1)
V14=SXSTEA(16,1)
V15=SXSTEA(21,1)
*DIM,SXSTEAD,,5,1
*VFILL,SXSTEAD,DATA,V11,V12,V13,V14,V15
R11=SXSTEA(1,1)/(-183.134)
R12=SXSTEA(6,1)/(-129.850)
R13=SXSTEA(11,1)/(-76.583)
R14=SXSTEA(16,1)/(-34.512)
R15=SXSTEA(21,1)/(-6.742)
PRPATH,SZSTEADY
*DIM,SZSTEA,ARRAY,21,1
*DO,JJ,1,21,5
*GET,SZSTEA(JJ,1),PATH,0,ITEM,SZSTEADY,PATHPT,JJ
*ENDDO
V16=SZSTEA(1,1)
V17=SZSTEA(6,1)
V18=SZSTEA(11,1)
V19=SZSTEA(16,1)
V20=SZSTEA(21,1)
*DIM,SZSTEAD,,5,1
*VFILL,SZSTEAD,DATA,V16,V17,V18,V19,V20
R16=SZSTEA(1,1)/(140.547)
R17=SZSTEA(6,1)/(172.463)
R18=SZSTEA(11,1)/(204.427)
R19=SZSTEA(16,1)/(229.672)
```

```
R20=SZSTEA(21,1)/(246.329)
*DIM,TIME,CHAR,10
*DIM,TSXELAST,CHAR,10
*DIM,TSZELAST,CHAR,10
*DIM,TSXSTEAD,CHAR,10
*DIM,TSZSTEAD,CHAR,10
*DIM,RSXELAST,,5,1
*DIM,RSZELAST,,5,1
*DIM,RSXSTEAD,,5,1
*DIM,RSZSTEAD,,5,1
TIME(1)='100','125','150','175','200'
TSXELAST(1)='-194.074','-100.337','-50.123','-19.487','.635'
TSZELAST(1)='327.407','233.670','183.457','152.821','132.698'
TSXSTEAD(1)='-183.134','-129.850','-76.583','-34.512','-6.742'
TSZSTEAD(1)='140.547','172.463','204.427','229.672','246.329'
*VFILL,RSXELAST,DATA,R1,R2,R3,R4,R5
*VFILL,RSZELAST,DATA,R6,R7,R8,R9,R10
*VFILL,RSXSTEAD,DATA,R11,R12,R13,R14,R15
*VFILL,RSZSTEAD,DATA,R16,R17,R18,R19,R20
/COM,
/COM, ----------- vmr049-cr4-182 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-cr4-182.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 107, FIGURE 3.14.  THE TARGET VALUES
/COM, DISPLAYED ARE TAKEN FROM VMR049-CR4-183 BECAUSE GRAPH IS
/COM, NOT EXPLICIT ENOUGH, REFINING MESH WILL GIVE MORE ACCURATE RESULTS
/COM,
/COM,
/COM, ------ vmr049-cr4-182 ELASTIC RADIAL STRESS -------
/COM,
/COM, |  RADIUS  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TSXELAST(1),SXELAST(1,1),RSXELAST(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-cr4-182 ELASTIC HOOP STRESS -------
/COM,
/COM, |  RADIUS  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TSZELAST(1),SZELAST(1,1),RSZELAST(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-cr4-182 STEADY-STATE RADIAL STRESS -------
/COM,
/COM, |  RADIUS  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TSXSTEAD(1),SXSTEAD(1,1),RSXSTEAD(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-cr4-182 STEADY-STATE HOOP STRESS -------
/COM,
/COM, |  RADIUS  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TSZSTEAD(1),SZSTEAD(1,1),RSZSTEAD(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,4
*DIM,VALUE1,,4,3
LABEL1(1) = ' ELS6X ',' ELS6Z ',' SSS6X ',' SSS6Z '
*VFILL,VALUE1(1,1),DATA,V4,V9,V14,V19
*VFILL,VALUE1(1,2),DATA,R4,R9,R14,R19
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr4-182'

/OUT,vmr049-cr4-182,vrt
/COM
```

```
/COM,------------------- vmr049-cr4 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
/COM, RESULTS TAKEN AT RADIUS=175
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(4),VALUE1(4,1),VALUE1(4,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr4-182,vrt
```

VM-R049-4 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr4-183
/TITLE,vmr049-cr4-183,PRESSURISED CYLINDER CREEP BENCHMARK
/COM,NAFEMS R0049, TEST:  CR-4

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS !***
*SET,C1,3.125E-14
*SET,C2,5.0
*SET,C3,0.0
*SET,C4,0
C***  TIME PARAMETER
*SET,HOUR,100
C***   ELASTIC CONSTANT
MP,EX,1,0.2000E+06
MP,EY,1,0.2000E+06
MP,EZ,1,0.2000E+06
MP,GXY,1,0.7692E+05
MP,GYZ,1,0.7692E+05
MP,GXZ,1,0.7692E+05
MP,NUXY,1,0.3000E+00
MP,NUYZ,1,0.3000E+00
MP,NUXZ,1,0.3000E+00
TB,CREEP,1,,,6
TBDATA,1,C1,C2,C3,C4
N,1,100
N,9,200
FILL,1,9,7,2,1,1,1,1,
N,10,100,25
N,18,200,25
FILL,10,18,7,11,1,1,1,1,
N,19,100,12.5
N,27,200,12.5
FILL,19,27,3,21,2
ET,1,183,,,1
E,1,3,12,10,2,21,11,19
EGEN,4,2,1
NSEL,ALL
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
NSEL,S,LOC,Y,25
D,ALL,UY
NSEL,ALL
FINISH
```

```
/SOLU
RATE, OFF
SOLCONTROL,ON
ERESX,ON
NSEL,S,LOC,X,100
SF,ALL,PRES,200
NSEL,ALL
DELT,1.0E-8,1.0E-9,1.0E-8
TIME, 1.0E-8
OUTRES,ALL,LAST
/OUT,SCRATCH
SOLVE
/OUT
/SOLU
RATE, ON, ON
SOLCONTROL,ON
ERESX,OFF
NSUBST,1000,10000,100
TIME, 100
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE
/OUT

/POST1
SET,FIRST
FLST,2,2,1
FITEM,2,1
FITEM,2,9
PATH,PATH,2,30,20,
PPATH,P51X,1
PDEF,STAT
AVPRIN,0,0,
PDEF,SXELASTI,S,X,AVG
*DIM,SXELAS,ARRAY,21,1
*DO,JJ,1,21,5
*GET,SXELAS(JJ,1),PATH,0,ITEM,SXELASTI,PATHPT,JJ
*ENDDO
V1=SXELAS(1,1)
V2=SXELAS(6,1)
V3=SXELAS(11,1)
V4=SXELAS(16,1)
V5=SXELAS(21,1)
*DIM,SXELAST,,5,1
*VFILL,SXELAST,DATA,V1,V2,V3,V4,V5
R1=SXELAS(1,1)/(-194.074)
R2=SXELAS(6,1)/(-100.337)
R3=SXELAS(11,1)/(-50.123)
R4=SXELAS(16,1)/(-19.487)
R5=SXELAS(21,1)/(.635)
AVPRIN,0,0,
PDEF,SZELASTI,S,Z,AVG
*DIM,SZELAS,ARRAY,21,1
*DO,JJ,1,21,5
*GET,SZELAS(JJ,1),PATH,0,ITEM,SZELASTI,PATHPT,JJ
*ENDDO
V6=SZELAS(1,1)
V7=SZELAS(6,1)
V8=SZELAS(11,1)
V9=SZELAS(16,1)
V10=SZELAS(21,1)
*DIM,SZELAST,,5,1
*VFILL,SZELAST,DATA,V6,V7,V8,V9,V10
R6=SZELAS(1,1)/(327.407)
R7=SZELAS(6,1)/(233.670)
R8=SZELAS(11,1)/(183.457)
R9=SZELAS(16,1)/(152.821)
R10=SZELAS(21,1)/(132.698)
/AXLAB,X,RADIUS
/AXLAB,Y,STRESS
/XRANGE,0,100
```

```
/YRANGE,-250,500
/COLOR,CURVE,RED,1
PLPATH,SXELASTI
/NOERASE
/COLOR,CURVE,BLUE,1
PLPATH,SZELASTI
PRPATH,SXELASTI,SZELASTI
/NOERASE
SET,LAST
PDEF,SXSTEADY,S,X,AVG
AVPRIN,0,0,
PDEF,SZSTEADY,S,Z,AVG
/COLOR,CURVE,GREE,1
PLPATH,SXSTEADY
/COLOR,CURVE,YELL,1
PLPATH,SZSTEADY
PRPATH,SXSTEADY,SZSTEADY
*DIM,SXSTEA,ARRAY,21,1
*DO,JJ,1,21,5
*GET,SXSTEA(JJ,1),PATH,0,ITEM,SXSTEADY,PATHPT,JJ
*ENDDO
V11=SXSTEA(1,1)
V12=SXSTEA(6,1)
V13=SXSTEA(11,1)
V14=SXSTEA(16,1)
V15=SXSTEA(21,1)
*DIM,SXSTEAD,,5,1
*VFILL,SXSTEAD,DATA,V11,V12,V13,V14,V15
R11=SXSTEA(1,1)/(-183.134)
R12=SXSTEA(6,1)/(-129.850)
R13=SXSTEA(11,1)/(-76.583)
R14=SXSTEA(16,1)/(-34.512)
R15=SXSTEA(21,1)/(-6.742)
*DIM,SZSTEA,ARRAY,21,1
*DO,JJ,1,21,5
*GET,SZSTEA(JJ,1),PATH,0,ITEM,SZSTEADY,PATHPT,JJ
*ENDDO
V16=SZSTEA(1,1)
V17=SZSTEA(6,1)
V18=SZSTEA(11,1)
V19=SZSTEA(16,1)
V20=SZSTEA(21,1)
*DIM,SZSTEAD,,5,1
*VFILL,SZSTEAD,DATA,V16,V17,V18,V19,V20
R16=SZSTEA(1,1)/(140.547)
R17=SZSTEA(6,1)/(172.463)
R18=SZSTEA(11,1)/(204.427)
R19=SZSTEA(16,1)/(229.672)
R20=SZSTEA(21,1)/(246.329)
*DIM,TIME,CHAR,10
*DIM,TSXELAST,CHAR,10
*DIM,TSZELAST,CHAR,10
*DIM,TSXSTEAD,CHAR,10
*DIM,TSZSTEAD,CHAR,10
*DIM,RSXELAST,,5,1
*DIM,RSZELAST,,5,1
*DIM,RSXSTEAD,,5,1
*DIM,RSZSTEAD,,5,1
TIME(1)='100','125','150','175','200'
TSXELAST(1)='-194.074','-100.337','-50.123','-19.487',' 0.635'
TSZELAST(1)='327.407','233.670','183.457','152.821','132.698'
TSXSTEAD(1)='-183.134','-129.850','-76.583','-34.512','-6.742'
TSZSTEAD(1)='140.547','172.463','204.427','229.672','246.329'
*VFILL,RSXELAST,DATA,R1,R2,R3,R4,R5
*VFILL,RSZELAST,DATA,R6,R7,R8,R9,R10
*VFILL,RSXSTEAD,DATA,R11,R12,R13,R14,R15
*VFILL,RSZSTEAD,DATA,R16,R17,R18,R19,R20
/COM,
/COM, ----------- vmr049-cr4-183 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-cr4-183.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 107, FIGURE 3.14.  THE RESULTS
```

```
/COM, DISPLAYED ARE TAKEN FROM THIS TEST BECAUSE GRAPH RESULTS ARE
/COM, NOT EXPLICIT ENOUGH TO JUDGE ACTUAL VALUES.
/COM,
/COM,
/COM, ------ vmr049-cr4-183 ELASTIC RADIAL STRESS -------
/COM,
/COM, |  RADIUS  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TSXELAST(1),SXELAST(1,1),RSXELAST(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-cr4-183 ELASTIC HOOP STRESS  -------
/COM,
/COM, |  RADIUS  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TSZELAST(1),SZELAST(1,1),RSZELAST(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-cr4-183 STEADY-STATE RADIAL STRESS -------
/COM,
/COM, |  RADIUS  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TSXSTEAD(1),SXSTEAD(1,1),RSXSTEAD(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-cr4-183 STEADY-STATE HOOP STRESS -------
/COM,
/COM, |  RADIUS  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TSZSTEAD(1),SZSTEAD(1,1),RSZSTEAD(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,4
*DIM,VALUE1,,4,3
LABEL1(1) = ' ELS6X ',' ELS6Z ',' SSS6X ',' SSS6Z '
*VFILL,VALUE1(1,1),DATA,V4,V9,V14,V19
*VFILL,VALUE1(1,2),DATA,R4,R9,R14,R19
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr4-183'

/OUT,vmr049-cr4-183,vrt
/COM
/COM,------------------- vmr049-cr4 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
/COM, RESULTS TAKEN AT RADIUS=175
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(4),VALUE1(4,1),VALUE1(4,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr4-183,vrt
```

VM-R049-5 185 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr5-185
/TITLE,vmr049-cr5-185,TORSIONAL CREEP OF SQUARE SHAFT
/COM, THE COMPARISON IS MADE GRAPHICALLY WITH THE RESULTS OF THE TEST CR-5 (R0049)
/COM, FROM THE NAFEMS REPORT, FOR THE CONSTANT TWIST STUDY

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT
*SET,C1,1E4
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
C*** TIME PARAMETER
*SET,HOUR,100
ET,1,185
MP,EX,1,10
MP,NUXY,1,0.3
TOFF,1.0E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4,
BLOCK,0,1,0,1,0,0.2
ESIZE,0.125
VMESH,ALL
NODE10=NODE(1,0,0.2)
CSYS,1
NROTAT,ALL
*DIM,A,ARRAY,243
*DIM,B,ARRAY,243
*DO,I,1,243
A(I)=NX(I)
B(I)=NY(I)*3.1415926/180
*ENDDO
CSYS,0
NROTAT,ALL
NSEL,S,LOC,Z,
D,ALL,UX,0
D,ALL,UY,0
NSEL,ALL
NODE1=NODE(0,0,0)
NODE2=NODE(1,0,0)
NODE3=NODE(0,1,0)
D,NODE1,UZ,0
D,NODE2,UZ,0
D,NODE3,UZ,0
NSEL,ALL
NSEL,S,LOC,X,
NSEL,R,LOC,Z,0.1
NSEL,A,LOC,Y,
NSEL,R,LOC,Z,0.1
CP,163,UZ,ALL
NSEL,ALL
NSEL,S,LOC,X,
NSEL,R,LOC,Z,0.2
NSEL,A,LOC,Y,
NSEL,R,LOC,Z,0.2
CP,82,UZ,ALL
NSEL,ALL
NSEL,S,LOC,X,
NSEL,R,LOC,Z,
NSEL,A,LOC,Y,
NSEL,R,LOC,Z,
CP,2,UZ,ALL
NSEL,ALL

/SOLU
*DO,I,163,243
D,I,UX,-A(I)*0.001*SIN(B(I))
```

```
D,I,UY,A(I)*0.001*COS(B(I))
*ENDDO

*DO,I,82,162
D,I,UX,-A(I)*0.002*SIN(B(I))
D,I,UY,A(I)*0.002*COS(B(I))
*ENDDO

/SOLU
RATE, ON
DELT,.0001,.000099,.000101
TIME, .0001
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,.001,.00099,.00101
TIME, .001
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,.01,.009,.011
TIME, .01
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,0.10,0.09,0.11
TIME, 0.10
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,1,0.99,1.1
TIME, 1
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,10,9.99,10.01
TIME, 10
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,100,99.9,100.01
TIME, 100
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/POST26
```

```
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,LOGTIME
/AXLAB,Y,SHEAR STRESS(YZ)
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,LOGX,ON
/GROPT,DIVX,6
/GROPT,DIVY,3
/XRANGE,1E-4,1E2
/YRANGE,0,0.06
ANSOL,2,NODE10,S,YZ
PLVAR,2
PRVAR,2
/GROPT,DIVX,6
/GROPT,DIVY,5
/XRANGE,1E-4,1E2
/YRANGE,0,0.05
ANSOL,3,NODE10,EPEL,YZ
ANSOL,4,NODE10,EPCR,YZ
ADD,5,3,4,,ETOTAL
PLVAR,3,4,5
PRVAR,3,4,5
FINISH

/POST1
*DIM,LABEL,CHAR,10
*DIM,SYZ,ARRAY,7,1
*DIM,TARGET,CHAR,10
*DIM,RATIO,ARRAY,7,1
*DO,JJ,1,7,1
SET,JJ
*GET,SYZ(JJ),NODE,NODE10,S,YZ

*ENDDO
R1=SYZ(1)/0.05000
R2=SYZ(2)/0.04322
R3=SYZ(3)/0.03751
R4=SYZ(4)/0.03081
R5=SYZ(5)/0.02499
R6=SYZ(6)/0.01877
R7=SYZ(7)/0.01427
TARGET(1)='0.05000','0.04322','0.03751','0.03081','0.02499','0.01877','0.01427'
LABEL(1)='-4','-3','-2','-1','0','1','2'
*VFILL,RATIO,DATA,R1,R2,R3,R4,R5,R6,R7
/COM
/COM,--------- vmr049-cr5-185 RESULTS COMPARISON-----------
/COM,
/COM, vmr049-cr5-185.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 109, FIGURE 3.16(A).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,|  LOG(TIME) |  TARGET   |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,LABEL(1),TARGET(1),SYZ(1,1),RATIO(1,1)
(1X,A12,'   ',1X,A8,'   ',F14.6,'   ',1F12.3)
FINISH

*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' SYZ2 ',
*VFILL,VALUE1(1,1),DATA,SYZ(7)
*VFILL,VALUE1(1,2),DATA,R7
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr5-185'
```

```
/OUT,vmr049-cr5-185,vrt
/COM
/COM,------------------- vmr049-cr5 RESULTS COMPARISON ---------------------
/COM,
/COM,                |   Mechanical APDL    |   RATIO  |         INPUT         |
/COM,
/COM, SOLID185
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr5-185,vrt
```

VM-R049-5 186 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr5-186
/TITLE,vmr049-cr5-186,TORSIONAL CREEP OF SQUARE SHAFT
/COM NAFEMS: R0049  TEST: CR-5

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT
*SET,C1,1E4
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
*SET,HOUR,100
ET,1,186
MP,EX,1,10
MP,NUXY,1,0.3
TOFF,1.0E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4,
BLOCK,0,1,0,1,0,0.2
ESIZE,0.25
VMESH,ALL
NODE10=NODE(1,0,0.2)
CSYS,1
NROTAT,ALL
*DIM,A,ARRAY,155
*DIM,B,ARRAY,155
*DO,I,1,155
A(I)=NX(I)
B(I)=NY(I)*3.1415926/180
*ENDDO
CSYS,0
NROTAT,ALL
NSEL,S,LOC,Z,
D,ALL,UX,0
D,ALL,UY,0
NSEL,ALL
NODE1=NODE(0,0,0)
NODE2=NODE(1,0,0)
NODE3=NODE(0,1,0)
D,NODE1,UZ,0
D,NODE2,UZ,0
D,NODE3,UZ,0
NSEL,ALL
NSEL,S,LOC,X,
NSEL,R,LOC,Z,0.1
NSEL,A,LOC,Y,
NSEL,R,LOC,Z,0.1
CP,131,UZ,ALL
NSEL,ALL
NSEL,S,LOC,X,
```

```
NSEL,R,LOC,Z,0.2
NSEL,A,LOC,Y,
NSEL,R,LOC,Z,0.2
CP,66,UZ,ALL
NSEL,ALL
NSEL,S,LOC,X,
NSEL,R,LOC,Z,
NSEL,A,LOC,Y,
NSEL,R,LOC,Z,
CP,2,UZ,ALL
NSEL,ALL

/SOLU
*DO,I,131,155
D,I,UX,-A(I)*0.001*SIN(B(I))
D,I,UY,A(I)*0.001*COS(B(I))
*ENDDO

*DO,I,66,130
D,I,UX,-A(I)*0.002*SIN(B(I))
D,I,UY,A(I)*0.002*COS(B(I))
*ENDDO

/SOLU
RATE, ON
DELT,.0001,.000099,.000101
TIME, .0001
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,.001,.00099,.00101
TIME, .001
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,.01,.009,.011
TIME, .01
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,0.10,0.09,0.11
TIME, 0.10
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,1,0.99,1.1
TIME, 1
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,10,9.99,10.01
TIME, 10
```

```
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,100,99.9,100.01
TIME, 100
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,LOGTIME
/AXLAB,Y,SHEAR STRESS(YZ)
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,LOGX,ON
/GROPT,DIVX,6
/GROPT,DIVY,3
/XRANGE,1E-4,1E2
/YRANGE,0,0.06
ANSOL,2,NODE10,S,YZ
PLVAR,2
PRVAR,2
/GROPT,DIVX,6
/GROPT,DIVY,5
/XRANGE,1E-4,1E2
/YRANGE,0,0.05
ANSOL,3,NODE10,EPEL,YZ
ANSOL,4,NODE10,EPCR,YZ
ADD,5,3,4,,ETOTAL
PLVAR,3,4,5
PRVAR,3,4,5
FINISH

/POST1
*DIM,LABEL,CHAR,10
*DIM,SYZ,ARRAY,7,1
*DIM,TARGET,CHAR,10
*DIM,RATIO,ARRAY,7,1
*DO,JJ,1,7,1
SET,JJ
*GET,SYZ(JJ),NODE,NODE10,S,YZ
*ENDDO
R1=SYZ(1)/0.05000
R2=SYZ(2)/0.04322
R3=SYZ(3)/0.03751
R4=SYZ(4)/0.03081
R5=SYZ(5)/0.02499
R6=SYZ(6)/0.01877
R7=SYZ(7)/0.01427
TARGET(1)='0.0500','0.04322','0.03751','0.03081','0.02499','0.01877','0.01427'
LABEL(1)='-4','-3','-2','-1','0','1','2'
*VFILL,RATIO,DATA,R1,R2,R3,R4,R5,R6,R7
/COM
/COM,--------- vmr049-cr5-186 MIXED FORMULATION COMPARISON-----------
/COM,
/COM, vmr049-cr5-186.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 109, FIGURE 3.16(A).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
```

```
/COM,|  LOG(TIME) |  TARGET   |  Mechanical APDL   |  RATIO
/COM,
*VWRITE,LABEL(1),TARGET(1),SYZ(1,1),RATIO(1,1)
(1X,A12,'   ',1X,A8,'   ',F14.6,'   ',1F12.3)
FINISH

*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' SYZ2 '
*VFILL,VALUE1(1,1),DATA,SYZ(7)
*VFILL,VALUE1(1,2),DATA,R7
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr5-186'

/OUT,vmr049-cr5-186,vrt
/COM
/COM,------------------- vmr049-cr5 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID186
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr5-186,vrt
```

VM-R049-5 187 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-cr5-187
/TITLE,vmr049-cr5-187,TORSIONAL CREEP OF SQUARE SHAFT
/COM NAFEMS: R0049  TEST: CR-5

/PREP7
C*** PARAMETRIC INPUT FOR CREEP CONSTANT
*SET,C1,1E4
*SET,C2,5
*SET,C3,-0.5
*SET,C4,0
*SET,HOUR,100
ET,1,187
MP,EX,1,10
MP,NUXY,1,0.3
TOFF,1.0E-10
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4,
BLOCK,0,1,0,1,0,0.2
ESIZE,0.25
VMESH,ALL
NODE10=NODE(1,0,0.2)
CSYS,1
NROTAT,ALL
*DIM,A,ARRAY,349
*DIM,B,ARRAY,349
*DO,I,1,349
A(I)=NX(I)
B(I)=NY(I)*3.1415926/180
*ENDDO
CSYS,0
NROTAT,ALL
NSEL,S,LOC,Z,
D,ALL,UX,0
D,ALL,UY,0
NSEL,ALL
```

```
NODE1=NODE(0,0,0)
NODE2=NODE(1,0,0)
NODE3=NODE(0,1,0)
D,NODE1,UZ,0
D,NODE2,UZ,0
D,NODE3,UZ,0
NSEL,ALL
NSEL,S,LOC,X,
NSEL,R,LOC,Z,0.1
NSEL,A,LOC,Y,
NSEL,R,LOC,Z,0.1
CP,195,UZ,ALL
NSEL,ALL
NSEL,S,LOC,X,
NSEL,R,LOC,Z,0.2
NSEL,A,LOC,Y,
NSEL,R,LOC,Z,0.2
CP,98,UZ,ALL
NSEL,ALL
NSEL,S,LOC,X,
NSEL,R,LOC,Z,
NSEL,A,LOC,Y,
NSEL,R,LOC,Z,
CP,2,UZ,ALL
NSEL,ALL

/SOLU
NSEL,S,LOC,Z,0.1
*GET,_NMIN,NODE,,NUM,MIN
*GET,_NNUM,NODE,,COUNT

*DO,I,1,_NNUM
   D,_NMIN,UX,-A(_NMIN)*0.001*SIN(B(_NMIN))
   D,_NMIN,UY,A(_NMIN)*0.001*COS(B(_NMIN))
   NSEL,U,,,_NMIN
   *GET,_NMIN,NODE,,NUM,MIN
*ENDDO

NSEL,S,LOC,Z,0.2
*GET,_NMIN,NODE,,NUM,MIN
*GET,_NNUM,NODE,,COUNT

*DO,I,1,_NNUM
   D,_NMIN,UX,-A(_NMIN)*0.002*SIN(B(_NMIN))
   D,_NMIN,UY,A(_NMIN)*0.002*COS(B(_NMIN))
   NSEL,U,,,_NMIN
   *GET,_NMIN,NODE,,NUM,MIN
*ENDDO
NSEL,ALL
FINISH

/SOLU
RATE, ON
DELT,.0001,.000099,.000101
TIME, .0001
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,.001,.00099,.00101
TIME, .001
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,.01,.009,.011
```

```
TIME, .01
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,0.10,0.09,0.11
TIME, 0.10
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,1,0.99,1.1
TIME, 1
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,10,9.99,10.01
TIME, 10
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/SOLU
RATE, ON
DELT,100,99.9,100.01
TIME, 100
OUTRES,ALL,ALL
/OUTPUT,SCRATCH
SOLVE

/OUT
/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,LOGTIME
/AXLAB,Y,SHEAR STRESS(YZ)
/GTHK,AXIS,1
/GRTYP,0
/GROPT,DIG1,5
/GROPT,DIG2,3
/GROPT,LOGX,ON
/GROPT,DIVX,6
/GROPT,DIVY,3
/XRANGE,1E-4,1E2
/YRANGE,0,0.06
ANSOL,2,NODE10,S,YZ
PLVAR,2
PRVAR,2
/GROPT,DIVX,6
/GROPT,DIVY,5
/XRANGE,1E-4,1E2
/YRANGE,0,0.05
ANSOL,3,NODE10,EPEL,YZ
ANSOL,4,NODE10,EPCR,YZ
ADD,5,3,4,,ETOTAL
PLVAR,3,4,5
PRVAR,3,4,5
```

```
FINISH

/POST1
*DIM,LABEL,CHAR,10
*DIM,SYZ,ARRAY,7,1
*DIM,TARGET,CHAR,10
*DIM,RATIO,ARRAY,7,1
*DO,JJ,1,7,1
SET,JJ
*GET,SYZ(JJ),NODE,NODE10,S,YZ
*ENDDO
R1=SYZ(1)/0.05000
R2=SYZ(2)/0.04322
R3=SYZ(3)/0.03751
R4=SYZ(4)/0.03081
R5=SYZ(5)/0.02499
R6=SYZ(6)/0.01877
R7=SYZ(7)/0.01427
TARGET(1)='0.05000','0.04322','0.03751'
TARGET(4)='0.03081','0.02499','0.01877','0.01427'
LABEL(1)='-4','-3','-2','-1','0','1','2'
*VFILL,RATIO,DATA,R1,R2,R3,R4,R5,R6,R7
/COM
/COM,--------- vmr049-cr5-187 MIXED FORMULATION COMPARISON-----------
/COM,
/COM, vmr049-cr5-187.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 109, FIGURE 3.16(A).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,|  LOG(TIME) |  TARGET   |  Mechanical APDL   |  RATIO
/COM,
*VWRITE,LABEL(1),TARGET(1),SYZ(1,1),RATIO(1,1)
(1X,A12,'   ',1X,A8,'    ',F14.6,'    ',1F12.3)
FINISH

*DIM,LABEL1,CHAR,2
*DIM,VALUE1,,2,3
LABEL1(1) = ' SYZ2 ',
*VFILL,VALUE1(1,1),DATA,SYZ(7)
*VFILL,VALUE1(1,2),DATA,R7
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','cr5-187'

/OUT,vmr049-cr5-187,vrt
/COM
/COM,------------------- vmr049-cr5 RESULTS COMPARISON --------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID187
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr5-187,vrt
```

VM-R049-6 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR049-CR6-182
/TITLE,VMR049-CR6-182,THERMALLY INDUCED CREEP BENCHMARK
C*** REFERENCE NAFEMS101

/PREP7
CYL4,0,0,200,0,500,10
```

```
ET,1,PLANE182
KEYOPT,1,1,0
KEYOPT,1,3,1
LSEL,S,LINE,,1,3,2
LESIZE,ALL, , ,2
LSEL,ALL
LSEL,S,LINE,,2,4,2
LESIZE,ALL,,,20
AMESH,ALL
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS !***
*SET,C1,3E-6
*SET,C2,5.5
*SET,C3,0
*SET,C4,12500
*SET,C5,0
*SET,C6,1
C***  TIME PARAMETER
*SET,HOUR,10E10
C***   ELASTIC CONSTANT
MP,EX,1,1E4
MP,NUXY,1,0.25
TUNIF,HOT
TOFF,OFFS
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4,C5,C6
CSYS,1
NROTAT,ALL
 FINISH

 /SOLU
 NLGEOM,OFF
 RATE, OFF
 SOLCONTROL,ON


 NSEL,ALL
 NSEL,S,LOC,Y
 D,ALL,UY
 NSEL,ALL
 NSEL,S,LOC,Y,10
 D,ALL,UY
 NSEL,ALL
 NSEL,S,LOC,X,200
 SF,ALL,PRES,30
 NSEL,ALL
*DO,I,1,63
 *STATUS,I
 BF,I,TEMP,333*(1+100/NX(I))
*ENDDO
 DELT,1.0E-8,1E-8,1E-7
 TIME, 1.0E-8
 OUTRES,ALL,LAST
 /OUT
 OUTPR,ALL,LAST
 /OUT,SCRATCH
 SOLVE

 /SOLU
 NLGEOM,OFF
 RATE, ON, ON
 SOLCONTROL,ON
 /OUT,SCRATCH
 DELT,1,1,1E3
 TIME, 1E4
 OUTRES,ALL,LAST
 OUTPR,ALL,ALL
 /OUT,SCRATCH
 SOLVE

 /SOLU
 NLGEOM,OFF
 RATE, ON, ON
```

```
 SOLCONTROL,ON
 /OUT,SCRATCH
 DELT,1,1,1E4
 TIME, 1E5
 OUTRES,ALL,LAST
 OUTPR,ALL,ALL
 /OUT,SCRATCH
 SOLVE

 /SOLU
 NLGEOM,OFF
 RATE, ON, ON
 SOLCONTROL,ON
 /OUT,SCRATCH
 DELT,1,1,1E6
 TIME, 1E7
 OUTRES,ALL,LAST
 OUTPR,ALL,ALL
 /OUT,SCRATCH
 SOLVE

 /SOLU
 NLGEOM,OFF
 RATE, ON, ON
 SOLCONTROL,ON
 /OUT,SCRATCH
 DELT,1,1,1E7
 TIME, 1E8
 OUTRES,ALL,LAST
 OUTPR,ALL,ALL
 /OUT,SCRATCH
 SOLVE

 /SOLU
 NLGEOM,OFF
 RATE, ON, ON
 SOLCONTROL,ON
 /OUT,SCRATCH
 DELT,1,1,1E8
 TIME, 1E10
 OUTRES,ALL,ALL
 OUTPR,ALL,ALL
 /OUT,SCRATCH
 SOLVE
 FINISH

/POST1
 /GROPT,VIEW,0
 /GTHK,CURVE,1
 /GROPT,FILL,OFF
 /GRID,1
 /GTHK,GRID,1
 /GROPT,CGRID,1
 /AXLAB,X,RADIUS
 /AXLAB,Y,EFFECTIVE STRESS
 /GTHK,AXIS,1
 /GRTYP,0
 /GROPT,ASCAL,ON
 /GROPT,AXDV,ON
 /GROPT,AXNM,ON
 /GROPT,AXNSC,ON
 /GROPT,DIG1,5
 /GROPT,DIG2,3
 /GROPT,DIVX,2
 /GROPT,DIVY,3
 /XRANGE,0,300
 /YRANGE,0,60,ALL
SET,FIRST
FLST,2,2,1
FITEM,2,24
FITEM,2,1
PATH,PATH,2,30,25,
```

```
PPATH,P51X,1
PDEF,STAT
AVPRIN,0,0,
PDEF,1E-8 ,S,EQV,AVG
/PBC,PATH, ,0
/PSF,DEFA, ,1
/PBF,DEFA, ,1
/PSYMB,CS,0
/PSYMB,NDIR,0
/PSYMB,ESYS,0
/PSYMB,LDIR,0
/PSYMB,ECON,0
/PSYMB,XNODE,1
/PSYMB,DOT,1
/PSYMB,PCONV,
/PSYMB,LAYR,0
/PBC,MAST, ,0
/PBC,CP, ,0
/PBC,CE, ,0
/PBC,ACEL, ,0
/PBC,OMEG, ,0
/PBC,PATH, ,1
/REP
PLPATH,1E-8
PRPATH,1E-8

/NOERASE
SET,NEXT
PDEF,1E4 ,S,EQV,AVG
/PBC,PATH, ,0
/PSF,DEFA, ,1,0
/PBF,DEFA, ,1
/PSYMB,CS,0
/PSYMB,NDIR,0
/PSYMB,ESYS,0
/PSYMB,LDIR,0
/PSYMB,ECON,1
/PSYMB,XNODE,0
/PSYMB,DOT,1
/PSYMB,PCONV,
/PSYMB,LAYR,0
/PBC,MAST, ,0
/PBC,CP, ,0
/PBC,CE, ,0
/PBC,ACEL, ,0
/PBC,OMEG, ,0
/PBC,PATH, ,1
/REP
PLPATH,1E4
PRPATH,1E4

/NOERASE
SET,NEXT
PDEF,1E5 ,S,EQV,AVG
/PBC,PATH, ,0
/PSF,DEFA, ,1,0
/PBF,DEFA, ,1
/PSYMB,CS,0
/PSYMB,NDIR,0
/PSYMB,ESYS,0
/PSYMB,LDIR,0
/PSYMB,ECON,1
/PSYMB,XNODE,0
/PSYMB,DOT,1
/PSYMB,PCONV,
/PSYMB,LAYR,0
/PBC,MAST, ,0
/PBC,CP, ,0
/PBC,CE, ,0
/PBC,ACEL, ,0
/PBC,OMEG, ,0
/PBC,PATH, ,1
```

```
/REP
PLPATH,1E5
PRPATH,1E5

/NOERASE
SET,NEXT
PDEF,1E7 ,S,EQV,AVG
/PBC,PATH, ,0
/PSF,DEFA, ,1,0
/PBF,DEFA, ,1
/PSYMB,CS,0
/PSYMB,NDIR,0
/PSYMB,ESYS,0
/PSYMB,LDIR,0
/PSYMB,ECON,1
/PSYMB,XNODE,0
/PSYMB,DOT,1
/PSYMB,PCONV,
/PSYMB,LAYR,0
/PBC,MAST, ,0
/PBC,CP, ,0
/PBC,CE, ,0
/PBC,ACEL, ,0
/PBC,OMEG, ,0
/PBC,PATH, ,1
/REP
PLPATH,1E7
PRPATH,1E7

/NOERASE
SET,NEXT
PDEF,1E8 ,S,EQV,AVG
/PBC,PATH, ,0
/PSF,DEFA, ,1,0
/PBF,DEFA, ,1
/PSYMB,CS,0
/PSYMB,NDIR,0
/PSYMB,ESYS,0
/PSYMB,LDIR,0
/PSYMB,ECON,1
/PSYMB,XNODE,0
/PSYMB,DOT,1
/PSYMB,PCONV,
/PSYMB,LAYR,0
/PBC,MAST, ,0
/PBC,CP, ,0
/PBC,CE, ,0
/PBC,ACEL, ,0
/PBC,OMEG, ,0
/PBC,PATH, ,1
/REP
PLPATH,1E8
PRPATH,1E8

/NOERASE
SET,LAST
PDEF,1E10 ,S,EQV,AVG
/PBC,PATH, ,0
/PSF,DEFA, ,1,0
/PBF,DEFA, ,1
/PSYMB,CS,0
/PSYMB,NDIR,0
/PSYMB,ESYS,0
/PSYMB,LDIR,0
/PSYMB,ECON,1
/PSYMB,XNODE,0
/PSYMB,DOT,1
/PSYMB,PCONV,
/PSYMB,LAYR,0
/PBC,MAST, ,0
/PBC,CP, ,0
/PBC,CE, ,0
```

```
/PBC,ACEL, ,0
/PBC,OMEG, ,0
/PBC,PATH, ,1
/REP
PLPATH,1E10
PRPATH,1E10

ERASE
/ERASE
 /POST26
 /GROPT,VIEW,0
 /GTHK,CURVE,1
 /GROPT,FILL,OFF
 /GRID,1
 /GTHK,GRID,1
 /GROPT,CGRID,1
 /AXLAB,X,LOG(TIME)
 /AXLAB,Y,STRESS
 /GTHK,AXIS,1
 /GRTYP,0
 /GROPT,ASCAL,ON
 /GROPT,AXDV,ON
 /GROPT,AXNM,ON
 /GROPT,AXNSC,ON
 /GROPT,DIG1,5
 /GROPT,DIG2,3
 /GROPT,LOGX,ON
 /GROPT,DIVX,10
 /GROPT,DIVY,3
 /XRANGE,1,1E10
 /YRANGE,0,30
 NODE1=NODE(200,0,0)
 NODE2=NODE(500,0,0)
 NSOL,2,NODE1,U,X
 NSOL,3,NODE2,U,X
 /GOPR
 /GOLIST
 PLVAR,2,3
 PRVAR,2,3
/GROPT,DIVY,5
 /YRANGE,0,50
 ESOL,4,39,NODE1,S,EQV
 ESOL,5,19,35,S,EQV
 ESOL,6,1,1,S,EQV
 PLVAR,4,5,6
 PRVAR,4,5,6
 FINISH

/POST1
SET,LIST
SET,1,1
*GET,X1,NODE,2,S,EQV
*GET,Y1,NODE,24,S,EQV
*GET,Z1,NODE,35,S,EQV
RX1=X1/3.17
RY1=Y1/44.71
RZ1=Z1/8.98
SET,2,27
*GET,X2,NODE,2,S,EQV
*GET,Y2,NODE,24,S,EQV
*GET,Z2,NODE,35,S,EQV
RX2=X2/3.21
RY2=Y2/41.93
RZ2=Z2/9.08
SET,3,31
*GET,X3,NODE,2,S,EQV
*GET,Y3,NODE,24,S,EQV
*GET,Z3,NODE,35,S,EQV
RX3=X3/3.42
RY3=Y3/34.56
RZ3=Z3/9.63
SET,4,43
```

```
*GET,X4,NODE,2,S,EQV
*GET,Y4,NODE,24,S,EQV
*GET,Z4,NODE,35,S,EQV
RX4=X4/5.55
RY4=Y4/17.56
RZ4=Z4/15.54
SET,5,48
*GET,X5,NODE,2,S,EQV
*GET,Y5,NODE,24,S,EQV
*GET,Z5,NODE,35,S,EQV
RX5=X5/9.12
RY5=Y5/13.33
RZ5=Z5/20.52
SET,6,53
*GET,X6,NODE,2,S,EQV
*GET,Y6,NODE,24,S,EQV
*GET,Z6,NODE,35,S,EQV
RX6=X6/18.63
RY6=Y6/11.36
RZ6=Z6/17.83
SET,6,144
*GET,X7,NODE,2,S,EQV
*GET,Y7,NODE,24,S,EQV
*GET,Z7,NODE,35,S,EQV
RX7=X7/21.16
RY7=Y7/11.25
RZ7=Z7/17.58
*DIM,VALUE1,,7,2
*DIM,VALUE2,,7,2
*DIM,VALUE3,,7,2
*DIM,LABEL3,CHAR,10
*DIM,LABEL1,CHAR,10
*DIM,LABEL2,CHAR,10
*DIM,LABEL4,CHAR,10
LABEL3(1) = '    1E-8','    1E4', '    1E5', '    1E7', '    1E8','    1E9', '    1E10'
LABEL1(1) = '   3.17','   3.21','   3.42','   5.55','   9.12','  18.63','  21.16'
*VFILL,VALUE1(1,1),DATA,X1,X2,X3,X4,X5,X6,X7
*VFILL,VALUE1(1,2),DATA,RX1,RX2,RX3,RX4,RX5,RX6,RX7
LABEL2(1) = '  44.71','  41.93','  34.56','  17.56','  13.33','  11.36','  11.25'
*VFILL,VALUE2(1,1),DATA,Y1,Y2,Y3,Y4,Y5,Y6,Y7
*VFILL,VALUE2(1,2),DATA,RY1,RY2,RY3,RY4,RY5,RY6,RY7
LABEL4(1) = '   8.98','   9.08','   9.63','  15.54','  20.52','  17.83','  17.58'
*VFILL,VALUE3(1,1),DATA,Z1,Z2,Z3,Z4,Z5,Z6,Z7
*VFILL,VALUE3(1,2),DATA,RZ1,RZ2,RZ3,RZ4,RZ5,RZ6,RZ7
/OUT
/COM
/COM
/COM,--------- vmr049-cr6-182 RESULTS COMPARISON-----------
/COM,   RADIUS=495
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL3(1), LABEL1(1), VALUE1(1,1), VALUE1(1,2)
(1X,A8,'   ',A8,'   ',F14.3,'   ',F12.3)
/SHOW,CLOSE

/COM
/COM
/COM,--------- vmr049-cr6-182 RESULTS COMPARISON-----------
/COM,   RADIUS=205
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL3(1), LABEL2(1), VALUE2(1,1), VALUE2(1,2)
(1X,A8,'   ',A8,'   ',F14.3,'   ',F12.3)
/SHOW,CLOSE

/COM
/COM
/COM,--------- vmr049-cr6-182 RESULTS COMPARISON-----------
/COM,   RADIUS=350
/COM,
```

```
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL3(1), LABEL4(1), VALUE3(1,1), VALUE3(1,2)
(1X,A8,'   ',A8,'   ',F14.3,'   ',F12.3)
/SHOW,CLOSE

/OUT,SCRATCH
*DIM,LABEL5,CHAR,7
*DIM,VALUE4,,3,3
LABEL5(1) = ' SR205 ',' SR350 ',' SR495 '
*VFILL,VALUE4(1,1),DATA,Y7,Z7,X7
*VFILL,VALUE4(1,2),DATA,RY7,RZ7,RX7
*DIM,LABEL6,CHAR,2
LABEL6(1) = 'vmr049-','cr6-182'

/OUT,vmr049-cr6-182,vrt
/COM
/COM,------------------- vmr049-cr6 RESULTS COMPARISON ---------------------
/COM,
/COM,              |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL5(1),VALUE4(1,1),VALUE4(1,2),LABEL6(1),LABEL6(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL5(2),VALUE4(2,1),VALUE4(2,2),LABEL6(1),LABEL6(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL5(3),VALUE4(3,1),VALUE4(3,2),LABEL6(1),LABEL6(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,---------------------------------------------------------------
/OUT
FINISH
*LIST,vmr049-cr6-182,vrt
```

VM-R049-6 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR049-CR6-183
/TITLE,VMR049-CR6-183,THERMALLY INDUCED CREEP BENCHMARK
C*** REFERENCE NAFEMS100

/PREP7
CYL4,0,0,200,0,500,10
ET,1,PLANE183
KEYOPT,1,3,1
LSEL,S,LINE,,1,3,2
LESIZE,ALL,,,1
LSEL,ALL
LSEL,S,LINE,,2,4,2
LESIZE,ALL,,,10
AMESH,ALL
C*** PARAMETRIC INPUT FOR CREEP CONSTANTS !***
*SET,C1,3E-6
*SET,C2,5.5
*SET,C3,0
*SET,C4,12500
*SET,C5,0
*SET,C6,1
C***  TIME PARAMETER
*SET,HOUR,1E9
C***   ELASTIC CONSTANT
MP,EX,1,1E4
MP,NUXY,1,0.25
TOFF,0
TB,CREEP,1,,,2
TBDATA,1,C1,C2,C3,C4,C5,C6
CSYS,1
 NSEL,ALL
```

```
NROTAT,ALL
 FINISH

 /SOLU
 RESCONTROL,,NONE
 NLGEOM,OFF
 RATE, OFF
 NSEL,S,LOC,Y
 D,ALL,UY
 NSEL,ALL
 NSEL,S,LOC,Y,10
 D,ALL,UY
 NSEL,ALL
 NSEL,S,LOC,X,200
 SF,ALL,PRES,30
 NSEL,ALL
*DO,I,1,53
 *STATUS,I
 BF,I,TEMP,333*(1+100/NX(I))
*ENDDO
 DELT,1.0E-8,1E-8,1E-7
 TIME, 1.0E-8
 OUTRES,ALL,LAST
 OUTPR,ALL,LAST
 /OUT,scratch
 SOLVE
 /SOLU
 NLGEOM,OFF
 RATE, ON, ON
 SOLCONTROL,ON
 /OUT,scratch
 DELT,1,1,1E3
 TIME, 1E4
 OUTRES,ALL,LAST
 OUTPR,ALL,LAST
 SOLVE

 /SOLU
 NLGEOM,OFF
 RATE, ON, ON
 SOLCONTROL,ON
 /OUT,scratch
 DELT,1,1,1E4
 TIME, 1E5
 OUTRES,ALL,-5
 OUTPR,ALL,-5
 SOLVE

 /SOLU
 NLGEOM,OFF
 RATE, ON, ON
 SOLCONTROL,ON
 /OUT,scratch
 DELT,1,1,1E6
 TIME, 1E7
 OUTRES,ALL,-5
 OUTPR,ALL,-5
 SOLVE

 /SOLU
 NLGEOM,OFF
 RATE, ON, ON
 SOLCONTROL,ON
 /OUT,scratch
 DELT,1,1,1E7
 TIME, 1E8
 OUTRES,ALL,-5
 OUTPR,ALL,-5
 SOLVE

 /SOLU
 NLGEOM,OFF
```

```
 RATE, ON, ON
 SOLCONTROL,ON
 /OUT,scratch
 DELT,1,1,1E8
 TIME, 1E10
 OUTRES,ALL,-10
 OUTPR,ALL,-10
 /OUT,scratch
 SOLVE
 FINISH


/POST1
 /GROPT,VIEW,0
 /GTHK,CURVE,1
 /GROPT,FILL,OFF
 /GRID,1
 /GTHK,GRID,1
 /GROPT,CGRID,1
 /AXLAB,X,RADIUS
 /AXLAB,Y,EFFECTIVE STRESS
 /GTHK,AXIS,1
 /GRTYP,0
 /GROPT,ASCAL,OFF
 /GROPT,AXDV,ON
 /GROPT,AXNM,ON
 /GROPT,AXNSC,ON
 /GROPT,DIG1,5
 /GROPT,DIG2,3
 /GROPT,DIVX,2
 /GROPT,DIVY,3
 /XRANGE,0,300
 /YRANGE,0,60,ALL
SET,FIRST
FLSTT,2,2,1
FITEM,2,24
FITEM,2,1
PATH,P3,2,30,20,
PPATH,P51X,1
PDEF,STAT
AVPRIN,0,0,
PDEF,1E-8,S,EQV,AVG
/PBC,PATH, ,0
/PSF,DEFA, ,1
/PBF,DEFA, ,1
/PSYMB,CS,0
/PSYMB,NDIR,0
/PSYMB,ESYS,0
/PSYMB,LDIR,0
/PSYMB,ECON,0
/PSYMB,XNODE,1
/PSYMB,DOT,1
/PSYMB,PCONV,
/PSYMB,LAYR,0
/PBC,MAST, ,0
/PBC,CP, ,0
/PBC,CE, ,0
/PBC,ACEL, ,0
/PBC,OMEG, ,0
/PBC,PATH, ,1
/REP
PLPATH,1E-8
PRPATH,1E-8

/NOERASE
SET,NEXT
PDEF,1E4,S,EQV,AVG
/PBC,PATH, ,0
/PSF,DEFA, ,1
/PBF,DEFA, ,1
/PSYMB,CS,0
/PSYMB,NDIR,0
```

```
/PSYMB,ESYS,0
/PSYMB,LDIR,0
/PSYMB,ECON,0
/PSYMB,XNODE,1
/PSYMB,DOT,1
/PSYMB,PCONV,
/PSYMB,LAYR,0
/PBC,MAST, ,0
/PBC,CP, ,0
/PBC,CE, ,0
/PBC,ACEL, ,0
/PBC,OMEG, ,0
/PBC,PATH, ,1
/REP
PLPATH,1E4
PRPATH,1E4

/NOERASE
SET,NEXT
PDEF,1E5,S,EQV,AVG
/PBC,PATH, ,0
/PSF,DEFA, ,1
/PBF,DEFA, ,1
/PSYMB,CS,0
/PSYMB,NDIR,0
/PSYMB,ESYS,0
/PSYMB,LDIR,0
/PSYMB,ECON,0
/PSYMB,XNODE,1
/PSYMB,DOT,1
/PSYMB,PCONV,
/PSYMB,LAYR,0
/PBC,MAST, ,0
/PBC,CP, ,0
/PBC,CE, ,0
/PBC,ACEL, ,0
/PBC,OMEG, ,0
/PBC,PATH, ,1
/REP
PLPATH,1E5
PRPATH,1E5

/NOERASE
SET,NEXT
PDEF,1E7,S,EQV,AVG
/PBC,PATH, ,0
/PSF,DEFA, ,1
/PBF,DEFA, ,1
/PSYMB,CS,0
/PSYMB,NDIR,0
/PSYMB,ESYS,0
/PSYMB,LDIR,0
/PSYMB,ECON,0
/PSYMB,XNODE,1
/PSYMB,DOT,1
/PSYMB,PCONV,
/PSYMB,LAYR,0
/PBC,MAST, ,0
/PBC,CP, ,0
/PBC,CE, ,0
/PBC,ACEL, ,0
/PBC,OMEG, ,0
/PBC,PATH, ,1
/REP
PLPATH,1E7
PRPATH,1E7

/NOERASE
SET,NEXT
PDEF,1E8,S,EQV,AVG
/PBC,PATH, ,0
/PSF,DEFA, ,1
```

```
/PBF,DEFA, ,1
/PSYMB,CS,0
/PSYMB,NDIR,0
/PSYMB,ESYS,0
/PSYMB,LDIR,0
/PSYMB,ECON,0
/PSYMB,XNODE,1
/PSYMB,DOT,1
/PSYMB,PCONV,
/PSYMB,LAYR,0
/PBC,MAST, ,0
/PBC,CP, ,0
/PBC,CE, ,0
/PBC,ACEL, ,0
/PBC,OMEG, ,0
/PBC,PATH, ,1
/REP
PLPATH,1E8
PRPATH,1E8

/NOERASE
SET,LAST
PDEF,1E10,S,EQV,AVG
/PBC,PATH, ,0
/PSF,DEFA, ,1
/PBF,DEFA, ,1
/PSYMB,CS,0
/PSYMB,NDIR,0
/PSYMB,ESYS,0
/PSYMB,LDIR,0
/PSYMB,ECON,0
/PSYMB,XNODE,1
/PSYMB,DOT,1
/PSYMB,PCONV,
/PSYMB,LAYR,0
/PBC,MAST, ,0
/PBC,CP, ,0
/PBC,CE, ,0
/PBC,ACEL, ,0
/PBC,OMEG, ,0
/PBC,PATH, ,1
/REP
PLPATH,1E10
PRPATH,1E10
ERASE
/ERASE

 /POST26
 /GROPT,VIEW,0
 /GTHK,CURVE,1
 /GROPT,FILL,OFF
 /GRID,1
 /GTHK,GRID,1
 /GROPT,CGRID,1
 /AXLAB,X,LOG(TIME)
 /AXLAB,Y,
 /GTHK,AXIS,1
 /GRTYP,0
 /GROPT,ASCAL,OFF
 /GROPT,AXDV,ON
 /GROPT,AXNM,ON
 /GROPT,AXNSC,ON
 /GROPT,DIG1,3
 /GROPT,DIG2,1
 /GROPT,LOGX,ON
 /GROPT,DIVX,10
 /GROPT,DIVY,3
 /XRANGE,1,1E10
 /YRANGE,0,30
 NODE1=NODE(200,0,0)
 NODE2=NODE(500,0,0)
 NSOL,2,NODE1,U,X
```

```
 NSOL,3,NODE2,U,X
 /GOPR
 /GOLIST
 PLVAR,2,3
 PRVAR,2,3
 /GROPT,DIVY,5
 /YRANGE,0,50
 ESOL,4,10,24,S,EQV
 ESOL,5,5,35,S,EQV
 ESOL,6,1,1,S,EQV
 PLVAR,4,5,6
 PRVAR,4,5,6
 FINISH

/POST1
SET,1,1
*GET,X1,NODE,2,S,EQV
*GET,Y1,NODE,24,S,EQV
*GET,Z1,NODE,35,S,EQV
RX1=X1/3.17
RY1=Y1/44.71
RZ1=Z1/8.98
SET,2,27
*GET,X2,NODE,2,S,EQV
*GET,Y2,NODE,24,S,EQV
*GET,Z2,NODE,35,S,EQV
RX2=X2/3.21
RY2=Y2/41.93
RZ2=Z2/9.08
SET,3,31
*GET,X3,NODE,2,S,EQV
*GET,Y3,NODE,24,S,EQV
*GET,Z3,NODE,35,S,EQV
RX3=X3/3.42
RY3=Y3/34.56
RZ3=Z3/9.63
SET,4,43
*GET,X4,NODE,2,S,EQV
*GET,Y4,NODE,24,S,EQV
*GET,Z4,NODE,35,S,EQV
RX4=X4/5.55
RY4=Y4/17.56
RZ4=Z4/15.54
SET,5,48
*GET,X5,NODE,2,S,EQV
*GET,Y5,NODE,24,S,EQV
*GET,Z5,NODE,35,S,EQV
RX5=X5/9.12
RY5=Y5/13.33
RZ5=Z5/20.52
SET,6,55
*GET,X6,NODE,2,S,EQV
*GET,Y6,NODE,24,S,EQV
*GET,Z6,NODE,35,S,EQV
RX6=X6/18.63
RY6=Y6/11.36
RZ6=Z6/17.83
SET,6,144
*GET,X7,NODE,2,S,EQV
*GET,Y7,NODE,24,S,EQV
*GET,Z7,NODE,35,S,EQV
RX7=X7/21.16
RY7=Y7/11.25
RZ7=Z7/17.58
*DIM,VALUE1,,7,2
*DIM,VALUE2,,7,2
*DIM,VALUE3,,7,2
*DIM,LABEL3,CHAR,10
*DIM,LABEL1,CHAR,10
*DIM,LABEL2,CHAR,10
*DIM,LABEL4,CHAR,10
LABEL3(1) = '    1E-8','    1E4', '    1E5', '    1E7', '    1E8','    1E9', '    1E10'
```

```
LABEL1(1) = '   3.17','   3.21','   3.42','   5.55','   9.12','  18.63','  21.16'
*VFILL,VALUE1(1,1),DATA,X1,X2,X3,X4,X5,X6,X7
*VFILL,VALUE1(1,2),DATA,RX1,RX2,RX3,RX4,RX5,RX6,RX7
LABEL2(1) = '  44.71','  41.93','  34.56','  17.56','  13.33','  11.36','  11.25'
*VFILL,VALUE2(1,1),DATA,Y1,Y2,Y3,Y4,Y5,Y6,Y7
*VFILL,VALUE2(1,2),DATA,RY1,RY2,RY3,RY4,RY5,RY6,RY7
LABEL4(1) = '   8.98','   9.08','   9.63','  15.54','  20.52','  17.83','  17.58'
*VFILL,VALUE3(1,1),DATA,Z1,Z2,Z3,Z4,Z5,Z6,Z7
*VFILL,VALUE3(1,2),DATA,RZ1,RZ2,RZ3,RZ4,RZ5,RZ6,RZ7
/OUT
/COM
/COM
/COM,--------- vmr049-cr6-183 RESULTS COMPARISON-----------
/COM,   RADIUS=495
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL3(1), LABEL1(1), VALUE1(1,1), VALUE1(1,2)
(1X,A8,'   ',A8,'   ',F14.3,'   ',F12.3)
/SHOW,CLOSE

/COM
/COM
/COM,--------- vmr049-cr6-183 RESULTS COMPARISON-----------
/COM,   RADIUS=205
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL3(1), LABEL2(1), VALUE2(1,1), VALUE2(1,2)
(1X,A8,'   ',A8,'   ',F14.3,'   ',F12.3)
/SHOW,CLOSE

/COM
/COM
/COM,--------- vmr049-cr6-183 RESULTS COMPARISON-----------
/COM,   RADIUS=350
/COM,
/COM,|   TIME   | TARGET |   Mechanical APDL  |   RATIO
/COM,
*VWRITE,LABEL3(1), LABEL4(1), VALUE3(1,1), VALUE3(1,2)
(1X,A8,'   ',A8,'   ',F14.3,'   ',F12.3)
/SHOW,CLOSE

/OUT,SCRATCH
*DIM,LABEL5,CHAR,7
*DIM,VALUE4,,3,3
LABEL5(1) = ' SR205 ',' SR350 ',' SR495 '
*VFILL,VALUE4(1,1),DATA,Y7,Z7,X7
*VFILL,VALUE4(1,2),DATA,RY7,RZ7,RX7
*DIM,LABEL6,CHAR,2
LABEL6(1) = 'vmr049-','cr6-183'

/OUT,vmr049-cr6-183,vrt
/COM
/COM,------------------- vmr049-cr6 RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL5(1),VALUE4(1,1),VALUE4(1,2),LABEL6(1),LABEL6(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL5(2),VALUE4(2,1),VALUE4(2,2),LABEL6(1),LABEL6(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL5(3),VALUE4(3,1),VALUE4(3,2),LABEL6(1),LABEL6(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-cr6-183,vrt
```

VM-R049-PL1A 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,VMR049-PL1A-182
/TITLE, VMR049-PL1A-182, 2D PLANE STRAIN PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT-R0049

/PREP7
R = 2.5E-5
ET,1,182,,,
KEYOPT,1,3,2
N,1,,,,
N,2,0,1,,
N,3,1,0,,
N,4,1,1,,
E, 1,3,4,2
MP,EX,1,250E3,
MP,NUXY,1,0.25,
TB,BISO,1,1, , ,
TBMODIF,2,1,5
TBMODIF,3,1,0.0
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
```

```
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,8
/YRANGE,-10,25
/OUT,
ESOL,2,1,4,S,X,
ESOL,3,1,4,S,Y,
ESOL,4,1,4,S,Z,
ESOL,5,1,4,S,EQV,
PLVAR,2,3,4,5
PRVAR,2,3,4,5

*DIM,VALUEX,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
R1=VALUEX(1,1)/7.500
R2=VALUEX(2,1)/11.666
R3=VALUEX(3,1)/14.166
R4=VALUEX(4,1)/16.418
R5=VALUEX(5,1)/9.927
R6=VALUEX(6,1)/5.134
R7=VALUEX(7,1)/2.635
R8=VALUEX(8,1)/1.218

*DIM,VALUEY,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R9=VALUEY(1,1)/2.500
R10=VALUEY(2,1)/6.666
R11=VALUEY(3,1)/14.166
R12=VALUEY(4,1)/19.669
R13=VALUEY(5,1)/15.622
R14=VALUEY(6,1)/10.745
R15=VALUEY(7,1)/3.245
R16=VALUEY(8,1)/(-3.715)

*DIM,VALUEZ,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEZ(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R17=VALUEZ(1,1)/2.500
R18=VALUEZ(2,1)/6.666
R19=VALUEZ(3,1)/9.166
R20=VALUEZ(4,1)/13.912
R21=VALUEZ(5,1)/11.951
R22=VALUEZ(6,1)/9.120
```

```
R23=VALUEZ(7,1)/6.620
R24=VALUEZ(8,1)/3.521

*DIM,VALUEEF,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEEF(JJ,1),VARI,5,RTIME,JJ
*ENDDO
R25=VALUEEF(1,1)/5.000
R26=VALUEEF(2,1)/5.000
R27=VALUEEF(3,1)/5.000
R28=VALUEEF(4,1)/5.000
R29=VALUEEF(5,1)/5.000
R30=VALUEEF(6,1)/5.000
R31=VALUEEF(7,1)/3.719
R32=VALUEEF(8,1)/5.000

*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,8,1
*DIM,RATIOY,,8,1
*DIM,RATIOZ,,8,1
*DIM,RATIOEF,,8,1
STEP(1)='1.0','2.0','3.0','4.0','5.0','6.0','7.0','8.0'
TARGETX(1)='7.500','11.666','14.166','16.418','9.927','5.134','2.635','1.218'
TARGETY(1)='2.500','6.666','14.166','19.669','15.622','10.745','3.245','-3.715'
TARGETZ(1)='2.500','6.666','9.166','13.914','11.951','9.120','6.620','3.521'
TARGETEF(1)='5.000','5.000','5.000','5.000','5.000','5.000','3.719','5.000'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5,R6,R7,R8
*VFILL,RATIOY,DATA,R9,R10,R11,R12,R13,R14,R15,R16
*VFILL,RATIOZ,DATA,R17,R18,R19,R20,R21,R22,R23,R24
*VFILL,RATIOEF,DATA,R25,R26,R27,R28,R29,R30,R31,R32
/COM,
/COM, ----------- VMR049-PL1A-182 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl1a-182.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 49, FIGURE 2.14(A).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ VMR049-PL1A-182 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ VMR049-PL1A-182 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ VMR049-PL1A-182 STRESS RESULTS IN Z DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ VMR049-PL1A-182 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
```

```
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' SX ',' SY ',' SZ '
*VFILL,VALUE1(1,1),DATA,VALUEX(6,1),VALUEY(6,1),VALUEZ(6,1)
*VFILL,VALUE1(1,2),DATA,R6,R14,R22
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl1a-182'

/OUT,vmr049-pl1a-182,vrt
/COM
/COM,------------------- vmr049-pl1a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
/COM, RESULTS LISTED USING LOAD STEP 6
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl1a-182,vrt
```

VM-R049-PL1A 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl1a-183
/TITLE, vmr049-pl1a-183, 2D PLANE STRAIN PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT-R0049, PL-1

/PREP7
R = 2.5E-5
ET,1,183,,,
KEYOPT,1,3,2
N,1,,,,
N,2,0.0,0.5,,
N,3,0.0,1.0,,
N,4,0.5,0.0,,
N,5,0.5,1.0,,
N,6,1.0,0.0,,
N,7,1.0,0.5,,
N,8,1.0,1.0,,
E,1,6,8,3,4,7,5,2
MP,EX,1,250E3,
MP,NUXY,1,0.25,
TB,BISO,1,1, , ,
TBMODIF,2,1,5
TBMODIF,3,1,0.0
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
FINISH
```

```
/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,8
/YRANGE,-10,25
/OUT,
ESOL,2,1,8,S,X,
ESOL,3,1,3,S,Y,
ESOL,4,1,8,S,Z,
ESOL,5,1,8,S,EQV
PLVAR,2,3,4,5
```

```
PRVAR,2,3,4,5

*DIM,VALUEX,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
R1=VALUEX(1,1)/7.500
R2=VALUEX(2,1)/11.666
R3=VALUEX(3,1)/14.166
R4=VALUEX(4,1)/16.418
R5=VALUEX(5,1)/9.927
R6=VALUEX(6,1)/5.134
R7=VALUEX(7,1)/2.635
R8=VALUEX(8,1)/1.218

*DIM,VALUEY,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R9=VALUEY(1,1)/2.500
R10=VALUEY(2,1)/6.666
R11=VALUEY(3,1)/14.166
R12=VALUEY(4,1)/19.669
R13=VALUEY(5,1)/15.622
R14=VALUEY(6,1)/10.745
R15=VALUEY(7,1)/3.245
R16=VALUEY(8,1)/(-3.715)

*DIM,VALUEZ,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEZ(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R17=VALUEZ(1,1)/2.500
R18=VALUEZ(2,1)/6.666
R19=VALUEZ(3,1)/9.166
R20=VALUEZ(4,1)/13.912
R21=VALUEZ(5,1)/11.951
R22=VALUEZ(6,1)/9.120
R23=VALUEZ(7,1)/6.620
R24=VALUEZ(8,1)/3.521

*DIM,VALUEEF,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEEF(JJ,1),VARI,5,RTIME,JJ
*ENDDO
R25=VALUEEF(1,1)/5.000
R26=VALUEEF(2,1)/5.000
R27=VALUEEF(3,1)/5.000
R28=VALUEEF(4,1)/5.000
R29=VALUEEF(5,1)/5.000
R30=VALUEEF(6,1)/5.000
R31=VALUEEF(7,1)/3.719
R32=VALUEEF(8,1)/5.000

*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,8,1
*DIM,RATIOY,,8,1
*DIM,RATIOZ,,8,1
*DIM,RATIOEF,,8,1
STEP(1)='1.0','2.0','3.0','4.0','5.0','6.0','7.0','8.0'
TARGETX(1)='7.500','11.666','14.166','16.418','9.927','5.134','2.635','1.218'
TARGETY(1)='2.500','6.666','14.166','19.669','15.622','10.745','3.245','-3.715'
TARGETZ(1)='2.500','6.666','9.166','13.914','11.951','9.120','6.620','3.521'
TARGETEF(1)='5.000','5.000','5.000','5.000','5.000','5.000','3.719','5.000'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5,R6,R7,R8
*VFILL,RATIOY,DATA,R9,R10,R11,R12,R13,R14,R15,R16
*VFILL,RATIOZ,DATA,R17,R18,R19,R20,R21,R22,R23,R24
*VFILL,RATIOEF,DATA,R25,R26,R27,R28,R29,R30,R31,R32
```

```
/COM,
/COM, ----------- vmr049-pl1a-183 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl1a-183.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 49, FIGURE 2.11(A).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl1a-183 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl1a-183 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl1a-183 STRESS RESULTS IN Z DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl1a-183 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' SX ',' SY ',' SZ '
*VFILL,VALUE1(1,1),DATA,VALUEX(6,1),VALUEY(6,1),VALUEZ(6,1)
*VFILL,VALUE1(1,2),DATA,R6,R14,R22
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl1a-183'

/OUT,vmr049-pl1a-183,vrt
/COM
/COM,------------------- vmr049-pl1a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
/COM, RESULTS LISTED USING LOAD STEP 6
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl1a-183,vrt
```

VM-R049-PL1B 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl1b-182
/TITLE, vmr049-pl1b-182,2D PLANE STRAIN PLASTICITY BENCHMARK
/COM,THE SOLUTION OBTAINED HERE IS COMPARED WITH THE SOLUTION GIVEN
/COM,IN THE NAFEMS REPORT-R0049

/PREP7
R = 2.5E-5
ET,1,182,,,
KEYOPT,1,3,2
N,1,,,,
N,2,0,1,,
N,3,1,0,,
N,4,1,1,,
E,1,3,4,2
MP,EX,1,250E3,
MP,NUXY,1,0.25,
TB,BISO,1,1, , ,
TBMODIF,2,1,5
TBMODIF,3,1,50000
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
```

```
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,8
/YRANGE,-5,25
/OUT,
ESOL,2,1,4,S,X,
ESOL,3,1,4,S,Y,
ESOL,4,1,4,S,Z,
ESOL,5,1,4,S,EQV,
PLVAR,2,3,4,5
PRVAR,2,3,4,5
*DIM,VALUEX,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
R1=VALUEX(1,1)/7.500
R2=VALUEX(2,1)/12.241
R3=VALUEX(3,1)/14.741
R4=VALUEX(4,1)/16.939
R5=VALUEX(5,1)/9.845
R6=VALUEX(6,1)/4.052
R7=VALUEX(7,1)/1.552
R8=VALUEX(8,1)/.324
*DIM,VALUEY,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R9=VALUEY(1,1)/(2.500)
R10=VALUEY(2,1)/(6.379)
R11=VALUEY(3,1)/13.879
R12=VALUEY(4,1)/20.193
R13=VALUEY(5,1)/16.877
R14=VALUEY(6,1)/12.452
R15=VALUEY(7,1)/4.953
R16=VALUEY(8,1)/(1.441)
*DIM,VALUEZ,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEZ(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R17=VALUEZ(1,1)/2.500
R18=VALUEZ(2,1)/6.379
R19=VALUEZ(3,1)/8.879
R20=VALUEZ(4,1)/12.867
R21=VALUEZ(5,1)/10.777
R22=VALUEZ(6,1)/8.495
R23=VALUEZ(7,1)/5.995
R24=VALUEZ(8,1)/4.615
```

```
*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,RATIOX,,8,1
*DIM,RATIOY,,8,1
*DIM,RATIOZ,,8,1
STEP(1)='1.0','2.0','3.0','4.0','5.0','6.0','7.0','8.0'
TARGETX(1)='7.500','12.241','14.741','16.938','9.845','4.052','1.552','0.324'
TARGETY(1)='2.500','6.379','13.879','20.193','16.877','12.452','4.953','1.441'
TARGETZ(1)='2.500','6.379','8.879','12.867','10.777','8.495','5.995','4.615'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5,R6,R7,R8
*VFILL,RATIOY,DATA,R9,R10,R11,R12,R13,R14,R15,R16
*VFILL,RATIOZ,DATA,R17,R18,R19,R20,R21,R22,R23,R24
/COM,
/COM, ----------- vmr049-pl1b-182 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl1b-182.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 49, FIGURE 2.11(B).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl1b-182 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl1b-182 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl1b-182 STRESS RESULTS IN Z DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' SX ',' SY ',' SZ '
*VFILL,VALUE1(1,1),DATA,VALUEX(7,1),VALUEY(7,1),VALUEZ(7,1)
*VFILL,VALUE1(1,2),DATA,R7,R15,R23
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl1b-182'

/OUT,vmr049-pl1b-182,vrt
/COM
/COM,------------------- vmr049-pl1b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
/COM, RESULTS REPORTED USING LOAD STEP 7
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT
```

```
FINISH
*LIST,vmr049-pl1b-182,vrt
```

VM-R049-PL1B 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl1b-183
/TITLE, vmr049-pl1b-183,2D PLANE STRAIN PLASTICITY BENCHMARK
/COM,REFERENCE: NAFEMS REPORT, PL-1, R0049.

/PREP7
R = 2.5E-5
ET,1,183,,,
KEYOPT,1,3,2
N,1,,,,
N,2,0.0,0.5,,
N,3,0.0,1.0,,
N,4,0.5,0.0,,
N,5,0.5,1.0,,
N,6,1.0,0.0,,
N,7,1.0,0.5,,
N,8,1.0,1.0,,
E,1,6,8,3,4,7,5,2
MP,EX,1,250E3,
MP,NUXY,1,0.25,
TB,BISO,1,1, , ,
TBMODIF,2,1,5
TBMODIF,3,1,50000
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,R
```

```
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,8
/YRANGE,-5,25
/OUT,
ESOL,2,1,8,S,X,
ESOL,3,1,8,S,Y,
ESOL,4,1,8,S,Z,
ESOL,5,1,8,S,EQV,
PLVAR,2,3,4,5
PRVAR,2,3,4,5

*DIM,VALUEX,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
R1=VALUEX(1,1)/7.500
R2=VALUEX(2,1)/12.241
R3=VALUEX(3,1)/14.741
R4=VALUEX(4,1)/16.938
R5=VALUEX(5,1)/9.845
R6=VALUEX(6,1)/4.052
R7=VALUEX(7,1)/1.552
R8=VALUEX(8,1)/0.324
*DIM,VALUEY,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R9=VALUEY(1,1)/2.500
R10=VALUEY(2,1)/6.379
R11=VALUEY(3,1)/13.879
R12=VALUEY(4,1)/20.193
R13=VALUEY(5,1)/16.877
R14=VALUEY(6,1)/12.452
R15=VALUEY(7,1)/4.953
R16=VALUEY(8,1)/1.441
*DIM,VALUEZ,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEZ(JJ,1),VARI,4,RTIME,JJ
```

```
*ENDDO
R17=VALUEZ(1,1)/2.500
R18=VALUEZ(2,1)/6.379
R19=VALUEZ(3,1)/8.879
R20=VALUEZ(4,1)/12.867
R21=VALUEZ(5,1)/10.777
R22=VALUEZ(6,1)/8.495
R23=VALUEZ(7,1)/5.995
R24=VALUEZ(8,1)/4.615
*DIM,TIME,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,RATIOX,,8,1
*DIM,RATIOY,,8,1
*DIM,RATIOZ,,8,1
TIME(1)='1.0','2.0','3.0','4.0','5.0','6.0','7.0','8.0'
TARGETX(1)='7.500','12.241','14.741','16.938','9.845','4.052','1.552','0.324'
TARGETY(1)='2.500','6.379','13.879','20.193','16.877','12.452','4.953','1.441'
TARGETZ(1)='2.500','6.379','8.879','12.867','10.777','8.495','5.995','4.615'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5,R6,R7,R8
*VFILL,RATIOY,DATA,R9,R10,R11,R12,R13,R14,R15,R16
*VFILL,RATIOZ,DATA,R17,R18,R19,R20,R21,R22,R23,R24
/COM,
/COM, ----------- vmr049-pl1b-183 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl1b-183.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS.  THE RESULTS DISPLAYED ARE INCREMENTED
/COM, FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl1b-183 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl1b-183 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl1b-183 STRESS RESULTS IN Z DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' SX ',' SY ',' SZ '
*VFILL,VALUE1(1,1),DATA,VALUEX(7,1),VALUEY(7,1),VALUEZ(7,1)
*VFILL,VALUE1(1,2),DATA,R7,R15,R23
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl1b-183'

/OUT,vmr049-pl1b-183,vrt
/COM
/COM,------------------- vmr049-pl1b RESULTS COMPARISON ---------------------
/COM,
/COM,           |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
/COM, RESULTS REPORTED USING LOAD STEP 7
```

```
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl1b-183,vrt
```

VM-R049-PL2A 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl2a-181
/TITLE, vmr049-pl2a-181,  2D PLANE STRESS PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049

/PREP7
R = 2.5E-5
ET,1,181
N, 1, 0.0, 0.0
N, 2, 0.0, 1.0
N, 3, 1.0, 0.0
N, 4, 1.0, 1.0
E, 1,3,4,2
R,1,1.0
MP,EX,1,250E3
MP,NUXY,1,0.25
TB,BISO,1,1
TBMODIF,2,1,5
TBMODIF,3,1,0
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
D,ALL,ROTX
D,ALL,ROTY
D,ALL,ROTZ
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
NSEL,ALL
D,ALL,UZ
D,ALL,ROTZ
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
```

```
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,8
/YRANGE,-8,8
ESOL,2,1,4,S,X,
ESOL,3,1,4,S,Y,
ESOL,4,1,4,S,EQV,
PLVAR,2,3,4
PRVAR,2,3,4
*DIM,VALUEX,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
```

```
R1=VALUEX(1,1)/5.620
R2=VALUEX(2,1)/5.761
R3=VALUEX(3,1)/4.078
R4=VALUEX(4,1)/3.191
R5=VALUEX(5,1)/(-2.736)
R6=VALUEX(6,1)/(-5.230)
R7=VALUEX(7,1)/(-4.664)
R8=VALUEX(8,1)/(-3.349)
*DIM,VALUEY,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R9=VALUEY(1,1)/1.666
R10=VALUEY(2,1)/2.551
R11=VALUEY(3,1)/5.578
R12=VALUEY(4,1)/5.762
R13=VALUEY(5,1)/3.035
R14=VALUEY(6,1)/(-0.497)
R15=VALUEY(7,1)/(-5.279)
R16=VALUEY(8,1)/(-5.747)
*DIM,VALUEEF,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEEF(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R17=VALUEEF(1,1)/5.000
R18=VALUEEF(2,1)/5.000
R19=VALUEEF(3,1)/5.000
R20=VALUEEF(4,1)/5.000
R21=VALUEEF(5,1)/5.000
R22=VALUEEF(6,1)/5.000
R23=VALUEEF(7,1)/5.000
R24=VALUEEF(8,1)/5.000
*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,8,1
*DIM,RATIOY,,8,1
*DIM,RATIOEF,,8,1
STEP(1)='1.0','2.0','3.0','4.0','5.0','6.0','7.0','8.0'
TARGETX(1)='5.620','5.761','4.078','3.191','-2.736','-5.230','-4.664','-3.349'
TARGETY(1)='1.666','2.551','5.578','5.762','3.035','-0.497','-5.279','-5.747'
TARGETEF(1)='5.000','5.000','5.000','5.000','5.000','5.000','5.000','5.000'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5,R6,R7,R8
*VFILL,RATIOY,DATA,R7,R8,R9,R10,R11,R12,R13,R14,R15,R16
*VFILL,RATIOEF,DATA,R17,R18,R19,R20,R21,R22,R23,R24
/COM,
/COM, ----------- vmr049-pl2a-181 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl2a-181.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 52, FIGURE 2.14(A).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl2a-181 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl2a-181 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl2a-181 EFFECTIVE RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
```

```
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' SX ',' SY ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(8,1),VALUEY(8,1),VALUEEF(8,1)
*VFILL,VALUE1(1,2),DATA,R8,R16,R24
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl2a-181'

/OUT,vmr049-pl2a-181,vrt
/COM
/COM,------------------- vmr049-pl2a RESULTS COMPARISON ---------------------
/COM,
/COM,                |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr049-pl2a-181,vrt
```

VM-R049-PL2A 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl2a-182
/TITLE, vmr049-pl2a-182,  2D PLANE STRESS PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049

/PREP7
R = 2.5E-5
ET,1,182
KEYOPT,1,3,0
N, 1, 0.0, 0.0
N, 2, 0.0, 1.0
N, 3, 1.0, 0.0
N, 4, 1.0, 1.0
E, 1,3,4,2
MP,EX,1,250E3
MP,NUXY,1,0.25
TB,BISO,1,1
TBMODIF,2,1,5
TBMODIF,3,1,0
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
FINISH

/SOLU
NLGEOM,ON
```

```
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
```

```
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,8
/YRANGE,-8,8
ESOL,2,1,4,S,X,
ESOL,3,1,4,S,Y,
ESOL,4,1,4,S,EQV,
PLVAR,2,3,4
PRVAR,2,3,4
*DIM,VALUEX,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
R1=VALUEX(1,1)/5.620
R2=VALUEX(2,1)/5.761
R3=VALUEX(3,1)/4.078
R4=VALUEX(4,1)/3.191
R5=VALUEX(5,1)/(-2.736)
R6=VALUEX(6,1)/(-5.230)
R7=VALUEX(7,1)/(-4.664)
R8=VALUEX(8,1)/(-3.349)
*DIM,VALUEY,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R9=VALUEY(1,1)/1.666
R10=VALUEY(2,1)/2.551
R11=VALUEY(3,1)/5.578
R12=VALUEY(4,1)/5.762
R13=VALUEY(5,1)/3.035
R14=VALUEY(6,1)/(-0.497)
R15=VALUEY(7,1)/(-5.279)
R16=VALUEY(8,1)/(-5.747)
*DIM,VALUEEF,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEEF(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R17=VALUEEF(1,1)/5.000
R18=VALUEEF(2,1)/5.000
R19=VALUEEF(3,1)/5.000
R20=VALUEEF(4,1)/5.000
R21=VALUEEF(5,1)/5.000
R22=VALUEEF(6,1)/5.000
R23=VALUEEF(7,1)/5.000
R24=VALUEEF(8,1)/5.000
*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,8,1
*DIM,RATIOY,,8,1
*DIM,RATIOEF,,8,1
STEP(1)='1.0','2.0','3.0','4.0','5.0','6.0','7.0','8.0'
TARGETX(1)='5.620','5.761','4.078','3.191','-2.736','-5.230','-4.664','-3.349'
TARGETY(1)='1.666','2.551','5.578','5.762','3.035','-0.497','-5.279','-5.747'
TARGETEF(1)='5.000','5.000','5.000','5.000','5.000','5.000','5.000','5.000'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5,R6,R7,R8
*VFILL,RATIOY,DATA,R7,R8,R9,R10,R11,R12,R13,R14,R15,R16
*VFILL,RATIOEF,DATA,R17,R18,R19,R20,R21,R22,R23,R24
/COM,
/COM, ----------- vmr049-pl2a-182 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl2a-182.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 52, FIGURE 2.14(A).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl2a-182 STRESS RESULTS IN X DIRECTION -------
/COM,
```

```
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl2a-182 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl2a-182 EFFECTIVE RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' SX ',' SY ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(8,1),VALUEY(8,1),VALUEEF(8,1)
*VFILL,VALUE1(1,2),DATA,R8,R16,R24
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl2a-182'

/OUT,vmr049-pl2a-182,vrt
/COM
/COM,------------------- vmr049-pl2a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr049-pl2a-182,vrt
```

VM-R049-PL2A 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl2a-183
/TITLE, vmr049-pl2a-183, 2D PLANE STRESS PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049

/PREP7
R = 2.5E-5
ET,1,183
KEYOPT,1,3,0
N, 1, 0.0, 0.0
N, 2, 0.0, 0.5
N, 3, 0.0, 1.0
N, 4, 0.5, 0.0
N, 5, 0.5, 1.0
N, 6, 1.0, 0.0
```

```
N, 7, 1.0, 0.5
N, 8, 1.0, 1.0
E, 1,6,8,3,4,7,5,2
MP,EX,1,250E3
MP,NUXY,1,0.25
TB,BISO,1,1
TBMODIF,2,1,5
TBMODIF,3,1,0
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
```

```
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,8
/YRANGE,-8,8
ESOL,2,1,8,S,X,
ESOL,3,1,8,S,Y,
ESOL,4,1,8,S,EQV,
PLVAR,2,3,4
PRVAR,2,3,4
*DIM,VALUEX,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
R1=VALUEX(1,1)/5.620
R2=VALUEX(2,1)/5.761
R3=VALUEX(3,1)/4.078
R4=VALUEX(4,1)/3.191
R5=VALUEX(5,1)/(-2.736)
R6=VALUEX(6,1)/(-5.230)
R7=VALUEX(7,1)/(-4.664)
R8=VALUEX(8,1)/(-3.349)
*DIM,VALUEY,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R9=VALUEY(1,1)/1.666
R10=VALUEY(2,1)/2.551
R11=VALUEY(3,1)/5.578
R12=VALUEY(4,1)/5.762
R13=VALUEY(5,1)/3.035
R14=VALUEY(6,1)/(-0.497)
R15=VALUEY(7,1)/(-5.279)
R16=VALUEY(8,1)/(-5.747)
*DIM,VALUEEF,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEEF(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R17=VALUEEF(1,1)/5.000
R18=VALUEEF(2,1)/5.000
R19=VALUEEF(3,1)/5.000
R20=VALUEEF(4,1)/5.000
R21=VALUEEF(5,1)/5.000
R22=VALUEEF(6,1)/5.000
R23=VALUEEF(7,1)/5.000
R24=VALUEEF(8,1)/5.000
*DIM,TIME,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETEF,CHAR,10
```

```
*DIM,RATIOX,,8,1
*DIM,RATIOY,,8,1
*DIM,RATIOEF,,8,1
TIME(1)='1.0','2.0','3.0','4.0','5.0','6.0','7.0','8.0'
TARGETX(1)='5.620','5.761','4.078','3.191','-2.736','-5.230','-4.664','-3.349'
TARGETY(1)='1.666','2.551','5.578','5.762','3.035','-0.497','-5.279','-5.747'
TARGETEF(1)='5.000','5.000','5.000','5.000','5.000','5.000','5.000','5.000'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5,R6,R7,R8
*VFILL,RATIOY,DATA,R9,R10,R11,R12,R13,R14,R15,R16
*VFILL,RATIOEF,DATA,R17,R18,R19,R20,R21,R22,R23,R24
/COM,
/COM, ----------- vmr049-pl2a-183 RESULTS COMPARISON -------------
/COM,
/COM, vmr049-pl2a-183.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 52, FIGURE 2.14(A).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl2a-183 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  TIME  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl2a-183 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  TIME  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl2a-183 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  TIME  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,TIME(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' SX ',' SY ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(8,1),VALUEY(8,1),VALUEEF(8,1)
*VFILL,VALUE1(1,2),DATA,R8,R16,R24
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl2a-183'

/OUT,vmr049-pl2a-183,vrt
/COM
/COM,------------------- vmr049-pl2a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr049-pl2a-183,vrt
```

VM-R049-PL2A 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl2a-281
/TITLE, vmr049-pl2a-281,  2D PLANE STRESS PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049
/PREP7
R = 2.5E-5
ET,1,SHELL281
N, 1, 0.0, 0.0
N, 2, 0.0, 1.0
N, 3, 1.0, 0.0
N, 4, 1.0, 1.0
N, 5, 0.5, 0.0
N, 6, 1.0, 0.5
N, 7, 0.5, 1.0
N, 8, 0.0, 0.5
E, 1,3,4,2,5,6,7,8
R,1,1.0
MP,EX,1,250E3
MP,NUXY,1,0.25
TB,BISO,1,1
TBMODIF,2,1,5
TBMODIF,3,1,0
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
D,ALL,ROTX
D,ALL,ROTY
D,ALL,ROTZ
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
NSEL,ALL
D,ALL,UZ
D,ALL,ROTZ
FINISH
/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
```

```
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH
/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,8
/YRANGE,-8,8
ESOL,2,1,4,S,X,
ESOL,3,1,4,S,Y,
ESOL,4,1,4,S,EQV,
PLVAR,2,3,4
PRVAR,2,3,4
*DIM,VALUEX,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
R1=VALUEX(1,1)/5.620
R2=VALUEX(2,1)/5.761
R3=VALUEX(3,1)/4.078
R4=VALUEX(4,1)/3.191
R5=VALUEX(5,1)/(-2.736)
R6=VALUEX(6,1)/(-5.230)
R7=VALUEX(7,1)/(-4.664)
R8=VALUEX(8,1)/(-3.349)
*DIM,VALUEY,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R9=VALUEY(1,1)/1.666
```

```
R10=VALUEY(2,1)/2.551
R11=VALUEY(3,1)/5.578
R12=VALUEY(4,1)/5.762
R13=VALUEY(5,1)/3.035
R14=VALUEY(6,1)/(-0.497)
R15=VALUEY(7,1)/(-5.279)
R16=VALUEY(8,1)/(-5.747)
*DIM,VALUEEF,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEEF(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R17=VALUEEF(1,1)/5.000
R18=VALUEEF(2,1)/5.000
R19=VALUEEF(3,1)/5.000
R20=VALUEEF(4,1)/5.000
R21=VALUEEF(5,1)/5.000
R22=VALUEEF(6,1)/5.000
R23=VALUEEF(7,1)/5.000
R24=VALUEEF(8,1)/5.000
*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,8,1
*DIM,RATIOY,,8,1
*DIM,RATIOEF,,8,1
STEP(1)='1.0','2.0','3.0','4.0','5.0','6.0','7.0','8.0'
TARGETX(1)='5.620','5.761','4.078','3.191','-2.736','-5.230','-4.664','-3.349'
TARGETY(1)='1.666','2.551','5.578','5.762','3.035','-0.497','-5.279','-5.747'
TARGETEF(1)='5.000','5.000','5.000','5.000','5.000','5.000','5.000','5.000'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5,R6,R7,R8
*VFILL,RATIOY,DATA,R7,R8,R9,R10,R11,R12,R13,R14,R15,R16
*VFILL,RATIOEF,DATA,R17,R18,R19,R20,R21,R22,R23,R24
/COM,
/COM, ----------- vmr049-pl2a-281 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl2a-281.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 52, FIGURE 2.14(A).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl2a-281 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl2a-281 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl2a-281 EFFECTIVE RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH
/POST26
*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' SX ',' SY ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(8,1),VALUEY(8,1),VALUEEF(8,1)
*VFILL,VALUE1(1,2),DATA,R8,R16,R24
*DIM,LABEL2,CHAR,2
```

```
LABEL2(1) = 'vmr049-','pl2a-281'
/OUT,vmr049-pl2a-281,vrt
/COM
/COM,------------------- vmr049-pl2a RESULTS COMPARISON ---------------------
/COM,
/COM,                |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F12.4,'       ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F12.4,'       ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F12.4,'       ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr049-pl2a-281,vrt
```

VM-R049-PL2B 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl2b-181
/TITLE, vmr049-pl2b-181,  2D PLANE STRESS PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049

/PREP7
R = 2.5E-5
ET,1,181,,,
KEYOPT,1,3,0
N, 1, 0.0, 0.0
N, 2, 0.0, 1.0
N, 3, 1.0, 0.0
N, 4, 1.0, 1.0
E, 1,3,4,2
R,1,1.0
MP,EX  ,1,250E3,
MP,NUXY,1,0.25,
TB,BISO,1, , , ,
TBMODIF,2,1,5
TBMODIF,3,1,50000
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
D,ALL,ROTX
D,ALL,ROTY
D,ALL,ROTZ
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
NSEL,ALL
D,ALL,UZ
D,ALL,ROTZ
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
```

```
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH

/POST26
/XRANGE,0,8
/YRANGE,-10,10
/AXLAB,X,STEP
/AXLAB,Y,STRESS
ESOL,2,1,4,S,X,
ESOL,3,1,4,S,Y,
ESOL,4,1,4,S,EQV,
PRVAR,2,3,4
PLVAR,2,3,4
*DIM,VALUEX,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
```

```
R1=VALUEX(1,1)/5.845
R2=VALUEX(2,1)/7.484
R3=VALUEX(3,1)/6.838
R4=VALUEX(4,1)/6.136
R5=VALUEX(5,1)/(-0.530)
R6=VALUEX(6,1)/(-5.822)
R7=VALUEX(7,1)/(-7.489)
R8=VALUEX(8,1)/(-9.155)
*DIM,VALUEY,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R9=VALUEY(1,1)/1.673
R10=VALUEY(2,1)/2.944
R11=VALUEY(3,1)/7.742
R12=VALUEY(4,1)/9.925
R13=VALUEY(5,1)/8.259
R14=VALUEY(6,1)/4.842
R15=VALUEY(7,1)/(-1.824)
R16=VALUEY(8,1)/(-8.491)
*DIM,VALUEEF,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEEF(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R17=VALUEEF(1,1)/5.214
R18=VALUEEF(2,1)/6.531
R19=VALUEEF(3,1)/7.332
R20=VALUEEF(4,1)/8.675
R21=VALUEEF(5,1)/8.536
R22=VALUEEF(6,1)/9.248
R23=VALUEEF(7,1)/6.764
R24=VALUEEF(8,1)/8.842
*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,8,1
*DIM,RATIOY,,8,1
*DIM,RATIOEF,,8,1
STEP(1)='1.0','2.0','3.0','4.0','5.0','6.0','7.0','8.0'
TARGETX(1)='5.845','7.484','6.838','6.136','-0.530','-5.822','-7.489','-9.155'
TARGETY(1)='1.673','2.944','7.742','9.925','8.259','4.842','-1.824','-8.491'
TARGETEF(1)='5.214','6.531','7.332','8.675','8.536','9.248','6.764','8.842'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5,R6,R7,R8
*VFILL,RATIOY,DATA,R9,R10,R11,R12,R13,R14,R15,R16
*VFILL,RATIOEF,DATA,R17,R18,R19,R20,R21,R22,R23,R24
/COM,
/COM, ----------- vmr049-pl2b-181 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl2b-181.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 52, FIGURE 2.14(B).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl2b-181 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl2b-181 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl2b-181 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
```

```
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' SX ',' SY ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(8,1),VALUEY(8,1),VALUEEF(8,1)
*VFILL,VALUE1(1,2),DATA,R8,R16,R24
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl2b-181'

/OUT,vmr049-pl2b-181,vrt
/COM
/COM,------------------- vmr049-pl2b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL181
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl2b-181,vrt
```

VM-R049-PL2B 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl2b-182
/TITLE, vmr049-pl2b-182,  2D PLANE STRESS PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049

/PREP7
R = 2.5E-5
ET,1,182,,,
KEYOPT,1,3,0
N, 1, 0.0, 0.0
N, 2, 0.0, 1.0
N, 3, 1.0, 0.0
N, 4, 1.0, 1.0
E, 1,3,4,2
MP,EX  ,1,250E3,
MP,NUXY,1,0.25,
TB,BISO,1, , , ,
TBMODIF,2,1,5
TBMODIF,3,1,50000
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY

/SOLU
NLGEOM,ON
```

```
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,8
/YRANGE,-10,10
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/OUT,
ESOL,2,1,4,S,X,
ESOL,3,1,4,S,Y,
ESOL,4,1,4,S,EQV,
PRVAR,2,3,4
PLVAR,2,3,4
*DIM,VALUEX,ARRAY,8,1
*DO,JJ,1,8,1
```

```
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
R1=VALUEX(1,1)/5.845
R2=VALUEX(2,1)/7.484
R3=VALUEX(3,1)/6.838
R4=VALUEX(4,1)/6.136
R5=VALUEX(5,1)/(-0.530)
R6=VALUEX(6,1)/(-5.822)
R7=VALUEX(7,1)/(-7.489)
R8=VALUEX(8,1)/(-9.155)
*DIM,VALUEY,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R9=VALUEY(1,1)/1.673
R10=VALUEY(2,1)/2.944
R11=VALUEY(3,1)/7.742
R12=VALUEY(4,1)/9.925
R13=VALUEY(5,1)/8.259
R14=VALUEY(6,1)/4.842
R15=VALUEY(7,1)/(-1.824)
R16=VALUEY(8,1)/(-8.491)
*DIM,VALUEEF,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEEF(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R17=VALUEEF(1,1)/5.214
R18=VALUEEF(2,1)/6.531
R19=VALUEEF(3,1)/7.332
R20=VALUEEF(4,1)/8.675
R21=VALUEEF(5,1)/8.536
R22=VALUEEF(6,1)/9.248
R23=VALUEEF(7,1)/6.764
R24=VALUEEF(8,1)/8.842
*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,8,1
*DIM,RATIOY,,8,1
*DIM,RATIOEF,,8,1
STEP(1)='1.0','2.0','3.0','4.0','5.0','6.0','7.0','8.0'
TARGETX(1)='5.845','7.484','6.838','6.136','-0.530','-5.822','-7.489','-9.155'
TARGETY(1)='1.673','2.944','7.742','9.925','8.259','4.842','-1.824','-8.491'
TARGETEF(1)='5.214','6.531','7.332','8.675','8.536','9.248','6.764','8.842'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5,R6,R7,R8
*VFILL,RATIOY,DATA,R9,R10,R11,R12,R13,R14,R15,R16
*VFILL,RATIOEF,DATA,R17,R18,R19,R20,R21,R22,R23,R24
/COM,
/COM, ----------- vmr049-pl2b-182 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl2b-182.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 52, FIGURE 2.14(B).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl2b-182 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl2b-182 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl2b-182 EFFECTIVE STRESS RESULTS -------
```

```
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' SX ',' SY ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(8,1),VALUEY(8,1),VALUEEF(8,1)
*VFILL,VALUE1(1,2),DATA,R8,R16,R24
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl2b-182'

/OUT,vmr049-pl2b-182,vrt
/COM
/COM,------------------- vmr049-pl2b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl2b-182,vrt
```

VM-R049-PL2B 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl2b-281
/TITLE, vmr049-pl2b-281,  2D PLANE STRESS PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049
/PREP7
R = 2.5E-5
ET,1,SHELL281,,,
KEYOPT,1,3,0
N, 1, 0.0, 0.0
N, 2, 0.0, 1.0
N, 3, 1.0, 0.0
N, 4, 1.0, 1.0
N, 5, 0.5, 0.0
N, 6, 1.0, 0.5
N, 7, 0.5, 1.0
N, 8, 0.0, 0.5
E, 1,3,4,2,5,6,7,8
R,1,1.0
MP,EX  ,1,250E3,
MP,NUXY,1,0.25,
TB,BISO,1, , , ,
TBMODIF,2,1,5
TBMODIF,3,1,50000
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
D,ALL,ROTX
D,ALL,ROTY
D,ALL,ROTZ
```

```
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
NSEL,ALL
D,ALL,UZ
D,ALL,ROTZ
FINISH
/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
```

```
OUTRES,ALL,5
/OUTPUT,SCRATCH
SOLVE
/OUT
FINISH
/POST26
/XRANGE,0,8
/YRANGE,-10,10
/AXLAB,X,STEP
/AXLAB,Y,STRESS
ESOL,2,1,4,S,X,
ESOL,3,1,4,S,Y,
ESOL,4,1,4,S,EQV,
PRVAR,2,3,4
PLVAR,2,3,4
*DIM,VALUEX,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
R1=VALUEX(1,1)/5.845
R2=VALUEX(2,1)/7.484
R3=VALUEX(3,1)/6.838
R4=VALUEX(4,1)/6.136
R5=VALUEX(5,1)/(-0.530)
R6=VALUEX(6,1)/(-5.822)
R7=VALUEX(7,1)/(-7.489)
R8=VALUEX(8,1)/(-9.155)
*DIM,VALUEY,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R9=VALUEY(1,1)/1.673
R10=VALUEY(2,1)/2.944
R11=VALUEY(3,1)/7.742
R12=VALUEY(4,1)/9.925
R13=VALUEY(5,1)/8.259
R14=VALUEY(6,1)/4.842
R15=VALUEY(7,1)/(-1.824)
R16=VALUEY(8,1)/(-8.491)
*DIM,VALUEEF,ARRAY,8,1
*DO,JJ,1,8,1
*GET,VALUEEF(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R17=VALUEEF(1,1)/5.214
R18=VALUEEF(2,1)/6.531
R19=VALUEEF(3,1)/7.332
R20=VALUEEF(4,1)/8.675
R21=VALUEEF(5,1)/8.536
R22=VALUEEF(6,1)/9.248
R23=VALUEEF(7,1)/6.764
R24=VALUEEF(8,1)/8.842
*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,8,1
*DIM,RATIOY,,8,1
*DIM,RATIOEF,,8,1
STEP(1)='1.0','2.0','3.0','4.0','5.0','6.0','7.0','8.0'
TARGETX(1)='5.845','7.484','6.838','6.136','-0.530','-5.822','-7.489','-9.155'
TARGETY(1)='1.673','2.944','7.742','9.925','8.259','4.842','-1.824','-8.491'
TARGETEF(1)='5.214','6.531','7.332','8.675','8.536','9.248','6.764','8.842'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5,R6,R7,R8
*VFILL,RATIOY,DATA,R9,R10,R11,R12,R13,R14,R15,R16
*VFILL,RATIOEF,DATA,R17,R18,R19,R20,R21,R22,R23,R24
/COM,
/COM, ----------- vmr049-pl2b-281 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl2b-281.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 52, FIGURE 2.14(B).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
```

```
/COM,
/COM, ------ vmr049-pl2b-281 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP   |  TARGET   |  Mechanical APDL   |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl2b-281 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP   |  TARGET   |  Mechanical APDL   |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl2b-281 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  STEP   |  TARGET   |  Mechanical APDL   |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH
/POST26
*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' SX ',' SY ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(8,1),VALUEY(8,1),VALUEEF(8,1)
*VFILL,VALUE1(1,2),DATA,R8,R16,R24
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl2b-281'
/OUT,vmr049-pl2b-281,vrt
/COM
/COM,------------------- vmr049-pl2b RESULTS COMPARISON ---------------------
/COM,
/COM,           |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SHELL281
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT
FINISH
*LIST,vmr049-pl2b-281,vrt
```

VM-R049-PL3A 185 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl3a-185
/TITLE, vmr049-pl3a-185,  3D PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049, PL-3

/PREP7
R = 2.5E-5
ET,1,185
N, 1, 0.0, 0.0, 0.0
N, 2, 0.0, 1.0, 0.0
N, 3, 1.0, 0.0, 0.0
N, 4, 1.0, 1.0, 0.0
N, 5, 0.0, 0.0, 1.0
N, 6, 0.0, 1.0, 1.0
```

```
N, 7, 1.0, 0.0, 1.0
N, 8, 1.0, 1.0, 1.0
E,1,3,4,2,5,7,8,6
MP,EX,1,250.0E3,
MP,NUXY,1,0.25,
TB,BISO,1,1, , ,
TBMODIF,2,1,5
TBMODIF,3,1,0
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,S,LOC,Z,1.0
D,ALL,UZ
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
```

```
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,13
/YRANGE,-10,30
/OUT,
ESOL,2,1,8,S,X,
ESOL,3,1,8,S,Y,
ESOL,4,1,8,S,Z,
ESOL,5,1,8,S,EQV,
PRVAR,2,3,4,5
PLVAR,2,3,4,5

*DIM,V,ARRAY,24
*DIM,VALUEX,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V(JJ),VARI,2,RTIME,JJ
*ENDDO
*VFILL,VALUEX,DATA,V(1),V(4),V(7),V(10),V(13)
R1=VALUEX(1)/7.499
R2=VALUEX(2)/16.365
R3=VALUEX(3)/17.595
R4=VALUEX(4)/8.710
R5=VALUEX(5)/2.747

*DIM,V2,ARRAY,24
*DIM,VALUEY,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V2(JJ),VARI,3,RTIME,JJ
*ENDDO
*VFILL,VALUEY,DATA,V2(1),V2(4),V2(7),V2(10),V2(13)
R6=VALUEY(1)/2.500
R7=VALUEY(2)/19.692
R8=VALUEY(3)/21.766
R9=VALUEY(4)/5.277
R10=VALUEY(5)/0.262
```

```
*DIM,V3,ARRAY,24
*DIM,VALUEZ,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V3(JJ),VARI,4,RTIME,JJ
*ENDDO
*VFILL,VALUEZ,DATA,V3(1),V3(4),V3(7),V3(10),V3(13)
R11=VALUEZ(1)/2.500
R12=VALUEZ(2)/13.942
R13=VALUEZ(3)/23.138
R14=VALUEZ(4)/11.013
R15=VALUEZ(5)/(-3.009)

*DIM,V4,ARRAY,24
*DIM,VALUEEF,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V4(JJ),VARI,5,RTIME,JJ
*ENDDO
*VFILL,VALUEEF,DATA,V4(1),V4(4),V4(7),V4(10),V4(13)
R16=VALUEEF(1)/5.000
R17=VALUEEF(2)/5.000
R18=VALUEEF(3)/5.000
R19=VALUEEF(4)/5.000
R20=VALUEEF(5)/5.000

*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,5,1
*DIM,RATIOY,,5,1
*DIM,RATIOZ,,5,1
*DIM,RATIOEF,,5,1
STEP(1)='1.0','4.0','7.0','10.0','13.0'
TARGETX(1)='7.500','16.365','17.595','8.710','2.747'
TARGETY(1)='2.500','19.692','21.766','5.277','0.262'
TARGETZ(1)='2.500','13.942','23.138','11.013','-3.009'
TARGETEF(1)='5.000','5.000','5.000','5.000','5.000'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5
*VFILL,RATIOY,DATA,R6,R7,R8,R9,R10
*VFILL,RATIOZ,DATA,R11,R12,R13,R14,R15
*VFILL,RATIOEF,DATA,R16,R17,R18,R19,R20
/COM,
/COM, ----------- vmr049-pl3a-185 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl3a-185.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 55, FIGURE 2.17(A).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl3a-185 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl3a-185 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl3a-185 STRESS RESULTS IN Z DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
```

```
/COM,
/COM, ------ vmr049-pl3a-185 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

*DIM,LABEL1,CHAR,4
*DIM,VALUE1,,4,3
LABEL1(1) = ' SX ',' SY ',' SZ ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(5),VALUEY(5),VALUEZ(5),VALUEEF(5)
*VFILL,VALUE1(1,2),DATA,R5,R10,R15,R20
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl3a-185'

/OUT,vmr049-pl3a-185,vrt
/COM
/COM,------------------- vmr049-pl3a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID185
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(4),VALUE1(4,1),VALUE1(4,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl3a-185,vrt
```

VM-R049-PL3A 186 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl3a-186
/TITLE, vmr049-pl3a-186, 3D PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049, PL-3

/PREP7
R = 2.5E-5
ET,1,186
N, 1, 0.0, 0.0, 0.0
N, 2, 0.0, 0.5, 0.0
N, 3, 0.0, 1.0, 0.0
N, 4, 0.5, 0.0, 0.0
N, 5, 0.5, 1.0, 0.0
N, 6, 1.0, 0.0, 0.0
N, 7, 1.0, 0.5, 0.0
N, 8, 1.0, 1.0, 0.0
N, 9, 0.0, 0.0, 1.0
N,10, 0.0, 0.5, 1.0
N,11, 0.0, 1.0, 1.0
N,12, 0.5, 0.0, 1.0
N,13, 0.5, 1.0, 1.0
N,14, 1.0, 0.0, 1.0
N,15, 1.0, 0.5, 1.0
N,16, 1.0, 1.0, 1.0
N,17, 0.0, 0.0, 0.5
```

```
N,18, 1.0, 0.0, 0.5
N,19, 1.0, 1.0, 0.5
N,20, 0.0, 1.0, 0.5
E,1,6,8,3,9,14,16,11
EMORE,4,7,5,2,12,15,13,10
EMORE,17,18,19,20
MP,EX,1,250.0E3
MP,NUXY,1,0.25
TB,BISO,1,1
TBMODIF,2,1,5
TBMODIF,3,1,0
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,S,LOC,Z,1.0
D,ALL,UZ
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
```

```
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,13
/YRANGE,-10,30
/OUT,
ESOL,2,1,16,S,X,
ESOL,3,1,16,S,Y,
ESOL,4,1,16,S,Z,
ESOL,5,1,16,S,EQV,
PRVAR,2,3,4,5
PLVAR,2,3,4,5

*DIM,V,ARRAY,24
*DIM,VALUEX,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V(JJ),VARI,2,RTIME,JJ
*ENDDO
*VFILL,VALUEX,DATA,V(1),V(4),V(7),V(10),V(13)
R1=VALUEX(1)/7.499
R2=VALUEX(2)/16.365
R3=VALUEX(3)/17.595
R4=VALUEX(4)/8.710
R5=VALUEX(5)/2.747

*DIM,V2,ARRAY,24
*DIM,VALUEY,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V2(JJ),VARI,3,RTIME,JJ
*ENDDO
*VFILL,VALUEY,DATA,V2(1),V2(4),V2(7),V2(10),V2(13)
R6=VALUEY(1)/2.500
R7=VALUEY(2)/19.692
R8=VALUEY(3)/21.766
```

```
R9=VALUEY(4)/5.277
R10=VALUEY(5)/0.262

*DIM,V3,ARRAY,24
*DIM,VALUEZ,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V3(JJ),VARI,4,RTIME,JJ
*ENDDO
*VFILL,VALUEZ,DATA,V3(1),V3(4),V3(7),V3(10),V3(13)
R11=VALUEZ(1)/2.500
R12=VALUEZ(2)/13.942
R13=VALUEZ(3)/23.138
R14=VALUEZ(4)/11.013
R15=VALUEZ(5)/(-3.009)

*DIM,V4,ARRAY,24
*DIM,VALUEEF,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V4(JJ),VARI,5,RTIME,JJ
*ENDDO
*VFILL,VALUEEF,DATA,V4(1),V4(4),V4(7),V4(10),V4(13)
R16=VALUEEF(1)/5.000
R17=VALUEEF(2)/5.000
R18=VALUEEF(3)/5.000
R19=VALUEEF(4)/5.000
R20=VALUEEF(5)/5.000

*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,5,1
*DIM,RATIOY,,5,1
*DIM,RATIOZ,,5,1
*DIM,RATIOEF,,5,1
STEP(1)='1.0','4.0','7.0','10.0','13.0'
TARGETX(1)='7.500','16.365','17.595','8.710','2.747'
TARGETY(1)='2.500','19.692','21.766','5.277','0.262'
TARGETZ(1)='2.500','13.942','23.138','11.013','-3.009'
TARGETEF(1)='5.000','5.000','5.000','5.000','5.000'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5
*VFILL,RATIOY,DATA,R6,R7,R8,R9,R10
*VFILL,RATIOZ,DATA,R11,R12,R13,R14,R15
*VFILL,RATIOEF,DATA,R16,R17,R18,R19,R20
/COM,
/COM, ----------- vmr049-pl3a-186 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl3a-186.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 55, FIGURE 2.17(A).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl3a-186 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl3a-186 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl3a-186 STRESS RESULTS IN Z DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
```

```
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl3a-186 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

*DIM,LABEL1,CHAR,4
*DIM,VALUE1,,4,3
LABEL1(1) = ' SX ',' SY ',' SZ ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(5),VALUEY(5),VALUEZ(5),VALUEEF(5)
*VFILL,VALUE1(1,2),DATA,R5,R10,R15,R20
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl3a-186'

/OUT,vmr049-pl3a-186,vrt
/COM
/COM,------------------- vmr049-pl3a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID186
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(4),VALUE1(4,1),VALUE1(4,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,---------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl3a-186,vrt
```

VM-R049-PL3A 187 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl3a-187
/TITLE, vmr049-pl3a-187, 3D PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049, PL-3

/PREP7
R = 2.5E-5
ET,1,187
BLOCK,0,1,0,1,0,1
ESIZE,1
VMESH,ALL,
MP,EX,1,250.0E3
MP,NUXY,1,0.25
TB,BISO,1,1
TBMODIF,2,1,5
TBMODIF,3,1,0
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
```

```
NSEL,S,LOC,Y,1.0
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,S,LOC,Z,1.0
D,ALL,UZ
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
```

```
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,13
/YRANGE,-10,30
/OUT,
NSEL,S,LOC,X,1
NSEL,R,LOC,Y,1
NSEL,R,LOC,Z,1
*GET,N1,NODE,,NUM,MAX
ESLN,S
*GET,E1,ELEM,,NUM,MIN
ESOL,2,E1,N1,S,X,
ESOL,3,E1,N1,S,Y,
ESOL,4,E1,N1,S,Z,
ESOL,5,E1,N1,S,EQV,
PRVAR,2,3,4,5
PLVAR,2,3,4,5

*DIM,V,ARRAY,24
*DIM,VALUEX,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V(JJ),VARI,2,RTIME,JJ
*ENDDO
*VFILL,VALUEX,DATA,V(1),V(4),V(7),V(10),V(13)
R1=VALUEX(1)/7.499
R2=VALUEX(2)/16.365
R3=VALUEX(3)/17.595
R4=VALUEX(4)/8.710
R5=VALUEX(5)/2.747

*DIM,V2,ARRAY,24
*DIM,VALUEY,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V2(JJ),VARI,3,RTIME,JJ
*ENDDO
*VFILL,VALUEY,DATA,V2(1),V2(4),V2(7),V2(10),V2(13)
R6=VALUEY(1)/2.500
R7=VALUEY(2)/19.692
R8=VALUEY(3)/21.766
R9=VALUEY(4)/5.277
R10=VALUEY(5)/0.262

*DIM,V3,ARRAY,24
*DIM,VALUEZ,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V3(JJ),VARI,4,RTIME,JJ
*ENDDO
*VFILL,VALUEZ,DATA,V3(1),V3(4),V3(7),V3(10),V3(13)
R11=VALUEZ(1)/2.500
R12=VALUEZ(2)/13.942
```

```
R13=VALUEZ(3)/23.138
R14=VALUEZ(4)/11.013
R15=VALUEZ(5)/(-3.009)

*DIM,V4,ARRAY,24
*DIM,VALUEEF,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V4(JJ),VARI,5,RTIME,JJ
*ENDDO
*VFILL,VALUEEF,DATA,V4(1),V4(4),V4(7),V4(10),V4(13)
R16=VALUEEF(1)/5.000
R17=VALUEEF(2)/5.000
R18=VALUEEF(3)/5.000
R19=VALUEEF(4)/5.000
R20=VALUEEF(5)/5.000

*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,5,1
*DIM,RATIOY,,5,1
*DIM,RATIOZ,,5,1
*DIM,RATIOEF,,5,1
STEP(1)='1.0','4.0','7.0','10.0','13.0'
TARGETX(1)='7.500','16.365','17.595','8.710','2.747'
TARGETY(1)='2.500','19.692','21.766','5.277','0.262'
TARGETZ(1)='2.500','13.942','23.138','11.013','-3.009'
TARGETEF(1)='5.000','5.000','5.000','5.000','5.000'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5
*VFILL,RATIOY,DATA,R6,R7,R8,R9,R10
*VFILL,RATIOZ,DATA,R11,R12,R13,R14,R15
*VFILL,RATIOEF,DATA,R16,R17,R18,R19,R20
/COM,
/COM, ----------- vmr049-pl3a-187 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl3a-187.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 55, FIGURE 2.17(A).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl3a-187 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl3a-187 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl3a-187 STRESS RESULTS IN Z DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl3a-187 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
```

```
/COM,
FINISH

*DIM,LABEL1,CHAR,4
*DIM,VALUE1,,4,3
LABEL1(1) = ' SX ',' SY ',' SZ ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(5),VALUEY(5),VALUEZ(5),VALUEEF(5)
*VFILL,VALUE1(1,2),DATA,R5,R10,R15,R20
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl3a-187'

/OUT,vmr049-pl3a-187,vrt
/COM
/COM,------------------- vmr049-pl3a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID187
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(4),VALUE1(4,1),VALUE1(4,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl3a-187,vrt
```

VM-R049-PL3B 185 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl3b-185
/TITLE, vmr049-pl3b-185,  3D PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049, PL-3

/PREP7
R = 2.5E-5
ET,1,185
N, 1, 0.0, 0.0, 0.0
N, 2, 0.0, 1.0, 0.0
N, 3, 1.0, 0.0, 0.0
N, 4, 1.0, 1.0, 0.0
N, 5, 0.0, 0.0, 1.0
N, 6, 0.0, 1.0, 1.0
N, 7, 1.0, 0.0, 1.0
N, 8, 1.0, 1.0, 1.0
E,1,3,4,2,5,7,8,6
MP,EX,1,250.0E3
MP,NUXY,1,0.25
TB,BISO,1,1, , ,
TBMODIF,2,1,5
TBMODIF,3,1,50000
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,S,LOC,Z,1.0
```

```
D,ALL,UZ
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
```

```
D,ALL,UZ,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,13
/YRANGE,-10,35
ESOL,2,1,8,S,X,
ESOL,3,1,8,S,Y,
ESOL,4,1,8,S,Z,
ESOL,5,1,8,S,EQV,
PLVAR,2,3,4,5
PRVAR,2,3,4,5

*DIM,V,ARRAY,24
*DIM,VALUEX,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V(JJ),VARI,2,RTIME,JJ
*ENDDO
*VFILL,VALUEX,DATA,V(1),V(4),V(7),V(10),V(13)
R1=VALUEX(1)/7.499
R2=VALUEX(2)/16.894
R3=VALUEX(3)/16.291
R4=VALUEX(4)/6.934
R5=VALUEX(5)/1.934

*DIM,V2,ARRAY,24
*DIM,VALUEY,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V2(JJ),VARI,3,RTIME,JJ
*ENDDO
*VFILL,VALUEY,DATA,V2(1),V2(4),V2(7),V2(10),V2(13)
R6=VALUEY(1)/2.500
R7=VALUEY(2)/20.218
R8=VALUEY(3)/22.236
R9=VALUEY(4)/4.459
R10=VALUEY(5)/(-0.541)

*DIM,V3,ARRAY,24
*DIM,VALUEZ,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V3(JJ),VARI,4,RTIME,JJ
*ENDDO
*VFILL,VALUEZ,DATA,V3(1),V3(4),V3(7),V3(10),V3(13)
R11=VALUEZ(1)/2.500
R12=VALUEZ(2)/12.886
R13=VALUEZ(3)/23.972
R14=VALUEZ(4)/13.606
R15=VALUEZ(5)/(-1.393)

*DIM,V4,ARRAY,24
*DIM,VALUEEF,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V4(JJ),VARI,5,RTIME,JJ
*ENDDO
*VFILL,VALUEEF,DATA,V4(1),V4(4),V4(7),V4(10),V4(13)
R16=VALUEEF(1)/5.000
R17=VALUEEF(2)/6.359
R18=VALUEEF(3)/6.976
```

```
R19=VALUEEF(4)/8.195
R20=VALUEEF(5)/2.994

*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,5,1
*DIM,RATIOY,,5,1
*DIM,RATIOZ,,5,1
*DIM,RATIOEF,,5,1
STEP(1)='1.0','4.0','7.0','10.0','13.0'
TARGETX(1)='7.500','16.894','16.291','6.934','1.934'
TARGETY(1)='2.500','20.218','22.236','4.459','-0.541'
TARGETZ(1)='2.500','12.886','23.972','13.606','-1.393'
TARGETEF(1)='5.000','6.359','6.976','8.195','2.994'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5
*VFILL,RATIOY,DATA,R6,R7,R8,R9,R10
*VFILL,RATIOZ,DATA,R11,R12,R13,R14,R15
*VFILL,RATIOEF,DATA,R16,R17,R18,R19,R20
/COM,
/COM, ----------- vmr049-pl3b-185 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl3b-185.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 55, FIGURE 2.17(B).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl3b-185 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl3b-185 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl3b-185 STRESS RESULTS IN Z DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl3b-185 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,4
*DIM,VALUE1,,4,3
LABEL1(1) = ' SX ',' SY ',' SZ ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(5),VALUEY(5),VALUEZ(5),VALUEEF(5)
*VFILL,VALUE1(1,2),DATA,R5,R10,R15,R20
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl3b-185'

/OUT,vmr049-pl3b-185,vrt
```

```
/COM
/COM,------------------- vmr049-pl3b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID185
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'       ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'       ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'       ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(4),VALUE1(4,1),VALUE1(4,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'       ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl3b-185,vrt
```

VM-R049-PL3B 186 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl3b-186
/TITLE, vmr049-pl3b-186,  3D PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049, PL-3

/PREP7
R = 2.5E-5
ET,1,186
N, 1, 0.0, 0.0, 0.0
N, 2, 0.0, 0.5, 0.0
N, 3, 0.0, 1.0, 0.0
N, 4, 0.5, 0.0, 0.0
N, 5, 0.5, 1.0, 0.0
N, 6, 1.0, 0.0, 0.0
N, 7, 1.0, 0.5, 0.0
N, 8, 1.0, 1.0, 0.0
N, 9, 0.0, 0.0, 1.0
N,10, 0.0, 0.5, 1.0
N,11, 0.0, 1.0, 1.0
N,12, 0.5, 0.0, 1.0
N,13, 0.5, 1.0, 1.0
N,14, 1.0, 0.0, 1.0
N,15, 1.0, 0.5, 1.0
N,16, 1.0, 1.0, 1.0
N,17, 0.0, 0.0, 0.5
N,18, 1.0, 0.0, 0.5
N,19, 1.0, 1.0, 0.5
N,20, 0.0, 1.0, 0.5
E,1,6,8,3,9,14,16,11
EMORE,4,7,5,2,12,15,13,10
EMORE,17,18,19,20
MP,EX,1,250.0E3
MP,NUXY,1,0.25
TB,BISO,1,1, , ,
TBMODIF,2,1,5
TBMODIF,3,1,50000
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
NSEL,S,LOC,Z
```

```
D,ALL,UZ
NSEL,S,LOC,Z,1.0
D,ALL,UZ
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
```

```
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,13
/YRANGE,-10,35
/OUT,
ESOL,2,1,16,S,X,
ESOL,3,1,16,S,Y,
ESOL,4,1,16,S,Z,
ESOL,5,1,16,S,EQV,
PRVAR,2,3,4,5
PLVAR,2,3,4,5

*DIM,V,ARRAY,24
*DIM,VALUEX,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V(JJ),VARI,2,RTIME,JJ
*ENDDO
*VFILL,VALUEX,DATA,V(1),V(4),V(7),V(10),V(13)
R1=VALUEX(1)/7.499
R2=VALUEX(2)/16.894
R3=VALUEX(3)/16.291
R4=VALUEX(4)/6.934
R5=VALUEX(5)/1.934

*DIM,V2,ARRAY,24
*DIM,VALUEY,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V2(JJ),VARI,3,RTIME,JJ
*ENDDO
*VFILL,VALUEY,DATA,V2(1),V2(4),V2(7),V2(10),V2(13)
R6=VALUEY(1)/2.500
R7=VALUEY(2)/20.218
R8=VALUEY(3)/22.236
R9=VALUEY(4)/4.459
R10=VALUEY(5)/(-0.541)

*DIM,V3,ARRAY,24
*DIM,VALUEZ,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V3(JJ),VARI,4,RTIME,JJ
*ENDDO
*VFILL,VALUEZ,DATA,V3(1),V3(4),V3(7),V3(10),V3(13)
R11=VALUEZ(1)/2.500
R12=VALUEZ(2)/12.886
R13=VALUEZ(3)/23.972
R14=VALUEZ(4)/13.606
R15=VALUEZ(5)/(-1.393)

*DIM,V4,ARRAY,24
*DIM,VALUEEF,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V4(JJ),VARI,5,RTIME,JJ
*ENDDO
```

```
*VFILL,VALUEEF,DATA,V4(1),V4(4),V4(7),V4(10),V4(13)
R16=VALUEEF(1)/5.000
R17=VALUEEF(2)/6.359
R18=VALUEEF(3)/6.976
R19=VALUEEF(4)/8.195
R20=VALUEEF(5)/2.994

*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,5,1
*DIM,RATIOY,,5,1
*DIM,RATIOZ,,5,1
*DIM,RATIOEF,,5,1
STEP(1)='1.0','4.0','7.0','10.0','13.0'
TARGETX(1)='7.500','16.894','16.291','6.934','1.934'
TARGETY(1)='2.500','20.218','22.236','4.459','-0.541'
TARGETZ(1)='2.500','12.886','23.972','13.606','-1.393'
TARGETEF(1)='5.000','6.359','6.976','8.195','2.994'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5
*VFILL,RATIOY,DATA,R6,R7,R8,R9,R10
*VFILL,RATIOZ,DATA,R11,R12,R13,R14,R15
*VFILL,RATIOEF,DATA,R16,R17,R18,R19,R20
/COM,
/COM, ----------- vmr049-pl3b-186 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl3b-186.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 55, FIGURE 2.17(B).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl3b-186 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl3b-186 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl3b-186 STRESS RESULTS IN Z DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl3b-186 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH


/POST26
*DIM,LABEL1,CHAR,4
*DIM,VALUE1,,4,3
LABEL1(1) = ' SX ',' SY ',' SZ ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(5),VALUEY(5),VALUEZ(5),VALUEEF(5)
```

```
*VFILL,VALUE1(1,2),DATA,R5,R10,R15,R20
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl3b-186'

/OUT,vmr049-pl3b-186,vrt
/COM
/COM,------------------- vmr049-pl3b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLID186
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(4),VALUE1(4,1),VALUE1(4,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl3b-186,vrt
```

VM-R049-PL3B 187 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl3b-187
/TITLE, vmr049-pl3b-187, 3D PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049, PL-3

/PREP7
R = 2.5E-5
ET,1,187
BLOCK,0,1,0,1,0,1
ESIZE,1
VMESH,ALL
MP,EX,1,250.0E3
MP,NUXY,1,0.25
TB,BISO,1,1, , ,
TBMODIF,2,1,5
TBMODIF,3,1,50000
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,S,LOC,Z,1.0
D,ALL,UZ
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,1.0
```

```
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
```

```
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,13
/YRANGE,-10,35
/OUT,
NSEL,S,LOC,X,1
NSEL,R,LOC,Y,1
NSEL,R,LOC,Z,1
*GET,N1,NODE,,NUM,MAX
ESLN,S
*GET,E1,ELEM,,NUM,MIN
ESOL,2,E1,N1,S,X,
ESOL,3,E1,N1,S,Y,
ESOL,4,E1,N1,S,Z,
ESOL,5,E1,N1,S,EQV,
PLVAR,2,3,4,5
PRVAR,2,3,4,5

*DIM,V,ARRAY,24
*DIM,VALUEX,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V(JJ),VARI,2,RTIME,JJ
*ENDDO
*VFILL,VALUEX,DATA,V(1),V(4),V(7),V(10),V(13)
R1=VALUEX(1)/7.499
R2=VALUEX(2)/16.894
R3=VALUEX(3)/16.291
R4=VALUEX(4)/6.934
R5=VALUEX(5)/1.934

*DIM,V2,ARRAY,24
*DIM,VALUEY,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V2(JJ),VARI,3,RTIME,JJ
*ENDDO
*VFILL,VALUEY,DATA,V2(1),V2(4),V2(7),V2(10),V2(13)
R6=VALUEY(1)/2.500
R7=VALUEY(2)/20.218
R8=VALUEY(3)/22.236
R9=VALUEY(4)/4.459
R10=VALUEY(5)/(-0.541)

*DIM,V3,ARRAY,24
*DIM,VALUEZ,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V3(JJ),VARI,4,RTIME,JJ
*ENDDO
*VFILL,VALUEZ,DATA,V3(1),V3(4),V3(7),V3(10),V3(13)
R11=VALUEZ(1)/2.500
R12=VALUEZ(2)/12.886
R13=VALUEZ(3)/23.972
R14=VALUEZ(4)/13.606
R15=VALUEZ(5)/(-1.393)

*DIM,V4,ARRAY,24
*DIM,VALUEEF,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V4(JJ),VARI,5,RTIME,JJ
*ENDDO
*VFILL,VALUEEF,DATA,V4(1),V4(4),V4(7),V4(10),V4(13)
R16=VALUEEF(1)/5.000
R17=VALUEEF(2)/6.359
R18=VALUEEF(3)/6.976
R19=VALUEEF(4)/8.195
R20=VALUEEF(5)/2.994

*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
```

```
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,5,1
*DIM,RATIOY,,5,1
*DIM,RATIOZ,,5,1
*DIM,RATIOEF,,5,1
STEP(1)='1.0','4.0','7.0','10.0','13.0'
TARGETX(1)='7.500','16.894','16.291','6.934','1.934'
TARGETY(1)='2.500','20.218','22.236','4.459','-0.541'
TARGETZ(1)='2.500','12.886','23.972','13.606','-1.393'
TARGETEF(1)='5.000','6.359','6.976','8.195','2.994'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5
*VFILL,RATIOY,DATA,R6,R7,R8,R9,R10
*VFILL,RATIOZ,DATA,R11,R12,R13,R14,R15
*VFILL,RATIOEF,DATA,R16,R17,R18,R19,R20
/COM,
/COM, ----------- vmr049-pl3b-187 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl3b-187.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 55, FIGURE 2.17(B).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl3b-187 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl3b-187 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl3b-187 STRESS RESULTS IN Z DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl3b-187 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,4
*DIM,VALUE1,,4,3
LABEL1(1) = ' SX ',' SY ',' SZ ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(5),VALUEY(5),VALUEZ(5),VALUEEF(5)
*VFILL,VALUE1(1,2),DATA,R5,R10,R15,R20
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl3b-187'

/OUT,vmr049-pl3b-187,vrt
/COM
/COM,------------------- vmr049-pl3b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
```

```
/COM, SOLID187
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(4),VALUE1(4,1),VALUE1(4,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,---------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl3b-187,vrt
```

VM-R049-PL3B 190 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl3b-190
/TITLE, vmr049-pl3b-190,  3D PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049, PL-3

/PREP7
R = 2.5E-5
ET,1,190
N, 1, 0.0, 0.0, 0.0
N, 2, 0.0, 1.0, 0.0
N, 3, 1.0, 0.0, 0.0
N, 4, 1.0, 1.0, 0.0
N, 5, 0.0, 0.0, 1.0
N, 6, 0.0, 1.0, 1.0
N, 7, 1.0, 0.0, 1.0
N, 8, 1.0, 1.0, 1.0
E,1,3,4,2,5,7,8,6
MP,EX,1,250.0E3
MP,NUXY,1,0.25
TB,BISO,1,1, , ,
TBMODIF,2,1,5
TBMODIF,3,1,50000
TB,HILL,1
TBDATA,1,1.0,1.0,1.0,1.0,1.0,1.0
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Y,1.0
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,S,LOC,Z,1.0
D,ALL,UZ
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
```

```
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,2*R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,X,1.0
D,ALL,UX,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Y,1.0
D,ALL,UY,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,R
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
NSEL,S,LOC,Z,1.0
D,ALL,UZ,0.0
NSEL,ALL
NSUBST,10,10,10,
OUTRES,ALL,5
SOLVE
FINISH

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
```

```
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,13
/YRANGE,-5,30
/OUT,
ESOL,2,1,8,S,X,
ESOL,3,1,8,S,Y,
ESOL,4,1,8,S,Z,
ESOL,5,1,8,S,EQV,
PLVAR,2,3,4,5
PRVAR,2,3,4,5

*DIM,V,ARRAY,24
*DIM,VALUEX,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V(JJ),VARI,2,RTIME,JJ
*ENDDO
*VFILL,VALUEX,DATA,V(1),V(4),V(7),V(10),V(13)
R1=VALUEX(1)/7.499
R2=VALUEX(2)/16.894
R3=VALUEX(3)/16.291
R4=VALUEX(4)/6.934
R5=VALUEX(5)/1.934

*DIM,V2,ARRAY,24
*DIM,VALUEY,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V2(JJ),VARI,3,RTIME,JJ
*ENDDO
*VFILL,VALUEY,DATA,V2(1),V2(4),V2(7),V2(10),V2(13)
R6=VALUEY(1)/2.500
R7=VALUEY(2)/20.218
R8=VALUEY(3)/22.236
R9=VALUEY(4)/4.459
R10=VALUEY(5)/(-0.541)

*DIM,V3,ARRAY,24
*DIM,VALUEZ,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V3(JJ),VARI,4,RTIME,JJ
*ENDDO
*VFILL,VALUEZ,DATA,V3(1),V3(4),V3(7),V3(10),V3(13)
R11=VALUEZ(1)/2.500
R12=VALUEZ(2)/12.886
R13=VALUEZ(3)/23.972
R14=VALUEZ(4)/13.606
R15=VALUEZ(5)/(-1.393)

*DIM,V4,ARRAY,24
*DIM,VALUEEF,ARRAY,5
*DO,JJ,1.0,24,3
*GET,V4(JJ),VARI,5,RTIME,JJ
*ENDDO
*VFILL,VALUEEF,DATA,V4(1),V4(4),V4(7),V4(10),V4(13)
R16=VALUEEF(1)/5.000
R17=VALUEEF(2)/6.359
R18=VALUEEF(3)/6.976
R19=VALUEEF(4)/8.195
R20=VALUEEF(5)/2.994

*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,5,1
*DIM,RATIOY,,5,1
*DIM,RATIOZ,,5,1
*DIM,RATIOEF,,5,1
STEP(1)='1.0','4.0','7.0','10.0','13.0'
TARGETX(1)='7.500','16.894','16.291','6.934','1.934'
TARGETY(1)='2.500','20.218','22.236','4.459','-0.541'
```

```
TARGETZ(1)='2.500','12.886','23.972','13.606','-1.393'
TARGETEF(1)='5.000','6.359','6.976','8.195','2.994'
*VFILL,RATIOX,DATA,R1,R2,R3,R4,R5
*VFILL,RATIOY,DATA,R6,R7,R8,R9,R10
*VFILL,RATIOZ,DATA,R11,R12,R13,R14,R15
*VFILL,RATIOEF,DATA,R16,R17,R18,R19,R20
/COM,
/COM, ----------- vmr049-pl3b-190 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl3b-190.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 55, FIGURE 2.17(B).  THE RESULTS
/COM, DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl3b-190 STRESS RESULTS IN X DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl3b-190 STRESS RESULTS IN Y DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl3b-190 STRESS RESULTS IN Z DIRECTION -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl3b-190 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,4
*DIM,VALUE1,,4,3
LABEL1(1) = ' SX ',' SY ',' SZ ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(5),VALUEY(5),VALUEZ(5),VALUEEF(5)
*VFILL,VALUE1(1,2),DATA,R5,R10,R15,R20
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl3b-190'

/OUT,vmr049-pl3b-190,vrt
/COM
/COM,------------------- vmr049-pl3b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, SOLSH190
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(4),VALUE1(4,1),VALUE1(4,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
```

```
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl3b-190,vrt
```

VM-R049-PL5A 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl5a-182
/TITLE, vmr049-pl5a-182, PRESSURISED CYLINDER PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049. TEST PL-5

/PREP7
R = 2.5E-5
ET,1,182,,,
KEYOPT,1,3,1
N,1,100,0,,
N,2,100,50,,
N,3,100,100,,
N,4,125,0,,
N,5,125,50,,
N,6,125,100,,
N,7,150,0,,
N,8,150,50,,
N,9,150,100,,,
N,10,175,0,,
N,11,175,50,,
N,12,175,100,,
N,13,200,0,,
N,14,200,50,,
N,15,200,100,,
E, 1,4,5,2
E, 2,5,6,3
E, 4,7,8,5
E, 5,8,9,6
E, 7,10,11,8
E, 8,11,12,9
E, 10,13,14,11
E, 11,14,15,12
MP,EX,1,21E3,
MP,NUXY,1,0.3,
TB,BISO,1
TBMODIF,2,1,24.0
TBMODIF,3,1,0.0
NSEL,U,LOC,Y,50
D,ALL,UY,0.0
NSEL,ALL,
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,100
SF,ALL,PRES,10.0
NSEL,ALL,
NSUBST,10,,,
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,100
SF,ALL,PRES,14.0
NSEL,ALL,
NSUBST,10,,,
SOLVE
NSEL,S,LOC,X,100
SF,ALL,PRES,16.6
NSEL, ALL,
NSUBST,10,,,
```

```
SOLVE
NSEL,S,LOC,X,100
SF,ALL,PRES,19.1
NSEL,ALL,
NSUBST,10,,,
SOLVE

/POST26
/XRANGE,0,4
/YRANGE,-40,60
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/OUT,
ESOL,2,1,1,S,X,
ESOL,3,1,1,S,Y,
ESOL,4,1,1,S,Z,
ESOL,5,1,1,S,EQV,
PLVAR,2,3,4,5
PRVAR,2,3,4,5

*DIM,VALUEX,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
R1=VALUEX(1,1)/(-8.603)
R2=VALUEX(2,1)/(-10.642)
R3=VALUEX(3,1)/(-13.319)
R4=VALUEX(4,1)/(-15.774)
*DIM,VALUEY,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R5=VALUEY(1,1)/1.599
R6=VALUEY(2,1)/1.810
R7=VALUEY(3,1)/0.303
R8=VALUEY(4,1)/(-1.879)
*DIM,VALUEZ,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEZ(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R9=VALUEZ(1,1)/15.706
R10=VALUEZ(2,1)/17.019
R11=VALUEZ(3,1)/14.386
R12=VALUEZ(4,1)/11.934
*DIM,VALUEEF,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEEF(JJ,1),VARI,5,RTIME,JJ
*ENDDO
R13=VALUEEF(1,1)/21.153
R14=VALUEEF(2,1)/24.0
R15=VALUEEF(3,1)/24.0
R16=VALUEEF(4,1)/24.0
*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,4,1
*DIM,RATIOY,,4,1
*DIM,RATIOZ,,4,1
*DIM,RATIOEF,,4,1
STEP(1)='1.0','2.0','3.0','4.0'
TARGETX(1)='-8.603','-10.642','-13.319','-15.774'
TARGETY(1)='1.599','1.810','0.303','-1.879'
TARGETZ(1)='15.706','17.019','14.386','11.934'
TARGETEF(1)='21.153','24.000','24.000','24.000'
*VFILL,RATIOX,DATA,R1,R2,R3,R4
*VFILL,RATIOY,DATA,R5,R6,R7,R8
*VFILL,RATIOZ,DATA,R9,R10,R11,R12
*VFILL,RATIOEF,DATA,R13,R14,R15,R16
/COM,
/COM, ----------- vmr049-pl5a-182 RESULTS COMPARISON --------------
```

```
/COM,
/COM, vmr049-pl5a-182.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 61 FIGURE 2.23(A).
/COM, THE RESULTS DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl5a-182 RADIAL STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl5a-182 AXIAL STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl5a-182 HOOP STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl5a-182 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,4
*DIM,VALUE1,,4,3
LABEL1(1) = ' SRAD ',' SAXI ',' SHOOP ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(4,1),VALUEY(4,1),VALUEZ(4,1),VALUEEF(4,1)
*VFILL,VALUE1(1,2),DATA,R4,R8,R12,R16
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl5a-182'

/OUT,vmr049-pl5a-182,vrt
/COM
/COM,------------------- vmr049-pl5a RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(4),VALUE1(4,1),VALUE1(4,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl5a-182,vrt
```

VM-R049-PL5A 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl5a-183
/TITLE, vmr049-pl5a-183, PRESSURISED CYLINDER PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT:R0049. TEST PL-5

/PREP7
ET,1,183,,,
KEYOPT,1,3,1
N,1,100,0,,
N,2,100,50,,
N,3,100,100,,
N,4,125,0,,
N,5,125,100,,
N,6,150,0,,
N,7,150,50,,
N,8,150,100,,
N,9,175,0,,
N,10,175,100,,
N,11,200,0,,
N,12,200,50,,
N,13,200,100,,
E, 1,6,8,3,4,7,5,2
E, 6,11,13,8,9,12,10,7
MP,EX,1,21E3,
MP,NUXY,1,0.3,
TB,BISO,1
TBMODIF,2,1,24.0
TBMODIF,3,1,0.0
D,ALL,UY,0.0
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,100
SF,ALL,PRES,10.0
NSEL,ALL,
NSUBST,10,,,
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,100
SF,ALL,PRES,14.0
NSEL,ALL,
NSUBST,10,,,
OUTRES,ALL,ALL
SOLVE
NSEL,S,LOC,X,100
SF,ALL,PRES,16.6
NSEL, ALL,
NSUBST,10,,,
SOLVE
NSEL,S,LOC,X,100
SF,ALL,PRES,19.0
NSEL,ALL,
NSUBST,10,,,
SOLVE

/POST26
/XRANGE,0,4
/YRANGE,-40,60
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/OUT,
ESOL,2,1,1,S,X,
ESOL,3,1,1,S,Y,
ESOL,4,1,1,S,Z,
ESOL,5,1,1,S,EQV
```

```
PLVAR,2,3,4,5
PRVAR,2,3,4,5

*DIM,VALUEX,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
R1=VALUEX(1,1)/(-8.603)
R2=VALUEX(2,1)/(-10.642)
R3=VALUEX(3,1)/(-13.319)
R4=VALUEX(4,1)/(-15.774)
*DIM,VALUEY,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R5=VALUEY(1,1)/1.599
R6=VALUEY(2,1)/1.810
R7=VALUEY(3,1)/0.303
R8=VALUEY(4,1)/(-1.879)
*DIM,VALUEZ,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEZ(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R9=VALUEZ(1,1)/15.706
R10=VALUEZ(2,1)/17.019
R11=VALUEZ(3,1)/14.386
R12=VALUEZ(4,1)/11.934
*DIM,VALUEEF,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEEF(JJ,1),VARI,5,RTIME,JJ
*ENDDO
R13=VALUEEF(1,1)/21.153
R14=VALUEEF(2,1)/24.0
R15=VALUEEF(3,1)/24.0
R16=VALUEEF(4,1)/24.0
*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,TARGETEF,CHAR,10
*DIM,RATIOX,,4,1
*DIM,RATIOY,,4,1
*DIM,RATIOZ,,4,1
*DIM,RATIOEF,,4,1
STEP(1)='1.0','2.0','3.0','4.0'
TARGETX(1)='-8.603','-10.642','-13.319','-15.774'
TARGETY(1)='1.599','1.810','0.303','-1.879'
TARGETZ(1)='15.706','17.019','14.386','11.934'
TARGETEF(1)='21.153','24.000','24.000','24.000'
*VFILL,RATIOX,DATA,R1,R2,R3,R4
*VFILL,RATIOY,DATA,R5,R6,R7,R8
*VFILL,RATIOZ,DATA,R9,R10,R11,R12
*VFILL,RATIOEF,DATA,R13,R14,R15,R16
/COM,
/COM, ----------- vmr049-pl5a-183 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl5a-183.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 61 FIGURE 2.23(A).
/COM, THE RESULTS DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl5a-183 RADIAL STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl5a-183 AXIAL STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
```

```
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl5a-183 HOOP STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl5a-183 EFFECTIVE STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETEF(1),VALUEEF(1,1),RATIOEF(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,4
*DIM,VALUE1,,4,3
LABEL1(1) = ' SRAD ',' SAXI ',' SHOOP ',' SEFF '
*VFILL,VALUE1(1,1),DATA,VALUEX(4,1),VALUEY(4,1),VALUEZ(4,1),VALUEEF(4,1)
*VFILL,VALUE1(1,2),DATA,R4,R8,R12,R16
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl5a-183'

/OUT,vmr049-pl5a-183,vrt
/COM
/COM,------------------- vmr049-pl5a RESULTS COMPARISON ---------------------
/COM,
/COM,           |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(4),VALUE1(4,1),VALUE1(4,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl5a-183,vrt
```

VM-R049-PL5B 182 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl5b-182
/TITLE, vmr049-pl5b-182, PRESSURISED CYLINDER PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT: R0049. TEST PL-5

/PREP7
ET,1,182,,,
KEYOPT,1,3,1
N,1,100,0,,
N,2,100,50,,
N,3,100,100,,
N,4,125,0,,
N,5,125,50,,
```

```
N,6,125,100,,
N,7,150,0,,
N,8,150,50,,
N,9,150,100,,
N,10,175,0,,
N,11,175,50,,
N,12,175,100,,
N,13,200,0,,
N,14,200,50,,
N,15,200,100,,
E, 1,4,5,2
E, 2,5,6,3
E, 4,7,8,5
E, 5,8,9,6
E, 7,10,11,8
E, 8,11,12,9
E, 10,13,14,11
E, 11,14,15,12
MP,EX,1,21.0E3,
MP,NUXY,1,0.3,
TB,BISO,1, , , ,
TBMODIF,2,1,24.0
TBMODIF,3,1,4200
NSEL,U,LOC,Y,50
D,ALL,UY,0.0
NSEL,ALL,
FINISH

/SOLU
NLGEOM,ON
NSEL,S,LOC,X,100
SF,ALL,PRES,10.0
NSEL,ALL,
NSUBST,10,,,
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,100
SF,ALL,PRES,14.0
NSEL,ALL,
NSUBST,10,,,
OUTRES,ALL,ALL
SOLVE
NSEL,S,LOC,X,100
SF,ALL,PRES,24.0
NSEL, ALL,
NSUBST,10,,,
SOLVE
NSEL,S,LOC,X,100
SF,ALL,PRES,34.0
NSEL,ALL,
NSUBST,10,,,
SOLVE
SAVE

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,4
/YRANGE,-40,60
/OUT,
ESOL,2,1,1,S,X,
ESOL,3,1,1,S,Y,
ESOL,4,1,1,S,Z,
```

```
ESOL,5,1,1,EPEL,X,
PLVAR,2,3,4
PRVAR,2,3,4,5

*DIM,VALUEX,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
R1=VALUEX(1,1)/(-8.603)
R2=VALUEX(2,1)/(-10.603)
R3=VALUEX(3,1)/(-19.307)
R4=VALUEX(4,1)/(-27.025)
*DIM,VALUEY,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R5=VALUEY(1,1)/1.598
R6=VALUEY(2,1)/2.094
R7=VALUEY(3,1)/0.946
R8=VALUEY(4,1)/3.632
*DIM,VALUEZ,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEZ(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R9=VALUEZ(1,1)/15.706
R10=VALUEZ(2,1)/18.193
R11=VALUEZ(3,1)/22.820
R12=VALUEZ(4,1)/37.778
*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,RATIOX,,4,1
*DIM,RATIOY,,4,1
*DIM,RATIOZ,,4,1
STEP(1)='1.0','2.0','3.0','4.0'
TARGETX(1)='-8.603','-10.603','-19.307','-27.025'
TARGETY(1)='1.598','2.094','0.964','3.632'
TARGETZ(1)='15.706','18.193','22.820','37.778'
*VFILL,RATIOX,DATA,R1,R2,R3,R4
*VFILL,RATIOY,DATA,R5,R6,R7,R8
*VFILL,RATIOZ,DATA,R9,R10,R11,R12
/COM,
/COM, ----------- vmr049-pl5b-182 RESULTS COMPARISON --------------
/COM,
/COM, vmr049-pl5b-182.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 61 FIGURE 2.23(C).
/COM, THE RESULTS DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl5b-182 RADIAL STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl5b-182 AXIAL STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl5b-182 HOOP STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
```

```
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' SRAD ',' SAXI ',' SHOOP '
*VFILL,VALUE1(1,1),DATA,VALUEX(4,1),VALUEY(4,1),VALUEZ(4,1)
*VFILL,VALUE1(1,2),DATA,R4,R8,R12
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl5b-182'

/OUT,vmr049-pl5b-182,vrt
/COM
/COM,------------------- vmr049-pl5b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE182
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,----------------------------------------------------------------
/OUT

FINISH
*LIST,vmr049-pl5b-182,vrt
```

VM-R049-PL5B 183 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmr049-pl5b-183
/TITLE, vmr049-pl5b-183, PRESSURISED CYLINDER PLASTICITY BENCHMARK
/COM, REFERENCE: NAFEMS REPORT:R0049. TEST PL-5
/PREP7
ET,1,183,,,
KEYOPT,1,3,1
N,1,100,0,,
N,2,100,50,,
N,3,100,100,,
N,4,125,0,,
N,5,125,100,,
N,6,150,0,,
N,7,150,50,,
N,8,150,100,,
N,9,175,0,,
N,10,175,100,,
N,11,200,0,,
N,12,200,50,,
N,13,200,100,,
E, 1,6,8,3,4,7,5,2
E, 6,11,13,8,9,12,10,7
MP,EX,1,21E3,
MP,NUXY,1,0.3,
TB,BISO,1, , , ,
TBMODIF,2,1,24.0
TBMODIF,3,1,4200
NSEL,U,LOC,Y,50
D,ALL,UY,0.0
NSEL,ALL
FINISH

/SOLU
NLGEOM,ON
```

```
NSEL,S,LOC,X,100
SF,ALL,PRES,10.0
NSEL,ALL,
NSUBST,10,,,
OUTRES,ALL,ALL
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,X,100
SF,ALL,PRES,14.0
NSEL,ALL,
NSUBST,10,,,
OUTRES,ALL,ALL
SOLVE
NSEL,S,LOC,X,100
SF,ALL,PRES,24.0
NSEL, ALL,
NSUBST,10,,,
SOLVE
NSEL,S,LOC,X,100
SF,ALL,PRES,34.0
NSEL,ALL,
NSUBST,10,,,
SOLVE
SAVE

/POST26
/GROPT,VIEW,0
/GTHK,CURVE,1
/GROPT,FILL,OFF
/GRID,1
/GTHK,GRID,1
/GROPT,CGRID,1
/AXLAB,X,STEP
/AXLAB,Y,STRESS
/GTHK,AXIS,1
/GRTYP,0
/XRANGE,0,4
/YRANGE,-40,60
/OUT,
ESOL,2,1,1,S,X,
ESOL,3,1,1,S,Y,
ESOL,4,1,1,S,Z,
ESOL,5,1,1,EPEL,X,
PLVAR,2,3,4
PRVAR,2,3,4,5

*DIM,VALUEX,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEX(JJ,1),VARI,2,RTIME,JJ
*ENDDO
R1=VALUEX(1,1)/(-8.603)
R2=VALUEX(2,1)/(-10.603)
R3=VALUEX(3,1)/(-19.307)
R4=VALUEX(4,1)/(-27.025)
*DIM,VALUEY,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEY(JJ,1),VARI,3,RTIME,JJ
*ENDDO
R5=VALUEY(1,1)/1.598
R6=VALUEY(2,1)/2.094
R7=VALUEY(3,1)/.964
R8=VALUEY(4,1)/3.632
*DIM,VALUEZ,ARRAY,4,1
*DO,JJ,1,4,1
*GET,VALUEZ(JJ,1),VARI,4,RTIME,JJ
*ENDDO
R9=VALUEZ(1,1)/15.706
R10=VALUEZ(2,1)/18.193
R11=VALUEZ(3,1)/22.820
R12=VALUEZ(4,1)/37.778
*DIM,STEP,CHAR,10
*DIM,TARGETX,CHAR,10
```

```
*DIM,TARGETY,CHAR,10
*DIM,TARGETZ,CHAR,10
*DIM,RATIOX,,4,1
*DIM,RATIOY,,4,1
*DIM,RATIOZ,,4,1
STEP(1)='1.0','2.0','3.0','4.0'
TARGETX(1)='-8.603','-10.603','-19.307','-27.025'
TARGETY(1)='1.598','2.094','0.964','3.632'
TARGETZ(1)='15.706','18.193','22.820','37.778'
*VFILL,RATIOX,DATA,R1,R2,R3,R4
*VFILL,RATIOY,DATA,R5,R6,R7,R8
*VFILL,RATIOZ,DATA,R9,R10,R11,R12
/COM,
/COM, ----------- vmr049-pl5b-183 RESULTS COMPARISON -------------
/COM,
/COM, vmr049-pl5b-183.jpeg RESULTS SHOULD MATCH R0049 NAFEMS MANUAL
/COM, GRAPH RESULTS ON PAGE 61 FIGURE 2.23(C).
/COM, THE RESULTS DISPLAYED ARE INCREMENTED FOR THIS PURPOSE.
/COM,
/COM,
/COM, ------ vmr049-pl5b-183 RADIAL STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETX(1),VALUEX(1,1),RATIOX(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM, ------ vmr049-pl5b-183 AXIAL STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETY(1),VALUEY(1,1),RATIOY(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
/COM, ------ vmr049-pl5b-183 HOOP STRESS RESULTS -------
/COM,
/COM, |  STEP  |  TARGET  |  Mechanical APDL  |  RATIO
/COM,
*VWRITE,STEP(1),TARGETZ(1),VALUEZ(1,1),RATIOZ(1,1)
(1X,A8,'   ',1x,A8,'   ',F14.3,'   ',F12.3,'   ')
/COM,
/COM,
FINISH

/POST26
*DIM,LABEL1,CHAR,3
*DIM,VALUE1,,3,3
LABEL1(1) = ' SRAD ',' SAXI ',' SHOOP '
*VFILL,VALUE1(1,1),DATA,VALUEX(4,1),VALUEY(4,1),VALUEZ(4,1)
*VFILL,VALUE1(1,2),DATA,R4,R8,R12
*DIM,LABEL2,CHAR,2
LABEL2(1) = 'vmr049-','pl5b-183'

/OUT,vmr049-pl5b-183,vrt
/COM
/COM,------------------- vmr049-pl5b RESULTS COMPARISON ---------------------
/COM,
/COM,            |   Mechanical APDL   |   RATIO  |         INPUT         |
/COM,
/COM, PLANE183
*VWRITE,LABEL1(1),VALUE1(1,1),VALUE1(1,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(2),VALUE1(2,1),VALUE1(2,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
*VWRITE,LABEL1(3),VALUE1(3,1),VALUE1(3,2),LABEL2(1),LABEL2(2)
(1X,A8,'      ',F14.4,'      ',F9.4,'     ',A7,A8)
/COM,
/COM,-----------------------------------------------------------------
/OUT

FINISH
```

```
*LIST,vmr049-pl5b-183,vrt
```

VM-R083-CA1 221 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY, VMR083-CA1-221
/TITLE, VMR083-CA1-221, SOUND RADIATION OF A VIBRATING SPHERE
/COM, REFERENCE: NAFEMS BENCHMARKS FOR RADIATION AND SCATTERING OF SOUND
/COM, TEST NAME: CA1, R0038

/OUT,SCRATCH
/NOPR
/PREP7

PI = ACOS(-1)

c0 = 340                    ! SPEED OF SOUND IN m/s
rho = 1.225                 ! DENSITY OF AIR IN kg/m^3

R = 1                       ! SPHERE RADIUS IN m
Vn = 0.1                    ! NORMAL VELOCITY IN m/s

FREQA = 100
FREQB = 500
WAVE = c0/FREQB
H = WAVE/12

ET,1,FLUID221               ! FLUID221 ELEMENT
KEYOPT,1,2,1                ! NO FSI
MP,SONC,1,c0
MP,DENS,1,rho
ET,2,FLUID130               ! FLUID30 ELEMENT
KEYOPT,2,1,2
MSHAPE,1,2D
R,2,R+4*H

SPHERE,R,R+4*H,0,90
TYPE,1
MAT,1
ESIZE,H
VMESH,ALL
ALLSEL,ALL

CSYS,2
NSEL,S,LOC,X,R+4*H
TYPE,2
REAL,2
MAT,1
ESIZE,H
ESURF
ALLSEL,ALL

NSEL,S,LOC,X,R+4*H
SF,ALL,MXWF
ALLSEL,ALL

NSEL,S,LOC,X,R
SF,ALL,SHLD,Vn
CSYS,0
ALLSEL,ALL
FINISH

/SOLU
ANTY,HARMONIC
HROPT,AUTO
HARFRQ,0,FREQA
NSUB,5
SOLVE
```

```
FINISH

/POST26
N1=NODE(1,0,0)          ! NODE AT LOCATION X=1,Y=0,Z=0
NSOL,2,N1,SPL
/OUT
/COM, ------ r=1m, 0-100 Hz with 5 substeps------
/COM,
PRVAR,2
ALLSEL,ALL
FINISH

/POST1
HFSYM,0,SHB,SHB
SET,LIST
*GET,NUMSET,ACTIVE,0,SET,SBST
*DIM,Freq1,ARRAY,NUMSET
*DIM,SPLR,ARRY,NUMSET
*DIM,SPL1,ARRAY,NUMSET
*DIM,RATIO1,ARRAY,NUMSET
NSET = 0
*DO,i0,1,NUMSET,1
   NSET=NSET+1
   SET,1,i0,,0
   *GET,frq,ACTIVE,0,SET,FREQ
   Freq1(NSET)=frq
   k = 2*PI*Freq1(NSET)/c0
   p = rho*c0*vn*R**2/(1+(k**2)*(R**2))*CXABS(R*k**2,-k)
   p0 = 2e-5
   SPL1(nset)= 20*log10((p/SQRT(2))/p0)
*ENDDO
R1 = 114.161/SPL1(1)
R2 = 118.845/SPL1(2)
R3 = 120.778/SPL1(3)
R4 = 121.727/SPL1(4)
R5 = 122.247/SPL1(5)
*VFILL,SPLR,DATA,114.161,118.845,120.778,121.727,122.247
*VFILL,RATIO1,DATA,R1,R2,R3,R4,R5
SAVE,TABLE_1
FINISH

/POST1
HFSYM,0,SHB,SHB
SET,LIST
*GET,NUMSET,ACTIVE,0,SET,SBST
*DIM,Freq2,ARRAY,NUMSET
*DIM,SPL2,ARRAY,NUMSET
*DIM,SPL3,ARRAY,NUMSET
*DIM,RATIO2,ARRAY,NUMSET
NSET = 0
*DO,i0,1,NUMSET,1
   NSET=NSET+1
   SET,1,i0,,0
   *GET,frq,ACTIVE,0,SET,FREQ
   Freq2(NSET)=frq
   PRFAR,PRES,SPLC,0,0,0,0,0,0,15          ! FAR FIELD PRESSURE
   *GET,SPL2(NSET),ACUS,0,SPL
   k = 2*PI*Freq2(NSET)/c0
   p = rho*c0*vn*R**2/(1+(k**2)*(R**2))*CXABS(R*k**2/15,-k/15)*CXABS(COS(14*k),SIN(14*k))
   p0 = 2e-5
   SPL3(NSET) = 20*log10((p/SQRT(2))/p0)
*ENDDO
R21 = SPL2(1)/SPL3(1)
R22 = SPL2(2)/SPL3(2)
R23 = SPL2(3)/SPL3(3)
R24 = SPL2(4)/SPL3(4)
R25 = SPL2(5)/SPL3(5)
*VFILL,RATIO2,DATA,R21,R22,R23,R24,R25
SAVE,TABLE_2
FINISH

/OUT,SCRATCH
```

```
/SOLU
ANTY,HARMONIC
HROPT,AUTO
HARFRQ,FREQA,FREQB
NSUB,4
SOLVE
FINISH

/POST26
N1=NODE(1,0,0)          ! NODE AT LOCATION X=1,Y=0,Z=0
NSOL,3,N1,SPL
/OUT
/COM, ------ r=1m, 100-500 Hz with 4 substeps------
/COM,
PRVAR,3
FINISH

/POST1
HFSYM,0,SHB,SHB
SET,LIST
*GET,NUMSET,ACTIVE,0,SET,SBST
*DIM,Freq3,ARRAY,NUMSET
*DIM,SPL4R,ARRAY,NUMSET
*DIM,SPL4,ARRAY,NUMSET
*DIM,RATIO3,ARRAY,NUMSET
NSET = 0
*DO,i0,1,NUMSET,1
   NSET=NSET+1
   SET,1,i0,,0
   *GET,frq,ACTIVE,0,SET,FREQ
   Freq3(NSET)=frq
   k = 2*PI*Freq3(NSET)/c0
   p = rho*c0*vn*R**2/(1+(k**2)*(R**2))*CXABS(R*k**2,-k)
   p0 = 2e-5
   SPL4(nset)= 20*log10((p/SQRT(2))/p0)
*ENDDO
R31 = 123.053/SPL4(1)
R32 = 123.222/SPL4(2)
R33 = 123.282/SPL4(3)
R34 = 123.310/SPL4(4)
*VFILL,RATIO3,DATA,R31,R32,R33,R34
*VFILL,SPL4R,DATA,123.053,123.222,123.282,123.310
SAVE,TABLE_3
FINISH

/POST1
HFSYM,0,SHB,SHB
SET,LIST
*GET,NUMSET,ACTIVE,0,SET,SBST
*DIM,Freq4,ARRAY,NUMSET
*DIM,SPL5,ARRAY,NUMSET
*DIM,SPL6,ARRAY,NUMSET
*DIM,RATIO4,ARRAY,NUMSET
NSET = 0
*DO,i0,1,NUMSET,1
   NSET=NSET+1
   SET,1,i0,,0
   *GET,frq,ACTIVE,0,SET,FREQ
   Freq4(NSET)=frq
   PRFAR,PRES,SPLC,0,0,0,0,0,0,15           ! FAR FIELD PRESSURES
   *GET,SPL5(NSET),ACUS,0,SPL
   k = 2*PI*Freq4(NSET)/c0
   p = rho*c0*vn*R**2/(1+(k**2)*(R**2))*CXABS(R*k**2/15,-k/15)*CXABS(COS(14*k),SIN(14*k))
   p0 = 2e-5
   SPL6(NSET) = 20*log10((p/SQRT(2))/p0)
*ENDDO
R41 = SPL5(1)/SPL6(1)
R42 = SPL5(2)/SPL6(2)
R43 = SPL5(3)/SPL6(3)
R44 = SPL5(4)/SPL6(4)
*VFILL,RATIO4,DATA,R41,R42,R43,R44
SAVE,TABLE_4
```

```
FINISH
/OUT,vmr083-ca1-221,vrt
/COM,
/COM, ---------------------------------------------------------------------
/COM,
/COM, |  Freq(Hz)  |  Mechanical APDL    |  ANALYTICAL     |  RATIO  |
/COM,
/NOPR
RESUME,TABLE_1
/GOPR
/COM,  R=1m, 0-100 Hz
/COM,
*VWRITE,Freq1(1),SPLR(1),SPL1(1),RATIO1(1)
 (4x,e13.6,5x,e13.5,5x,e13.5,5x,f7.4)
/COM,
/NOPR
RESUME,TABLE_2
/GOPR
/COM,  R=15m, 0-100 Hz
/COM,
*VWRITE,Freq2(1),SPL2(1),SPL3(1),RATIO2(1)
 (4x,e13.6,5x,e13.5,5x,e13.5,5x,f7.4)
/COM,
/NOPR
RESUME,TABLE_3
/GOPR
/COM,  R=1m, 100-500 Hz
/COM,
*VWRITE,Freq3(1),SPL4R(1),SPL4(1),RATIO3(1)
 (4x,e13.6,5x,e13.5,5x,e13.5,5x,f7.4)
/COM,
/NOPR
RESUME,TABLE_4
/GOPR
/COM,  R=15m, 100-500 Hz
/COM,
*VWRITE,Freq4(1),SPL5(1),SPL6(1),RATIO4(1)
 (4x,e13.6,5x,e13.5,5x,e13.5,5x,f7.4)
/COM,
/COM, ----------------------------------------------------------------
/OUT,
*LIST,vmr083-ca1-221,vrt
FINISH
```

VM-R083-CA2 221 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY, VMR083-CA2-221
/TITLE, VMR083-CA2-221, SOUND RADIATION OF A CYLINDER WITH VIBRATING LATERAL SURFACE
/COM, REFERENCE: NAFEMS BENCHMARKS FOR RADIATION AND SCATTERING OF SOUND
/COM, TEST NO: CA2, R0038

/NOPR
/PREP7
/OUT,SCRATCH
PI = ACOS(-1)
c0 = 340                        ! SPEED OF SOUND IN m/s
rho = 1.225                     ! DENSITY OF FLUID IN kg/m^3

R = 1                           ! RADIUS in m
L = 4                           ! LENGTH in m

ET,1,FLUID221,,1                ! FLUID221, NO FSI
ET,2,FLUID221,,1,,1             ! FLUID221, NO FSI,INCLUDE PML ABSORBING

MP,SONC,1,c0
MP,DENS,1,rho
```

```
vn = 1                          ! RADIAL VELOCITY IN m/s
z0 = rho*c0

k1 = 1
k2 = 2
FREQ1 = k1*c0/(2*PI)
FREQ2 = k2*c0/(2*PI)
WAVE = c0/FREQ2
H = WAVE/12

NA = 3
NPML = 4
A1 = R+NA*H
A2 = L/2+NA*H
B1 = A1+NPML*H
B2 = A2+NPML*H

CYLIND,0,R,-L/2,L/2,0,180
BLOCK,-A1,A1,,A1,-A2,A2
BLOCK,-B1,B1,,B1,-B2,B2
VSBV,3,2,,DELETE,KEEP
VSBV,2,1,,DELETE,DELETE
ALLSEL,ALL
VGLUE,ALL

TYPE,1
MAT,1
VSEL,S,,,3
ESIZE,H
VMESH,ALL
ALLSEL,ALL

TYPE,2
MAT,1
VSEL,S,,,4
ESIZE,H
VMESH,ALL
ALLSEL,ALL

CSYS,1
NSEL,S,LOC,X,R
SF,ALL,SHLD,-vn
CSYS,0
ALLSEL,ALL

NSEL,S,LOC,Z,L/2
NSEL,A,LOC,Z,-L/2
SF,ALL,SHLD,0
ALLSEL,ALL

NSEL,S,LOC,Z,B2
NSEL,A,LOC,Z,-B2
NSEL,A,LOC,X,B1
NSEL,A,LOC,X,-B1
NSEL,A,LOC,Y,B1
D,ALL,PRES,0
ALLSEL,ALL
FINISH

/SOLU
ANTY,HARMONIC
HROPT,AUTO
HARFRQ,FREQ1
SOLVE
FINISH

/POST1
HFSYM,0,,SHB
SET,1
/OUT
*DIM,P1,ARRAY,10,1
*DO,i,1,10,1
```

```
DEG = (i-1)*10
PRFAR,PRES,SUMC,90,90,0,DEG,DEG,0,100
*GET,P1(i,1),ACUS,0,PRES
*ENDDO
A1 = P1(1,1)/5.3532
A2 = P1(2,1)/5.3532
A3 = P1(3,1)/5.3532
A4 = P1(4,1)/5.3532
A5 = P1(5,1)/5.3532
A6 = P1(6,1)/5.3532
A7 = P1(7,1)/5.3532
A8 = P1(8,1)/5.3532
A9 = P1(9,1)/5.3532
A10 = P1(10,1)/5.3532
*DIM,ANS1,,10,1
*DIM,ANG,CHAR,10,1
*DIM,NAD1,CHAR,10,1
*DIM,RATIO1,,10,1
ANG(1)='0','10','20','30','40','50','60','70','80','90'
NAD1(1)='0.770','0.780','0.800','0.840','0.880','0.920','0.950','0.990','1.000','1.000'
R1 = A1/0.77
R2 = A2/0.78
R3 = A3/0.80
R4 = A4/0.84
R5 = A5/0.88
R6 = A6/0.92
R7 = A7/0.95
R8 = A8/0.99
R9 = A9/1.00
R10 = A10/1.00
*VFILL,ANS1,DATA,A1,A2,A3,A4,A5,A6,A7,A8,A9,A10
*VFILL,RATIO1,DATA,R1,R2,R3,R4,R5,R6,R7,R8,R9,R10
SAVE,TABLE_1
FINISH

/OUT,SCRATCH
/SOLU
ANTY,HARMONIC
HROPT,AUTO
HARFRQ,FREQ2
SOLVE
FINISH

/POST1
HFSYM,0,,SHB
SET,1
/OUT
*DIM,P2,ARRAY,10,1
*DO,i,1,10,1
DEG = (i-1)*10
PRFAR,PRES,SUMC,90,90,0,DEG,DEG,0,100
*GET,P2(i,1),ACUS,0,PRES
*ENDDO
A11 = P2(1,1)/8.4103
A12 = P2(2,1)/8.4103
A13 = P2(3,1)/8.4103
A14 = P2(4,1)/8.4103
A15 = P2(5,1)/8.4103
A16 = P2(6,1)/8.4103
A17 = P2(7,1)/8.4103
A18 = P2(8,1)/8.4103
A19 = P2(9,1)/8.4103
A20 = P2(10,1)/8.4103
*DIM,ANS2,,10,1
*DIM,NAD2,CHAR,10,1
*DIM,RATIO2,,10,1
NAD2(1)='0.460','0.410','0.290','0.100','0.160','0.390','0.600','0.790','0.930','1.000'
R11 = A11/0.46
R12 = A12/0.41
R13 = A13/0.29
R14 = A14/0.10
R15 = A15/0.16
```

```
R16 = A16/0.39
R17 = A17/0.60
R18 = A18/0.79
R19 = A19/0.93
R20 = A20/1.00
*VFILL,ANS2,DATA,A11,A12,A13,A14,A15,A16,A17,A18,A19,A20
*VFILL,RATIO2,DATA,R11,R12,R13,R14,R15,R16,R17,R18,R19,R20
SAVE,TABLE_2
FINISH
/OUT,vmr083-ca2-221,vrt
/COM,
/COM,------------------------------------------------------------
/COM,
/COM,|  THETA  |  Mechanical APDL  |  NADwork  |  RATIO  |
/COM,
/COM,
/COM,                   Pn (k = 1)
/COM,
/NOPR
RESUME,TABLE_1
/GOPR
/COM,
*VWRITE,ANG(1),ANS1(1,1),NAD1(1),RATIO1(1,1)
(6X,A8,'  ',F5.3,'  ',10X,A8,'  ',F7.3,'  ')
/COM,
/COM,
/COM,                  Pn (k = 2)
/NOPR
RESUME,TABLE_2
/GOPR
/COM,
*VWRITE,ANG(1),ANS2(1,1),NAD2(1),RATIO2(1,1)
(6X,A8,'  ',F5.3,'  ',10X,A8,'  ',F7.3,'  ')
/COM,
/COM,-----------------------------------------------------------
/OUT,
*LIST,vmr083-ca2-221,vrt
FINISH
```

VMFEBSTA-LE1 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmfebsta-le1-181
/TITLE,vmfebsta-le1-181,LINEAR ELASTIC ANALYSIS IN ELLIPTICAL MEMBRANE
/COM, REFERENCE:" DAVIS ET AL, SELECTED FE BENCHMARKS IN STRUCTURAL AND
/COM,    THERMAL ANALYSIS,FEBSTA,AUG 1986,1-7-86/1
/COM, ORIGINIAL TEST NUMBER: LE1
/OUT,SCRATCH
/PREP7

_geomgen = 0
*if,_geomgen,eq,1,then

ET,1,SHELL181                          ! SHELL 181 ELEMENT
KEYOPT,1,1,1                       ! MEMBRANE STIFFNESS
KEYOPT,1,3,2      ! FULL INTEGRATION

SECTYPE,1,SHELL
SECDATA,0.1,1

MP,EX,1,210e9
MP,NUXY,1,0.3

K,1,0,1,0
K,2,0.25,0.9921,0
K,3,0.5,0.9682,0
K,4,0.75,0.92702,
K,5,1,0.8660254
```

```
K,6,1.25,0.78062,
K,7,1.5,0.661437
K,8,1.75,0.4841229
K,9,2.0,0
K,10,2.25,0,
K,11,2.50,0,
K,12,2.75,0,
K,13,3.0,0,
K,14,3.25,0,
K,15,3.0,1.05769
K,16,2.75,1.46558
K,17,2.50,1.7571
K,18,2.25,1.9844
K,19,2.00,2.1676
K,20,1.75,2.3172
K,21,1.50,2.4395
K,22,1.25,2.5384
K,23,1.00,2.6165
K,24,0.75,2.6757
K,25,0.50,2.7172
K,26,0.25,2.7418
K,27,0,2.75,0

A,1,3,4,5,6,7,8,9,14,15,16,17,19,21,23,25,27


LSEL,S,LINE,,17
LSEL,A,LINE,,8
LESIZE,ALL,,,5

LSEL,S,LINE,,7,9,2
LESIZE,ALL,,,5

LSEL,S,LINE,,1,6,1
LSEL,A,LINE,,10,16,1
LESIZE,ALL,,,2

AMESH,ALL
ALLSEL,ALL

LSEL,S,LINE,,9,16,1
NSLL,S,1
SF,ALL,PRES,-10E6*0.1
LSEL,ALL

NSEL,S,LOC,X,0
D,ALL,UX,0
NSEL,ALL


NSEL,S,LOC,Y,0
D,ALL,UY,0
NSEL,ALL

D,ALL,UZ,0
ALLSEL,ALL
  cdwrite,db,vmfebsta-le1-181,cdb
*else
  cdread,db,vmfebsta-le1-181,cdb
*endif
FINI

/SOLU
ANTYPE,STATIC
NSUBS,10,10,10
OUTRES,ALL,ALL
SOLVE
FINI

/POST1
SET,LAST
N1 = NODE(2,0,0)
```

```
*GET,SY1,NODE,N1,S,Y          ! STRESS FROM Mechanical APDL IN PA
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'TANG_STRESS'
*VFILL,VALUE(1,1),DATA,92.7
*VFILL,VALUE(1,2),DATA,(SY1/1000000)
*VFILL,VALUE(1,3),DATA,((SY1/1000000)/(92.7))
/OUT,vmfebsta-le1-181,vrt
/COM,------------------- vmfebsta-le1-181 RESULTS COMPARISON --------------
/COM,
/COM,             |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,-----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmfebsta-le1-181,vrt
```

VMFEBSTA-LE5 181 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmfebsta-le5-181
/TITLE,vmfebsta-le5-181, Z-SECTION CANTILEVER SHELL
/COM, REFERENCE: DAVIES ET AL, SELECTED FE BENCHMARKS IN STRUCTURAL AND
/COM,             THERMAL ANALYSIS FEBSTA, AUG 1986,1-7-86/1
/COM, ORIGINAL TEST NUMBER: LE5
/OUT,SCRATCH
/PREP7
ET,1,SHELL181   ! SHELL 181 ELEMENT
KEYOPT,1,3,0    ! REDUCED INTEGRATION
KEYOPT,1,8,2    ! STORE DATA FOR ALL LAYERS
SECTYPE,1,SHELL
SECDATA,0.1,1,0,5

MP,EX,1,210E9
MP,NUXY,1,0.3

K,1,0,1,-1
K,2,0,0,-1
K,3,0,0,1
K,4,0,-1,1
K,5,10,-1,1
K,6,10,0,1
K,7,10,0,-1
K,8,10,1,-1

A,1,2,7,8
A,2,3,6,7
A,3,4,5,6

ESIZE,1.25
AMESH,1
AMESH,3
ALLSEL,ALL

LESIZE,6,,,8
LESIZE,2,,,8
LESIZE,5,,,1
LESIZE,7,,,1
AMESH,2
ALLSEL,ALL
NUMMRG,NODE

NSEL,S,LOC,X,0
D,ALL,ALL,0     ! CANTILEVERED STRUCTURE
NSEL,ALL
```

```
NSEL,S,LOC,X,10
NSEL,R,LOC,Y,0,1
NSEL,R,LOC,Z,-1
F,ALL,FY,600000   ! UNIFORMLY DISTRIBUTED EDGE SHEARS

NSEL,S,LOC,X,10
NSEL,R,LOC,Y,0,-1
NSEL,R,LOC,Z,1
F,ALL,FY,-600000   ! UNIFORMLY DISTRIBUTED EDGE SHEARS
NSEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,ALL,ALL
NSUBS,10,10,10
TIME,1
SOLVE
FINI

/POST1
SET,LAST
N1=NODE(2.5,-1,1)
SHELL,BOT        ! BOTTOM SHELL LAYER
PRNSOL,S
*GET,SX1,NODE,N1,S,X      ! AXIAL STRESS AT NODE 23 IN PA
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'STRESS-AX'
*VFILL,VALUE(1,1),DATA,-108  ! REFERENCE STRESS IN MPA
*VFILL,VALUE(1,2),DATA,(SX1/1000000)
*VFILL,VALUE(1,3),DATA,ABS((SX1/1000000)/(-108))
/OUT,vmfebsta-le5-181,vrt
/COM,----------------------vmfebsta-le5-181 RESULTS COMPARISON-----------------
/COM,
/COM,
/COM,            |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,----------------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmfebsta-le5-181,vrt
```

VMFEBSTA-LE5 281 Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/VERIFY,vmfebsta-le5-281
/TITLE,vmfebsta-le5-281, Z-SECTION CANTILEVER SHELL
/COM, REFERENCE: DAVIES ET AL, SELECTED FE BENCHMARKS IN STRUCTURAL AND
/COM,            THERMAL ANALYSIS FEBSTA, AUG 1986,1-7-86/1
/COM, ORIGINAL TEST NUMBER: LE5
/OUT,SCRATCH
/PREP7
ET,1,SHELL281   ! SHELL 281 ELEMENT
KEYOPT,1,8,2   ! STORE DATA FOR ALL LAYERS
SECTYPE,1,SHELL
SECDATA,0.1,1,0,5

MP,EX,1,210E9
MP,NUXY,1,0.3

K,1,0,1,-1
K,2,0,0,-1
K,3,0,0,1
```

```
K,4,0,-1,1
K,5,10,-1,1
K,6,10,0,1
K,7,10,0,-1
K,8,10,1,-1

A,1,2,7,8
A,2,3,6,7
A,3,4,5,6

ESIZE,1.25
AMESH,1
AMESH,3
ALLSEL,ALL

LESIZE,6,,,8
LESIZE,2,,,8
LESIZE,5,,,1
LESIZE,7,,,1
AMESH,2
ALLSEL,ALL
NUMMRG,NODE

NSEL,S,LOC,X,0
D,ALL,ALL,0    ! CANTILEVERED STRUCTURE
NSEL,ALL

ET,2,SURF156
KEYOPT,2,2,1            ! APPLY LOADS IN LOCAL COORDINATE SYSTEM
KEYOPT,2,4,0            ! NO MIDSIDE NODES
KEYOPT,2,5,1            ! NO ORIENTATION NODE
KEYOPT,2,7,1            ! USE ORIGINAL AREA

LOCAL,12,0,0,0,0,0,0,0
CSYS,0

TYPE,2
ESYS,12
E,4,20,21
ALLSEL,ALL

ET,3,SURF156
KEYOPT,3,2,1        ! APPLY LOADS IN LOCAL COORDINATE SYSTEM
KEYOPT,3,4,0        ! NO MIDSIDE NODES
KEYOPT,3,5,1        ! NO ORIENTATION NODE
KEYOPT,3,7,1        ! USE ORIGINAL AREA

LOCAL,13,0,0,0,0,0,0,0
CSYS,0

TYPE,3
ESYS,13
E,63,47,64
ESEL,ALL

ESEL,S,TYPE,,2
SFE,ALL,2,PRES,1,600000
ESEL,ALL

ESEL,S,TYPE,,3
SFE,ALL,2,PRES,1,-600000
ESEL,ALL
FINI

/SOLU
ANTYPE,STATIC
OUTRES,ALL,ALL
NSUBS,10,10,10
TIME,1
SOLVE
FINI
```

```
/POST1
SET,LAST
N1=NODE(2.5,-1,1)
SHELL,BOT        ! BOTTOM SHELL LAYER
PRNSOL,S
*GET,SX1,NODE,N1,S,X      ! AXIAL STRESS AT NODE 23 IN PA
/VIEW,1,1,1,1
PLNSOL,U,SUM
PLNSOL,S,EQV
*DIM,LABEL,CHAR,1
*DIM,VALUE,,1,3
LABEL(1,1) = 'STRESS-AX'
*VFILL,VALUE(1,1),DATA,-108  ! REFERENCE STRESS IN MPA
*VFILL,VALUE(1,2),DATA,(SX1/1000000)
*VFILL,VALUE(1,3),DATA,ABS((SX1/1000000)/(-108))
/OUT,vmfebsta-le5-281,vrt
/COM,----------------------vmfebsta-le5-281 RESULTS COMPARISON-----------------
/COM,
/COM,
/COM,           |  TARGET  |   Mechanical APDL  |  RATIO
/COM,
/COM,
*VWRITE,LABEL(1,1),VALUE(1,1),VALUE(1,2),VALUE(1,3)
(1X,A8,'   ',F10.4,'  ',F14.4,'   ',F15.3)
/COM,----------------------------------------------------------------------
/OUT,
FINISH
*LIST,vmfebsta-le5-281,vrt
```

Appendix E. NRC Piping Benchmarks Input Listings

This appendix contains all of the input listings for the NRC Piping Benchmarks problems documented in Part V: NRC Piping Benchmarks (p. 1023).

demonstration-problem2-290 Input Listing
demonstration-problem2-281 Input Listing
demonstration-problem2-16-18 Input Listing
demonstration_problem3-289-290 Input Listing
demonstration-problem3-281 Input Listing
demonstration-problem3-16-18 Input Listing

vm-nr1677-1-1a-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-1-1a-a
/title,vm-nr1677-1-1a-a,NRC Piping Benchmark Problems,Volume 1,Problem 1

/com,***************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,       NUREG/CR--1677-Vol.1
/com,       P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com,  Elements used: Pipe16, Pipe18 and Mass21
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com,***************************************************************************

/out,scratch

/prep7
et,1,pipe16      ! Element 1 - PIPE16 (Straight Pipe Element)
et,2,pipe18      ! Element 2 - PIPE18 (Pipe Bend Element)
et,3,mass21      ! Element 3 - MASS21 (Mass Element)

keyopt,3,3,2     ! 3-D Mass without Rotary Inertia

/com, Real Constants
/com,****************

r,1,7.288,0.241,0.0,0.0,0.0,0.0
r,2,7.288,0.241,36.30,0.0,0.0,0.0

/com, Nodes
/com,*******

n,1,0.0,0.0,0.0
n,2,0.0,54.45,0.0
n,3,0.0,108.9,0.0
n,4,10.632,134.568,0.0
n,5,36.3,145.2,0.0
n,6,54.15,145.2,0.0
n,7,72.0,145.2,0.0
n,8,97.668,145.2,10.632
n,9,108.3,145.2,36.3
n,10,108.3,145.2,56.80
n,11,108.3,145.2,77.3

/com, Straight Pipe (Tangent Elements)
/com,**********************************

type,1
mat,1
real,1
en,1,1,2
en,2,2,3
```

```
en,5,5,6
en,6,6,7
en,9,9,10
en,10,10,11

/com, Bend Pipe Elements
/com,**********************************

type,2
mat,1
real,2
en,3,3,4,2
en,4,4,5,6
en,7,7,8,6
en,8,8,9,10

mp,ex,1,24e6
mp,nuxy,1,0.3

/com, Real constants for mass element
/com, *******************************

r,12,0.03988
r,13,0.05032
r,14,0.02088
r,15,0.01698
r,16,0.01307
r,17,0.01698
r,18,0.01044
r,19,0.01795
r,20,0.01501

/com, Mass Elements
/com,***************

type,3
real,12
e,2

real,13
e,3

real,14
e,4

real,15
e,5

real,16
e,6

real,17,
e,7

real,18
e,8

real,19
e,9

real,20
e,10

/com, Constraints
/com,*************

d,1,all,0
d,11,all,0

allsel,all
save
finish
```

```
/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,5     ! LANB mode extraction method
mxpand,,,,yes
solve
save

/com,===========================
/com, Compare Modal Frequencies
/com,===========================
/com,

*dim,label,,5
*dim,freq_ans,,5
*dim,freq_exp,,5
*dim,freq_err,,5

*do,i,1,5
 label(i)=i
*enddo

*do,i,1,5
 *get,freq_ans(i),mode,i,freq
*enddo

*vfill,freq_exp,data,0.2853e+02,0.5577e+02,0.8150e+02,0.1417e+03,0.1628e+03

*do,i,1,5
 freq_err(i)=abs(freq_ans(i)/freq_exp(i))
*enddo

*status,freq_err
save,table_1
finish

/com,------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,sprs      ! Single Point Excitation Response Spectrum
dmprat,0.02      ! Constant Damping Ratio
grp,0.001      ! Group Modes based on significance level
svtyp,2      ! Seismic Acceleration Response Loading

sed,1       ! Excitation in X direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve

sed,,1      ! Excitation in Y direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,266.7,580.7,580.7,466.7,792,792,293.3,516.7,516.7
sv,0.02,355.5,311.5,295.7,253.3,192.7,159.6,128.4,122.7,96.7
solve
```

```
sed,,,1      ! Excitation in Z direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve
fini

/com,------------------------------------------------------------------------------

/post1
/input,,mcom

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1

/com,-------------------------

label2(1,1) = 'ux_5'
label2(1,2) = 'uy_7'
label2(1,3) = 'uz_4'
label2(1,4) = 'rotx_3'
label2(1,5) = 'roty_7'
label2(1,6) = 'rotz_3'

/com,-----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,-----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,-----------------------------------

/com, *=========================================================
/com, * Maximum nodal displacements and rotations comparsion
/com, *===========================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,5,U,X
*GET,AdisY,NODE,7,U,Y
*GET,AdisZ,NODE,4,U,Z
*GET,ArotX,NODE,3,ROT,X
*GET,ArotY,NODE,7,ROT,Y
*GET,ArotZ,NODE,3,ROT,Z

/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,7.84967e-03
*SET,EdisY,2.49629e-03
*SET,EdisZ,1.74471e-02
*SET,ErotX,1.84130e-04
*SET,ErotY,2.12142e-04
*SET,ErotZ,7.01236e-05
```

```
/com, Error computation
/com, *********************

ERdisX=ABS((AdisX)/(EdisX))
ERdisY=ABS((AdisY)/(EdisY))
ERdisZ=ABS((AdisZ)/(EdisZ))
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,-----------------------------------------------------------

/com, *========================================================
/com, * Element Forces and Moments Comparison
/com, *==========================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*dim,elem_res_I,,3,6
*dim,elem_res_J,,3,6

*dim,pxi,,3
*dim,vyi,,3
*dim,vzi,,3
*dim,txi,,3
*dim,myi,,3
*dim,mzi,,3

*dim,pxj,,3
*dim,vyj,,3
*dim,vzj,,3
*dim,txj,,3
*dim,myj,,3
*dim,mzj,,3

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========
```

```
/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #10
/com,*************

*get,pxi(2,1),elem,10,smisc,1
*get,vyi(2,1),elem,10,smisc,2
*get,vzi(2,1),elem,10,smisc,3
*get,txi(2,1),elem,10,smisc,4
*get,myi(2,1),elem,10,smisc,5
*get,mzi(2,1),elem,10,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com, Element #4
/com,***********

*get,pxi(3,1),elem,4,smisc,1
*get,vyi(3,1),elem,4,smisc,2
*get,vzi(3,1),elem,4,smisc,3
*get,txi(3,1),elem,4,smisc,4
*get,myi(3,1),elem,4,smisc,5
*get,mzi(3,1),elem,4,smisc,6

*vfill,elem_res_I(3,1),data,pxi(3,1)
*vfill,elem_res_I(3,2),data,vyi(3,1)
*vfill,elem_res_I(3,3),data,vzi(3,1)
*vfill,elem_res_I(3,4),data,txi(3,1)
*vfill,elem_res_I(3,5),data,myi(3,1)
*vfill,elem_res_I(3,6),data,mzi(3,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)
```

```
/com, Element #10
/com,*************

*get,pxj(2,1),elem,10,smisc,7
*get,vyj(2,1),elem,10,smisc,8
*get,vzj(2,1),elem,10,smisc,9
*get,txj(2,1),elem,10,smisc,10
*get,myj(2,1),elem,10,smisc,11
*get,mzj(2,1),elem,10,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com, Element #4
/com,************

*get,pxj(3,1),elem,4,smisc,7
*get,vyj(3,1),elem,4,smisc,8
*get,vzj(3,1),elem,4,smisc,9
*get,txj(3,1),elem,4,smisc,10
*get,myj(3,1),elem,4,smisc,11
*get,mzj(3,1),elem,4,smisc,12

*vfill,elem_res_J(3,1),data,pxj(3,1)
*vfill,elem_res_J(3,2),data,vyj(3,1)
*vfill,elem_res_J(3,3),data,vzj(3,1)
*vfill,elem_res_J(3,4),data,txj(3,1)
*vfill,elem_res_J(3,5),data,myj(3,1)
*vfill,elem_res_J(3,6),data,mzj(3,1)

/com,----------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,3,6
*dim,exp_J,,3,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,4.958e+00
*vfill,exp_I(1,2),data,1.788e+01
*vfill,exp_I(1,3),data,3.643e+01
*vfill,exp_I(1,4),data,6.296e+02
*vfill,exp_I(1,5),data,3.227e+03
*vfill,exp_I(1,6),data,1.394e+03

*vfill,exp_J(1,1),data,4.958e+00
*vfill,exp_J(1,2),data,1.788e+01
*vfill,exp_J(1,3),data,3.643e+01
*vfill,exp_J(1,4),data,6.296e+02
*vfill,exp_J(1,5),data,1.260e+03
*vfill,exp_J(1,6),data,4.742e+02

/com, Element #10
/com,*************

*vfill,exp_I(2,1),data,2.402e+01
*vfill,exp_I(2,2),data,7.472e+00
*vfill,exp_I(2,3),data,3.478e+01
*vfill,exp_I(2,4),data,1.130e+02
*vfill,exp_I(2,5),data,1.871e+03
*vfill,exp_I(2,6),data,6.501e+02

*vfill,exp_J(2,1),data,2.402e+01
*vfill,exp_J(2,2),data,7.472e+00
```

```
*vfill,exp_J(2,3),data,3.478e+01
*vfill,exp_J(2,4),data,1.130e+02
*vfill,exp_J(2,5),data,2.477e+03
*vfill,exp_j(2,6),data,7.745e+02

/com, Element #4
/com,*************

*vfill,exp_I(3,1),data,9.300e+00
*vfill,exp_I(3,2),data,1.063e+01
*vfill,exp_I(3,3),data,9.239e+00
*vfill,exp_I(3,4),data,1.421e+02
*vfill,exp_I(3,5),data,2.899e+02
*vfill,exp_I(3,6),data,8.284e+02

*vfill,exp_J(3,1),data,1.238e+01
*vfill,exp_J(3,2),data,1.063e+01
*vfill,exp_J(3,3),data,4.305e+00
*vfill,exp_J(3,4),data,4.237e+02
*vfill,exp_J(3,5),data,2.613e+02
*vfill,exp_J(3,6),data,5.419e+02

/com,------------------------------------------------------------------------------

/com, Error computation
/com, ********************

*dim,elem_error_I,,3,6
*dim,elem_error_J,,3,6
*dim,elem_tab,,36,3

/com,============
/com,   Node I
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,-----------------------------------------------------------------------------

*do,i,1,3
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,elem_res_I(i,j)
  *vfill,elem_tab(n,2),data,exp_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+18
  *vfill,elem_tab(m,1),data,elem_res_J(i,j)
  *vfill,elem_tab(m,2),data,exp_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3
```

```
/com,------------------------------------------------------------------------
/com,

/com
/com,-----------------vm-nr1677-1-1a-a Results Verification----------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-1-1a-a,vrt
/com,
/com, =============================================
/com,    COMPARISON OF MODAL FREQUENCY
/com,   WITH EXPECTED RESULTS
/com, =============================================
/com,

/com,   Mode | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label(1),freq_exp(1),freq_ans(1),freq_err(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,'  ')

/com,

/com,------------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr

/com,
/com,=====================================================
/com,  COMPARISON OF MAXIMUM NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,=====================================================
/com,

/com,   Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,------------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,==============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,==============================================
/com,
```

```
/com,------------------------------------------------
/com, Note: Element Forces and Moments along Y & Z
/com,  directions are flipped between Mechanical APDL
/com,  and NRC results
/com,------------------------------------------------

/com,    Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 10
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(25,1),elem_tab(25,2),elem_tab(25,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 4
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(31,1),elem_tab(31,2),elem_tab(31,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)


/com,
/com,
/com,*******************************************************************
/com,*******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-1-1a-a,vrt
fini
```

vm-nr1677-1-2a-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-1-2a-a
/title,vm-nr1677-1-2a-a,NRC Piping Benchmark Problems,Volume 1,Problem 2

/com,*******************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,       NUREC/CR--1677-Vol.1
/com,       P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com,  Elements used: Pipe16, Mass21 element
/com,
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com,*******************************************************************************

/out,scratch

/prep7
et,1,pipe16    ! Element 1 - PIPE16 (Straight Pipe Element)
et,2,mass21    ! Element 2 - MASS21 (Mass Element)

/com, Real Constants
/com,****************

r,1,2.37500000,0.15400000,0.0,0.0,0.0
r,2,0.447000518e-01,0.447000518e-01,0.447000518e-01,0.0,0.0,0.0
r,3,0.447000518e-01,0.447000518e-01,0.447000518e-01,0.0,0.0,0.0
r,4,0.447000518e-01,0.447000518e-01,0.447000518e-01,0.0,0.0,0.0
r,5,0.447000518e-01,0.447000518e-01,0.447000518e-01,0.0,0.0,0.0
r,6,0.432699275e-01,0.432699275e-01,0.432699275e-01,0.0,0.0,0.0
r,7,0.893995859e-02,0.893995859e-02,0.893995859e-02,0.0,0.0,0.0
r,8,0.432699275e-01,0.432699275e-01,0.432699275e-01,0.0,0.0,0.0
r,9,0.893995859e-02,0.893995859e-02,0.893995859e-02,0.0,0.0,0.0
r,10,0.893995859e-02,0.893995859e-02,0.893995859e-02,0.0,0.0,0.0
r,11,0.432699275e-01,0.432699275e-01,0.432699275e-01,0.0,0.0,0.0
r,12,0.893995859e-02,0.893995859e-02,0.893995859e-02,0.0,0.0,0.0
r,13,0.432699275e-01,0.432699275e-01,0.432699275e-01,0.0,0.0,0.0
r,14,0.893995859e-02,0.893995859e-02,0.893995859e-02,0.0,0.0,0.0
r,15,0.893995859e-02,0.893995859e-02,0.893995859e-02,0.0,0.0,0.0

/com, Nodes
/com,*******

n,1,0.0,-30.00    ! Node Numbers, Global Co-ordinates
n,2,27.25,-30.00
n,3,27.25,-30.00,17.250
n,4,0.0,-30.00,17.250
n,5,0.0,18.625,17.250
n,6,0.0,18.625,8.625
n,7,0.0,18.625
n,8,8.625,18.625,
n,9,18.625,18.625
n,10,27.25,18.625
n,11,27.25,18.625,8.625
n,12,27.25,18.625,17.250
n,13,18.625,18.625,17.250
n,14,8.625,18.625,17.250
n,15,0.0,-80.00
n,16,27.25,-80.00
n,17,27.25,-80.00,17.250
n,18,0.0,-80.00,17.25
```

```
/com, Straight Pipe (Tangent Elements)
/com,*********************************

mat,1
type,1
real,1

en,1,15,1
en,2,1,7
en,3,7,6
en,4,6,5
en,5,5,4
en,6,4,18
en,7,16,2
en,8,2,10
en,9,10,11
en,10,11,12
en,11,12,3
en,12,3,17
en,13,12,13
en,14,13,14
en,15,14,5
en,16,7,8
en,17,8,9
en,18,9,10

/com, Mass Elements
/com,***************

mat,1
type,2

real,2
en,19,1

real,3
en,20,2

real,4
en,21,3

real,5
en,22,4

real,6
en,23,5

real,7
en,24,6

real,8
en,25,7

real,9
en,26,8

real,10
en,27,9

real,11
en,28,10

real,12
en,29,11

real,13
en,30,12

real,14
en,31,13
```

```
real,15
en,32,14

nsel,s,node,,15
nsel,a,node,,16
nsel,a,node,,17
nsel,a,node,,18
cm,fixedsu,node
allsel,all

mp,ex,1,27899996.8
mp,nuxy,1,0.3
mp,dens,1,2.587991718e-10

/com, Constraints
/com,*************

d,15,all,0
d,16,all,0
d,17,all,0
d,18,all,0
save
allsel,all
finish

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,5    ! Use LANB solver
mxpand,,,,yes
solve
save
finish

/com,-----------------------------------------------------------------------------

/com, ============================================
/com,    COMPARISON OF MODAL FREQUENCY
/com,   WITH EXPECTED RESULTS
/com, ============================================

*dim,label,,5
*dim,freq_ans,,5
*dim,freq_exp,,5
*dim,freq_err,,5

*do,i,1,5
 label(i)=i
*enddo

*do,i,1,5
 *get,freq_ans(i),mode,i,freq
*enddo

*vfill,freq_exp,data,0.8712e+01,0.8806e+01,0.1751e+02,0.4037e+02,0.4163e+02

*do,i,1,5
 freq_err(i)=abs(freq_ans(i)/freq_exp(i))
*enddo

*status,freq_err
save,table_1
finish     ! Finish Solution routine

/com,-----------------------------------------------------------------------------

/com,
```

```
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr    ! Perform Spectrum analysis
spopt,sprs     ! Single Point Excitation Response Spectrum
dmprat,0.02     ! Constant Damping Ratio
grp,0.001     ! Group Modes based on Significance Level
svtyp,2     ! Seismic Acceleration Response Loading

sed,1
freq
freq,3.1,4,5,5.8,7.1,8.8,11,14.1,17.2
freq,35,40,588
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,380,348.6,145
solve

sed,,1
freq
freq,3.1,4,5,5.8,7.1,8.8,11,14.1,17.2
freq,35,40,588
sv,0.02,266.7,580.7,580.7,466.7,792,792,293.3333,516.7,516.7
sv,0.02,253.3,232.4,96.7
solve

sed,,,1
freq
freq,3.1,4,5,5.8,7.1,8.8,11,14.1,17.2
freq,35,40,588
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,380,348.6,145
solve
fini

/com,-------------------------------------------------------------------------------

/post1
/input,,mcom    ! compute SSRS

/com, Labels
/com,********

*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1

/com,------------------------

label2(1,1) = 'ux_6'
label2(1,2) = 'uy_8'
label2(1,3) = 'uz_8'
label2(1,4) = 'rotx_1'
label2(1,5) = 'roty_9'
label2(1,6) = 'rotz_1'

/com,------------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,------------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
```

```
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,-------------------------------------------------------------------------------


/com, *=========================================================
/com, * Maximum nodal displacements and rotations comparsion
/com, *===========================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,6,U,X
*GET,AdisY,NODE,8,U,Y
*GET,AdisZ,NODE,8,U,Z
*GET,ArotX,NODE,1,ROT,X
*GET,ArotY,NODE,9,ROT,Y
*GET,ArotZ,NODE,1,ROT,Z

/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,4.61886e-01
*SET,EdisY,2.35426e-03
*SET,EdisZ,4.46591e-01
*SET,ErotX,6.53919e-03
*SET,ErotY,1.27731e-05
*SET,ErotZ,6.72098e-03

/com, Error computation
/com, *********************

ERdisX=ABS((AdisX)/(EdisX))
ERdisY=ABS((AdisY)/(EdisY))
ERdisZ=ABS((AdisZ)/(EdisZ))
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,-------------------------------------------------------------------------------

/com, *=========================================================
```

```
/com, * Element Forces and Moments Comparison
/com, *==========================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*dim,elem_res_I,,2,6
*dim,elem_res_J,,2,6

*dim,pxi,,2
*dim,vyi,,2
*dim,vzi,,2
*dim,txi,,2
*dim,myi,,2
*dim,mzi,,2

*dim,pxj,,2
*dim,vyj,,2
*dim,vzj,,2
*dim,txj,,2
*dim,myj,,2
*dim,mzj,,2

esel,s,ename,,16

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #18
/com,*************

*get,pxi(2,1),elem,18,smisc,1
*get,vyi(2,1),elem,18,smisc,2
*get,vzi(2,1),elem,18,smisc,3
*get,txi(2,1),elem,18,smisc,4
*get,myi(2,1),elem,18,smisc,5
*get,mzi(2,1),elem,18,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
```

```
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #18
/com,*************

*get,pxj(2,1),elem,18,smisc,7
*get,vyj(2,1),elem,18,smisc,8
*get,vzj(2,1),elem,18,smisc,9
*get,txj(2,1),elem,18,smisc,10
*get,myj(2,1),elem,18,smisc,11
*get,mzj(2,1),elem,18,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com,-------------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,2,6
*dim,exp_J,,2,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,5.554e+02
*vfill,exp_I(1,2),data,1.082e+02
*vfill,exp_I(1,3),data,1.093e+02
*vfill,exp_I(1,4),data,1.610e+00
*vfill,exp_I(1,5),data,5.135e+03
*vfill,exp_I(1,6),data,5.229e+03

*vfill,exp_J(1,1),data,5.554e+02
*vfill,exp_J(1,2),data,1.088e+02
*vfill,exp_J(1,3),data,1.093e+02
*vfill,exp_J(1,4),data,1.610e+00
*vfill,exp_J(1,5),data,2.769e+02
*vfill,exp_J(1,6),data,2.351e+02

/com, Element #18
/com,*************

*vfill,exp_I(2,1),data,1.400e+01
*vfill,exp_I(2,2),data,2.972e+02
*vfill,exp_I(2,3),data,1.228e+01
*vfill,exp_I(2,4),data,1.408e-02
*vfill,exp_I(2,5),data,4.771e+01
*vfill,exp_I(2,6),data,1.480e+03

*vfill,exp_J(2,1),data,1.400e+01
*vfill,exp_J(2,2),data,2.972e+02
*vfill,exp_J(2,3),data,1.228e+01
*vfill,exp_J(2,4),data,1.408e-02
*vfill,exp_J(2,5),data,6.043e+01
*vfill,exp_J(2,6),data,4.049e+03
```

```
/com,-------------------------------------------------------------------------------

/com, Error computation
/com, ********************

*dim,elem_error_I,,2,6
*dim,elem_error_J,,2,6
*dim,elem_tab,,24,3

/com,============
/com,   Node I
/com,============

*do,i,1,2
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,2
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,------------------------------------------------------------------------------

*do,i,1,2
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+12
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3

/com,-----------------------------------------------------------------------------
/com,

/com
/com,--------------------------Results Verification--------------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-1-2a-a,vrt

/com,
/com, ============================================
/com,    COMPARISON OF MODAL FREQUENCY
/com,   WITH EXPECTED RESULTS
/com, ============================================
/com,

/com,   Mode | Expected | Mechanical APDL |  Ratio
/com,
```

```
*vwrite,label(1),freq_exp(1),freq_ans(1),freq_err(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,'  ')

/com,

/com,------------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr

/com,
/com,==========================================================
/com,  COMPARISON OF MAXIMUM NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,==========================================================
/com,

/com,   Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,------------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,===============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,===============================================
/com,

/com,------------------------------------------------
/com, Note: Element Forces and Moments along Y & Z
/com,  directions are flipped between Mechanical APDL
/com,  and NRC results
/com,------------------------------------------------

/com,   Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
```

```
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 18
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,
/com,*****************************************************************
/com,*****************************************************************
/com,
/com,

/out,
*list,vm-nr1677-1-2a-a,vrt
fini
```

vm-nr1677-1-3a-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-1-3a-a
/title,vm-nr1677-1-3a-a,NRC Piping Benchmark Problems,Volume 1,Problem 3

/com,**************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,       NUREC/CR--1677-Vol.1
/com,       P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com, Elements used: Pipe16, Pipe18, Combin14, Mass21
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com,**************************************************************************

/out,scratch

/prep7

et,1,pipe16     ! Element 1 - PIPE16

et,2,pipe18     ! Element 2 - PIPE18
keyopt,2,3,1    ! Use ANSYS Flexibility with Pressure term

et,3,combin14    ! Element 3 - COMBIN14
keyopt,3,2,1    ! UX Degree of Freedom

et,4,combin14    ! Element 4 - COMBIN14
keyopt,4,2,2    ! UY Degree of Freedom

et,5,combin14    ! Element 5 - COMBIN14
keyopt,5,2,3    ! UZ Degree of Freedom
```

```
et,6,mass21     ! Element 6 - MASS21
keyopt,6,3,2    ! 3D Mass with Rotary Inertia

/com, Material Properties
/com,*********************

mp,ex,1,24e6
mp,prxy,1,.3
mp,dens,1,0.001057

mp,ex,2,24e6
mp,prxy,2,.3
mp,dens,2,0.001057

/com, Real Constants
/com,****************

r,1,7.288,0.241    ! Real Constant Set 1
r,2,7.288,0.241,36.30   ! Real Constant Set 2
r,3,0.1e+5     ! Real Constant Set 3
r,4,0.1e+9     ! Real Constant Set 4
r,5,0.1e+11     ! Real Constant Set 5
r,6,1.518     ! Real Constant Set 6

/com, Nodes
/com,*******

n,1,0,0,0
n,2,0,54.45,0
n,3,0,108.9,0
n,4,10.632,134.568,0
n,5,36.3,145.2,0
n,6,54.15,145.2,0
n,7,72.0,145.2,0
n,8,97.668,145.2,10.632
n,9,108.3,145.2,36.3
n,10,108.3,145.2,56.8
n,11,108.3,145.2,77.3
n,12,108.3,145.2,97.8
n,13,108.3,145.2,118.3
n,14,108.3,145.2,188.8
n,15,108.3,181.5,225.1
n,16,108.3,236,225.1
n,17,108.3,290,225.1
n,18,148.3,145.2,97.8
n,19,188.3,145.2,97.8
n,20,224.6,145.2,61.5
n,21,224.6,145.2,20

/com, Elastic support Nodes
/com,***********************

n,22,1,0,0
n,23,0,1,0
n,24,0,0,1
n,25,72,145.2,-1
n,26,109.3,145.2,36.3
n,27,108.3,146.2,77.3
n,28,108.3,146.2,118.3
n,29,107.3,182.5,226.5
n,30,109.3,290,225.1
n,31,108.3,291,225.1
n,32,108.3,290,226.1
n,33,225.6,145.2,20
n,34,224.6,146.2,20
n,35,224.6,145.2,21

/com, Straight Pipe (Tangent Elements)
/com,**********************************

type,1     ! Element Type 1
```

```
real,1     ! Real Constant Set 1
mat,1      ! Material ID 1

en,1, 1, 2
en,2, 2, 3
en,5, 5, 6
en,6, 6, 7
en,9, 9,10
en,10,10,11
en,11,11,12
en,12,12,13
en,13,13,14
en,15,15,16
en,16,16,17
en,17,12,18
en,18,18,19
en,20,20,21

/com, Curved pipe elements
/com,**********************

type,2     ! Element Type 2
real,2     ! Real Constant Set 2
mat,1      ! Material ID 1

en,3,3,4,2
en,4,4,5,6
en,7,7,8,6
en,8,8,9,10
en,14,14,15,16
en,19,19,20,18

/com, Elastic supports and anchors
/com,******************************

/com, **rotate nodes with less than 3 supports**

wplane,,nx(15),ny(15),nz(15),nx(29),ny(29),nz(29),nx(16),ny(16),nz(16)
cswplane,11,0
nrotat,15
nrotat,29
csys,0

real,3
type,4
en,21,11,27
en,22,13,28

real,4
type,3
en,23,9,26
en,24,15,29
type,5
en,25,7,25

real,5
type,3
en,26,1,22
en,27,17,30
en,28,21,33

type,4
en,29,1,23
en,30,17,31
en,31,21,34

type,5
en,32,1,24
en,33,17,32
en,34,21,35

/com, Mass Elements
```

```
/com,***************

type,6
real,6
en,35,18

/com, Constraints
/com,*************

nsel,,node,,22,35
d,all,all
alls
d,1,rotx,,,,,roty,rotz
d,21,rotx,,,,,roty,rotz

/com, Loading
/com,*********

/com, **Internal Pressure on PIPE elements**
esel,s,ename,,18
esel,a,ename,,16
sfe,all,1,pres,,350
allsel,all
save
finish

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal    ! Perform Modal Analysis
modopt,lanb,10
mxpand,,,,yes    ! Expand solution with Element Calculations ON
lumpm,on     ! Use Lumped Mass Approximation
solve
save
fini


/com,
/com,===========================
/com, Compare Modal Frequencies
/com,===========================
/com,

*dim,label,,10
*dim,freq_ans,,10
*dim,freq_exp,,10
*dim,freq_err,,10

*do,i,1,10
 label(i)=i
*enddo

*do,i,1,10
 *get,freq_ans(i),mode,i,freq
*enddo

*vfill,freq_exp,data,9.360,12.710,15.380,17.80,21.60,25.10,32.03,38.07,40.29,48.90
*status,freq_ans
*status,freq_exp

*do,i,1,10
 freq_err(i)=abs(freq_ans(i)/freq_exp(i))
*enddo

*status,freq_err
save,table_1
finish
```

```
/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/com, **Spectrum in X, Y, and Z directions**
/com, **Spectra values in Y direction are 67% of the values for the X and Z directions**

/solution
antype,spectr    ! Perform Spectrum Analysis
spopt,sprs     ! Single Point Excitation Response Spectrum
dmprat,0.02     ! Constant Damping Ratio
grp,0.001     ! Group Modes based on Significance Level
svtyp,2     ! Seismic Acceleration Response Loading

sed,1      ! Excitation in X direction
freq
freq,3.1,4,5,5.81,7.09,8.77,9,10,10.99
freq,14.08,17.24,20,25,30,34.97,40,45,50
freq,588.93
sv,0.02,400,871,871,700,1188,1188,1090,733,440
sv,0.02,775,775,668,533,444,380,349,324,306
sv,0.02,145
solve

sed,,1     ! Excitation in Y direction
freq
freq,3.1,4,5,5.81,7.09,8.77,9,10,10.99
freq,14.08,17.24,20,25,30,34.97,40,45,50
freq,588.93
sv,0.02,267,581,581,467,792,792,727,489,293
sv,0.02,517,517,445,355,296,253,232,216,204
sv,0.02,97
solve

sed,,,1     ! Excitation in Z direction
freq
freq,3.1,4,5,5.81,7.09,8.77,9,10,10.99
freq,14.08,17.24,20,25,30,34.97,40,45,50
freq,588.93
sv,0.02,400,871,871,700,1188,1188,1090,733,440
sv,0.02,775,775,668,533,444,380,349,324,306
sv,0.02,145
solve
fini

/post1
/input,,mcom

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1

/com,-------------------------

label2(1,1) = 'ux_14'
label2(1,2) = 'uy_8'
label2(1,3) = 'uz_9'
label2(1,4) = 'rotx_3'
label2(1,5) = 'roty_7'
label2(1,6) = 'rotz_17'

/com,-----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
```

```
label3(6,1)='MZ(I)'

/com,----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,----------------------------------

/com, *=====================================================
/com, * Maximum nodal displacements and rotations comparsion
/com, *=======================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,14,U,X
*GET,AdisY,NODE,8,U,Y
*GET,AdisZ,NODE,9,U,Z
*GET,ArotX,NODE,3,ROT,X
*GET,ArotY,NODE,7,ROT,Y
*GET,ArotZ,NODE,17,ROT,Z

/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,2.29130e-01
*SET,EdisY,9.80058e-02
*SET,EdisZ,1.66289e-01
*SET,ErotX,2.71028e-03
*SET,ErotY,4.99380e-03
*SET,ErotZ,2.39003e-03

/com, Error computation
/com, *********************

ERdisX=ABS((AdisX)/(EdisX))
ERdisY=ABS((AdisY)/(EdisY))
ERdisZ=ABS((AdisZ)/(EdisZ))
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ
```

```
save,table_2

/com,-----------------------------------------------------------

/com, *=========================================================
/com, * Element Forces and Moments Comparison
/com, *===========================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*dim,elem_res_I,,3,6
*dim,elem_res_J,,3,6

*dim,pxi,,3
*dim,vyi,,3
*dim,vzi,,3
*dim,txi,,3
*dim,myi,,3
*dim,mzi,,3

*dim,pxj,,3
*dim,vyj,,3
*dim,vzj,,3
*dim,txj,,3
*dim,myj,,3
*dim,mzj,,3

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #20
/com,*************

*get,pxi(2,1),elem,20,smisc,1
*get,vyi(2,1),elem,20,smisc,2
*get,vzi(2,1),elem,20,smisc,3
*get,txi(2,1),elem,20,smisc,4
*get,myi(2,1),elem,20,smisc,5
*get,mzi(2,1),elem,20,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com, Element #7
/com,***********
```

```
*get,pxi(3,1),elem,7,smisc,1
*get,vyi(3,1),elem,7,smisc,2
*get,vzi(3,1),elem,7,smisc,3
*get,txi(3,1),elem,7,smisc,4
*get,myi(3,1),elem,7,smisc,5
*get,mzi(3,1),elem,7,smisc,6

*vfill,elem_res_I(3,1),data,pxi(3,1)
*vfill,elem_res_I(3,2),data,vyi(3,1)
*vfill,elem_res_I(3,3),data,vzi(3,1)
*vfill,elem_res_I(3,4),data,txi(3,1)
*vfill,elem_res_I(3,5),data,myi(3,1)
*vfill,elem_res_I(3,6),data,mzi(3,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #20
/com,*************

*get,pxj(2,1),elem,20,smisc,7
*get,vyj(2,1),elem,20,smisc,8
*get,vzj(2,1),elem,20,smisc,9
*get,txj(2,1),elem,20,smisc,10
*get,myj(2,1),elem,20,smisc,11
*get,mzj(2,1),elem,20,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com, Element #7
/com,************

*get,pxj(3,1),elem,7,smisc,7
*get,vyj(3,1),elem,7,smisc,8
*get,vzj(3,1),elem,7,smisc,9
*get,txj(3,1),elem,7,smisc,10
*get,myj(3,1),elem,7,smisc,11
*get,mzj(3,1),elem,7,smisc,12

*vfill,elem_res_J(3,1),data,pxj(3,1)
*vfill,elem_res_J(3,2),data,vyj(3,1)
*vfill,elem_res_J(3,3),data,vzj(3,1)
*vfill,elem_res_J(3,4),data,txj(3,1)
*vfill,elem_res_J(3,5),data,myj(3,1)
*vfill,elem_res_J(3,6),data,mzj(3,1)

/com,------------------------------------------------------------------------------
```

```
/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,3,6
*dim,exp_J,,3,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,1.544e+02
*vfill,exp_I(1,2),data,2.092e+02
*vfill,exp_I(1,3),data,4.633e+02
*vfill,exp_I(1,4),data,1.309e+04
*vfill,exp_I(1,5),data,4.313e+04
*vfill,exp_I(1,6),data,1.806e+04

*vfill,exp_J(1,1),data,1.544e+02
*vfill,exp_J(1,2),data,2.092e+02
*vfill,exp_J(1,3),data,4.633e+02
*vfill,exp_J(1,4),data,1.309e+04
*vfill,exp_J(1,5),data,1.876e+04
*vfill,exp_J(1,6),data,8.095e+03

/com, Element #20
/com,*************

*vfill,exp_I(2,1),data,6.333e+02
*vfill,exp_I(2,2),data,4.712e+02
*vfill,exp_I(2,3),data,1.012e+03
*vfill,exp_I(2,4),data,5.724e+03
*vfill,exp_I(2,5),data,9.985e+03
*vfill,exp_I(2,6),data,8.126e+03

*vfill,exp_J(2,1),data,6.333e+02
*vfill,exp_J(2,2),data,4.712e+02
*vfill,exp_J(2,3),data,1.012e+03
*vfill,exp_J(2,4),data,5.724e+03
*vfill,exp_J(2,5),data,4.468e+04
*vfill,exp_j(2,6),data,2.757e+04

/com, Element #7
/com,*************

*vfill,exp_I(3,1),data,2.706e+02
*vfill,exp_I(3,2),data,3.915e+01
*vfill,exp_I(3,3),data,1.813e+03
*vfill,exp_I(3,4),data,5.823e+03
*vfill,exp_I(3,5),data,2.004e+04
*vfill,exp_I(3,6),data,5.439e+03

*vfill,exp_J(3,1),data,1.200e+03
*vfill,exp_J(3,2),data,3.915e+01
*vfill,exp_J(3,3),data,1.386e+03
*vfill,exp_J(3,4),data,7.810e+03
*vfill,exp_J(3,5),data,3.174e+04
*vfill,exp_J(3,6),data,2.256e+03

/com,------------------------------------------------------------------------

/com, Error computation
/com, ********************

*dim,elem_error_I,,3,6
*dim,elem_error_J,,3,6
*dim,elem_tab,,36,3

/com,============
/com,   Node I
/com,============

*do,i,1,3
```

```
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,------------------------------------------------------------------------

*do,i,1,3
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+18
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3

/com,-----------------------------------------------------------------------
/com,

/out,

/com
/com,---------------vm-nr1677-1-3a-a Results Verification---------------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-1-3a-a,vrt

/com,
/com, =============================================
/com,    COMPARISON OF MODAL FREQUENCY
/com,   WITH EXPECTED RESULTS
/com, =============================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label(1),freq_exp(1),freq_ans(1),freq_err(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,'  ')

/com,

/com,-----------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr
```

```
/com,
/com,==================================================
/com,  COMPARISON OF MAXIMUM NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,==================================================
/com,

/com,   Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,----------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,===============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,===============================================
/com,

/com,------------------------------------------------
/com, Note: Element Forces and Moments along Y & Z
/com,  directions are flipped between Mechanical APDL
/com,  and NRC results
/com,------------------------------------------------

/com,    Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 20
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)
```

```
/com,

*vwrite,label4(1,1),elem_tab(25,1),elem_tab(25,2),elem_tab(25,3)
(1x,a5,'    ',f10.4,'  ',f10.4,'    ',f5.3)

/com,
/com,

/com,===============
/com,   Element 7
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a5,'    ',f10.4,'  ',f10.4,'    ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(31,1),elem_tab(31,2),elem_tab(31,3)
(1x,a5,'    ',f10.4,'  ',f10.4,'    ',f5.3)


/com,
/com,
/com,*******************************************************************
/com,*******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-1-3a-a,vrt
finish
```

vm-nr1677-1-4a-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-1-4a-a
/title,vm-nr1677-1-4a-a,NRC Piping Benchmark Problems,Volume 1,Problem 4


/com,****************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,         NUREG/CR--1677-Vol.1
/com,   P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com,
/com, Elements used: Pipe16, Combin14, Pipe18, Mass21
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces obtained from spectrum solution.
/com,****************************************************************************

/out,scratch

/prep7
et,2,combin14     ! COMBIN14 Spring-damper element
et,3,pipe16      ! Pipe16 element
et,5,pipe18      ! Pipe18 element
keyopt5,3,1
et,7,mass21      ! Mass21 element

/com, Real Constants
```

```
/com,****************

r,       1,        0.1000E+11,      0.00000000,      0.00000000,      0.00000000,      0.00000000,      0.000000
r,       2,        50000000.0,      0.00000000,      0.00000000,      0.00000000,      0.00000000,      0.000000
r,       3,        10000000.0,      0.00000000,      0.00000000,      0.00000000,      0.00000000,      0.000000
r,       4,        144.000000,      3.00000000,      0.00000000,      0.00000000,      0.00000000,      0.000000
r,       5,        36.0000000,      2.50000000,      0.00000000,      0.00000000,      0.00000000,      0.28138E
r,       6,        36.0000000,      2.50000000,      60.0000000,      0.00000000,      0.00000000,      0.000000
rmore, 0.281380000E-03
r,       7,        48.0000000,      3.75000000,      0.00000000,      0.00000000,      0.00000000,      0.32972E
r,       8,        48.0000000,      3.75000000,      117.900000,      0.00000000,      0.00000000,      0.000000
rmore, 0.329720000E-03
r,       9,        72.0000000,      4.00000000,      0.00000000,      0.00000000,      0.00000000,      0.000000
r,      10,        192.000000,      8.00000000,      0.00000000,      0.00000000,      0.00000000,      0.000000
r,      11,        135.000000,      0.40000000,      0.00000000,      0.00000000,      0.00000000,      0.000000
r,      12,        100.000000,      0.38000000,      0.00000000,      0.00000000,      0.00000000,      0.000000
r,      13,        518.000000,      518.000000,      518.000000,      0.00000000,      0.00000000,      0.000000
r,      14,        259.000000,      259.000000,      259.000000,      0.00000000,      0.00000000,      0.000000
r,      15,        906.000000,      906.000000,      906.000000,      0.00000000,      0.00000000,      0.000000
r,      16,        233.000000,      233.000000,      233.000000,      0.00000000,      0.00000000,      0.000000
r,      17,        130.000000,      130.000000,      130.000000,      0.00000000,      0.00000000,      0.000000
r,      18,        389.000000,      389.000000,      389.000000,      0.00000000,      0.00000000,      0.000000
r,      19,        2073.00000,      2073.00000,      2073.00000,      0.00000000,      0.00000000,      0.000000
r,      20,        1943.00000,      1943.00000,      1943.00000,      0.00000000,      0.00000000,      0.000000
r,      21,        1295.00000,      1295.00000,      1295.00000,      0.00000000,      0.00000000,      0.000000

/com,-----------------------------------------------------------------------
/com,

/com, Nodes
/com,*******

n,       1,                384.000000,      696.000000,
n,       2,                384.000000,      552.000000,
n,       3,                384.000000,      456.000000,
n,       4,                384.000000,      276.000000,
n,       5,                384.000000,      96.0000000,
n,       6,                384.000000,     -180.000000,
n,       7,                399.000000,      26.9000000,     -56.0000000
n,       8,                399.000000,      26.9000000,      56.0000000
n,       9,                338.800000,      42.1000000,
n,      10,                402.600000,     -11.6000000,     -69.5000000
n,      11,                248.400000,
n,      12,                402.600000,     -11.6000000,      69.5000000
n,      13,                402.600000,     -72.0000000,     -69.5000000
n,      14,                402.600000,     -72.0000000,      69.5000000
n,      15,                354.700000,     -132.000000,     -105.600000
n,      16,                354.700000,     -132.000000,      105.600000
n,      17,                335.900000,     -132.000000,     -119.900000
n,      18,                335.900000,     -132.000000,      119.900000
n,      19,                288.000000,     -72.0000000,     -156.000000
n,      20,                288.000000,     -72.0000000,      156.000000
n,      21,                288.000000,      0.00000000,     -156.000000
n,      22,                288.000000,      0.00000000,      156.000000
n,      23,                288.000000,     -180.000000,     -156.000000
n,      24,                288.000000,     -180.000000,      156.000000
n,      25,                288.000000,      126.000000,     -156.000000
n,      26,                288.000000,      126.000000,      156.000000
n,      27,                253.200000,      0.00000000,     -146.700000
n,      28,                253.200000,      0.00000000,      146.700000
n,      29,                187.300000,      0.00000000,     -128.500000
n,      30,                177.000000,
n,      31,                187.300000,      0.00000000,      128.500000
n,      32,                121.400000,      0.00000000,     -110.200000
n,      33,                96.0000000,
n,      34,                121.400000,      0.00000000,      110.200000
n,      35,                94.6000000,      0.00000000,     -94.6000000
n,      36,                94.6000000,      0.00000000,      94.6000000
n,      37,                0.00000000,
n,      38,                0.00000000,     -192.000000,
n,      39,                0.00000000,      84.0000000,
n,      40,                0.00000000,      156.000000,
```

```
n,    41,            0.00000000,    288.000000,
n,    42,           -94.6000000,    0.00000000,    -94.6000000
n,    43,           -96.0000000,
n,    44,           -94.6000000,    0.00000000,     94.6000000
n,    45,           -121.400000,    0.00000000,    -110.200000
n,    46,           -121.400000,    0.00000000,     110.200000
n,    47,           -187.300000,    0.00000000,    -128.500000
n,    48,           -177.000000,
n,    49,           -187.300000,    0.00000000,     128.500000
n,    50,           -253.200000,    0.00000000,    -146.700000
n,    51,           -248.400000,
n,    52,           -253.200000,    0.00000000,     146.700000
n,    53,           -288.000000,    0.00000000,    -156.000000
n,    54,           -288.000000,    0.00000000,     156.000000
n,    55,           -288.000000,    126.000000,    -156.000000
n,    56,           -288.000000,    126.000000,     156.000000
n,    57,           -288.000000,   -180.000000,    -156.000000
n,    58,           -288.000000,   -180.000000,     156.000000
n,    59,           -288.000000,   -72.0000000,    -156.000000
n,    60,           -288.000000,   -72.0000000,     156.000000
n,    61,           -335.900000,   -132.000000,    -119.900000
n,    62,           -335.900000,   -132.000000,     119.900000
n,    63,           -354.700000,   -132.000000,    -105.600000
n,    64,           -354.700000,   -132.000000,     105.600000
n,    65,           -402.600000,   -72.0000000,    -69.5000000
n,    66,           -402.600000,   -72.0000000,     69.5000000
n,    67,           -402.600000,   -11.6000000,    -69.5000000
n,    68,           -402.600000,   -11.6000000,     69.5000000
n,    69,           -399.000000,    26.9000000,    -56.0000000
n,    70,           -338.800000,    42.1000000,
n,    71,           -399.000000,    26.9000000,     56.0000000
n,    72,           -384.000000,    96.0000000,
n,    73,           -384.000000,   -180.000000,
n,    74,           -384.000000,    276.000000,
n,    75,           -384.000000,    456.000000,
n,    76,           -384.000000,    552.000000,
n,    77,           -384.000000,    696.000000,
n,   126,            387.131997,   -11.7130035,    -11.4949905
n,   127,            248.496000,    117.900000,
n,   128,            387.131997,   -11.7130035,     11.4949905
n,   129,            354.700000,   -72.0000000,    -105.600000
n,   130,            354.700000,   -72.0000000,     105.600000
n,   131,            335.900000,   -72.0000000,    -119.900000
n,   132,            335.900000,   -72.0000000,     119.900000
n,   133,            137.244000,    0.00000000,    -52.3916000
n,   134,            137.244000,    0.00000000,     52.3916000
n,   135,           -137.244000,    0.00000000,    -52.3916000
n,   136,           -137.244000,    0.00000000,     52.3916000
n,   137,           -335.900000,   -72.0000000,    -119.900000
n,   138,           -335.900000,   -72.0000000,     119.900000
n,   139,           -354.700000,   -72.0000000,    -105.600000
n,   140,           -354.700000,   -72.0000000,     105.600000
n,   141,           -387.164784,   -11.6665558,    -11.6179404
n,   142,           -248.538000,    117.810000,    -4.59695000
n,   143,           -387.164784,   -11.6665558,     11.6179404
n,   205,            383.000000,    276.000000,     0.00000000
n,   206,            384.000000,    276.000000,     1.00000000
n,   207,            385.000000,    276.000000,     0.00000000
n,   208,            384.000000,    276.000000,    -1.00000000
n,   241,            95.6000000,    0.00000000,    -93.6000000
n,   242,            96.0000000,    0.00000000,     1.00000000
n,   243,            93.6000000,    0.00000000,     95.6000000
n,   244,            94.6000000,   -1.00000000,    -94.6000000
n,   245,            96.0000000,   -1.00000000,     0.00000000
n,   246,            94.6000000,   -1.00000000,     94.6000000
n,   252,           -94.6000000,   -1.00000000,    -94.6000000
n,   253,           -96.0000000,   -1.00000000,     0.00000000
n,   254,           -94.6000000,   -1.00000000,     94.6000000
n,   255,           -95.6000000,    0.00000000,    -93.6000000
n,   256,           -96.0000000,    0.00000000,     1.00000000
n,   257,           -93.6000000,    0.00000000,     95.6000000
n,   291,           -383.000000,    276.000000,     0.00000000
```

```
n,     292,               -385.000000,      276.000000,      0.00000000
n,     293,               -384.000000,      276.000000,      1.00000000
n,     294,               -384.000000,      276.000000,     -1.00000000

/com,------------------------------------------------------------------------
/com,

/com, Material Properties

mp,ex,1,2.9e7    ! Young's Modulus for Mat ID 1
mp,nuxy,1,.3    ! Minor Poisson's Ratio for Mat ID 1

/com,------------------------------------------------------------------------
/com,

/com, Straight Pipe (Tangent Elements)
/com,**********************************

mat,1
type,3
real,4
en,1,1,2
en,2,2,3
en,3,3,4
en,4,4,5
en,6,5,7
en,7,5,8
en,8,5,9
en,73,69,72
en,74,70,72
en,75,71,72
en,77,72,74
en,78,74,75
en,79,75,76
en,80,76,77

/com,****************
/com,

mat,1
type,3
real,5
en,12,10,13
en,13,12,14
en,16,15,17
en,17,16,18
en,28,27,29
en,30,28,31
en,31,29,32
en,33,31,34
en,48,45,47
en,50,46,49
en,51,47,50
en,53,49,52
en,64,61,63
en,65,62,64
en,68,65,67
en,69,66,68

/com,****************
/com,

mat,1
type,3
real,7
en,29,11,30
en,32,30,33
en,49,43,48
en,52,48,51

/com,****************
/com,
```

```
mat,1
type,3
real,9
en,20,19,21
en,21,20,22
en,24,21,25
en,25,22,26
en,26,21,27
en,27,22,28
en,54,50,53
en,55,52,54
en,56,55,53
en,57,56,54
en,60,53,59
en,61,54,60

/com,****************
/com,

mat,1
type,3
real,10
en,36,35,37
en,37,33,37
en,38,36,37
en,39,38,37
en,40,37,39
en,41,39,40
en,42,40,41
en,43,37,42
en,44,37,43
en,45,37,44

/com,****************
/com,

mat,1
type,3
real,11
en,5,5,6
en,76,73,72

/com,****************
/com,

mat,1
type,3
real,12
en,22,23,21
en,23,24,22
en,58,53,57
en,59,54,58

/com,
/com, Pipe Bend Elements
/com,*********************

mat,1
type,5
real,6
en,9,7,10,126
en,11,8,12,128
en,14,13,15,129
en,15,14,16,130
en,18,17,19,131
en,19,18,20,132
en,34,32,35,133
en,35,34,36,134
en,46,42,45,135
en,47,44,46,136
en,62,59,61,137
```

```
en,63,60,62,138
en,66,63,65,139
en,67,64,66,140
en,70,67,69,141
en,72,68,71,143

/com,****************
/com,

mat,1
type,5
real,8
en,10,9,11,127
en,71,51,70,142

/com,
/com, Spring Elements
/com,*****************

type,2
real,1
en,206,4,206
en,207,4,207
en,208,4,208
en,292,74,292
en,293,74,293
en,294,74,294

/com,****************
/com,

type,2
real,2
en,244,35,244
en,245,33,245
en,246,36,246
en,252,42,252
en,253,43,253
en,254,44,254

/com,****************
/com,

type,2
real,3
en,241,35,241
en,242,33,242
en,243,36,243
en,255,42,255
en,256,43,256
en,257,44,257

/com,****************
/com,

type,2
real,1
en,205,4,205
en,291,74,291

/com,-------------------------------------------------------------------------------
/com,

/com, Mass Elements
/com,***************

type,7

real,13
en,129,1

real,14
```

```
en,130,2

real,14
en,131,3

real,15
en,132,4

real,16
en,133,5

real,17
en,134,21

real,17
en,135,22

real,18
en,136,25

real,18
en,137,26

real,19
en,138,37

real,20
en,139,38

real,21
en,140,39

real,13
en,141,40

real,18
en,142,41

real,18
en,143,55

real,18
en,144,56

real,17
en,145,53

real,17
en,146,54

real,16
en,147,72

real,15
en,148,74

real,14
en,149,75

real,14
en,150,76

real,13
en,151,77

/com,----------------------------------------------------------------------------
/com,

/com, Constraints
/com,*************

d,6,all,0
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d,23,all,0
d,24,all,0
d,57,all,0
d,58,all,0
d,73,all,0
d,205,all,0
d,206,all,0
d,207,all,0
d,208,all,0
d,241,all,0
d,242,all,0
d,243,all,0
d,244,all,0
d,245,all,0
d,246,all,0
d,252,all,0
d,253,all,0
d,254,all,0
d,255,all,0
d,256,all,0
d,257,all,0
d,291,all,0
d,292,all,0
d,293,all,0
d,294,all,0
allsel,all

/com,-------------------------------------------------------------------------
/com,

/com, Loads
/com,*******

sfe,9,1,pres,1,2400.00
sfe,10,1,pres,1,2400.00
sfe,11,1,pres,1,2400.00
sfe,14,1,pres,1,2400.00
sfe,15,1,pres,1,2400.00
sfe,18,1,pres,1,2400.00
sfe,19,1,pres,1,2400.00
sfe,34,1,pres,1,2400.00
sfe,35,1,pres,1,2400.00
sfe,46,1,pres,1,2400.00
sfe,47,1,pres,1,2400.00
sfe,62,1,pres,1,2400.00
sfe,63,1,pres,1,2400.00
sfe,66,1,pres,1,2400.00
sfe,67,1,pres,1,2400.00
sfe,70,1,pres,1,2400.00
sfe,71,1,pres,1,2400.00
sfe,72,1,pres,1,2400.00


allsel,all
save
finish

/com,-------------------------------------------------------------------------
/com,

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,30
mxpand,,,,yes    ! Expand Solution with Element Calculations ON
solve
save
```

```
/com,
/com,==========================
/com, Compare Modal Frequencies
/com,==========================
/com,

*dim,label,,30
*dim,freq_ans,,30
*dim,freq_exp,,30
*dim,freq_err,,30

*do,i,1,30
 label(i)=i
*enddo

*do,i,1,30
 *get,freq_ans(i),mode,i,freq
*enddo

*vfill,freq_exp,data,0.6133e+01,0.6183e+01,0.6557e+01,0.6571e+01,0.6632e+01,0.6636e+01
*vfill,freq_exp(7),data,0.6722e+01,0.7984e+01,0.1021e+02,0.1173e+02,0.1340e+02,0.1389e+02
*vfill,freq_exp(13),data,0.1425e+02,0.1450e+02,0.1471e+02,0.1557e+02,0.1710e+02,0.1890e+02
*vfill,freq_exp(19),data,0.2829e+02,0.2831e+02,0.2952e+02,0.2980e+02,0.3032e+02,0.3049e+02
*vfill,freq_exp(25),data,0.3050e+02,0.3183e+02,0.3186e+02,0.3950e+02,0.4042e+02,0.4073e+02

*status,freq_ans
*status,freq_exp

*do,i,1,30
 freq_err(i)=abs(freq_ans(i)/freq_exp(i))
*enddo

*status,freq_err
save,table_1
finish      ! Finish Solution routine

/com,-------------------------------------------------------------------------------
/com,

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
spopt,sprs     ! Perform Spectrum Analysis
dmprat,0.02     ! Constant Damping Ratio
grp,0.001     ! Grouping based on Significance Level
svtyp,2

sed,1      ! Excitation along X direction
freq
freq,1,1.05,1.15,1.28,1.60,1.62,1.9,1.92,2.4
freq,2.55,2.8,2.89,3.15,3.28,3.42,4.18,4.41,5.2
freq,5.33,6.52,6.75,7.08,8.65,10,14.07,14.90,17
freq,18.09,21.697,23.8,30,37.5,41,46.21,52,58.82
freq,71.89,98.04,200
sv,0.02,600,662,662,905,905,865,865,914,914
sv,0.02,812,812,855,855,1023,1057,1057,1140,1140
sv,0.02,1399,1399,1150,1222,1222,865,865,755,755
sv,0.02,652,555,475,437,407,255,255,170,243
sv,0.02,243,160,160
solve

sed,,1      ! Excitation along Y direction
freq
freq,1,1.05,1.15,1.28,1.6,1.62,1.9,1.92,2.4
freq,2.55,2.8,2.89,3.15,3.28,3.42,4.18,4.41,5.2
freq,5.33,6.52,6.75,7.08,8.65,10,14.07,14.90,17
freq,18.09,21.70,23.80,30,37.50,41,46.21,52,58.82
```

```
freq,71.89,98.04,200
sv,0.02,400,441.3,441.3,603.3,603.3,576.7,576.7,609.3,609.3
sv,0.02,541.3,541.3,570,570,682,704.7,704.7,760,760
sv,0.02,932.7,932.7,766.7,814.7,814.7,576.7,576.7,503.3,503.3
sv,0.02,434.7,370,316.7,292.5,271.3,170,170,113.3,162
sv,0.02,162,106.7,106.7
solve

sed,,,1      ! Excitation along Z direction
freq
freq,1,1.05,1.15,1.28,1.60,1.62,1.9,1.92,2.4
freq,2.55,2.8,2.89,3.15,3.28,3.42,4.18,4.41,5.2
freq,5.33,6.52,6.75,7.08,8.65,10,14.07,14.90,17
freq,18.09,21.697,23.8,30,37.5,41,46.21,52,58.82
freq,71.89,98.04,200
sv,0.02,600,662,662,905,905,865,865,914,914
sv,0.02,812,812,855,855,1023,1057,1057,1140,1140
sv,0.02,1399,1399,1150,1222,1222,865,865,755,755
sv,0.02,652,555,475,437,407,255,255,170,243
sv,0.02,243,160,160
solve
fini

/com,-----------------------------------------------------------------------
/com,

/post1
/input,,mcom

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,3,1
*dim,label4,char,3,1

/com,------------------------

label2(1,1) = 'ux_55'
label2(1,2) = 'uy_77'
label2(1,3) = 'uz_55'
label2(1,4) = 'rotx_55'
label2(1,5) = 'roty_47'
label2(1,6) = 'rotz_55'

/com,----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
!label3(4,1)='TX(I)'
!label3(5,1)='MY(I)'
!label3(6,1)='MZ(I)'

/com,----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
!label4(4,1)='TX(J)'
!label4(5,1)='MY(J)'
!label4(6,1)='MZ(J)'

/com,--------------------------------

/com, *=====================================================
/com, * Maximum nodal displacements and rotations comparsion
/com, *=======================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,55,U,X
*GET,AdisY,NODE,77,U,Y
```

```
*GET,AdisZ,NODE,55,U,Z
*GET,ArotX,NODE,55,ROT,X
*GET,ArotY,NODE,47,ROT,Y
*GET,ArotZ,NODE,55,ROT,Z

/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,0.45489
*SET,EdisY,0.76248e-01
*SET,EdisZ,0.95090
*SET,ErotX,0.40966e-02
*SET,ErotY,0.25113e-02
*SET,ErotZ,0.21399e-02

/com, Error computation
/com, *********************

ERdisX=ABS((AdisX)/(EdisX))
ERdisY=ABS((AdisY)/(EdisY))
ERdisZ=ABS((AdisZ)/(EdisZ))
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,------------------------------------------------------------
/com

/com, *========================================================
/com, * Element Forces and Moments Comparison
/com, *==========================================================

/com, Solution obtained from Mechanical APDL
/com, *****************************

*dim,elem_res_I,,2,6
*dim,elem_res_J,,2,6

*dim,pxi,,2
*dim,vyi,,2
*dim,vzi,,2
*dim,txi,,2
*dim,myi,,2
*dim,mzi,,2
```

```
*dim,pxj,,2
*dim,vyj,,2
*dim,vzj,,2
*dim,txj,,2
*dim,myj,,2
*dim,mzj,,2

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #80
/com,*************

*get,pxi(2,1),elem,80,smisc,1
*get,vyi(2,1),elem,80,smisc,2
*get,vzi(2,1),elem,80,smisc,3
*get,txi(2,1),elem,80,smisc,4
*get,myi(2,1),elem,80,smisc,5
*get,mzi(2,1),elem,80,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #80
/com,*************
```

```
*get,pxj(2,1),elem,80,smisc,7
*get,vyj(2,1),elem,80,smisc,8
*get,vzj(2,1),elem,80,smisc,9
*get,txj(2,1),elem,80,smisc,10
*get,myj(2,1),elem,80,smisc,11
*get,mzj(2,1),elem,80,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com,----------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,2,6
*dim,exp_J,,2,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,3.154e+05
*vfill,exp_I(1,2),data,6.330e+05
*vfill,exp_I(1,3),data,6.382e+05
*vfill,exp_I(1,4),data,1.0000e-20
*vfill,exp_I(1,5),data,1.965e-06
*vfill,exp_I(1,6),data,1.163e-05

*vfill,exp_J(1,1),data,3.153e+05
*vfill,exp_J(1,2),data,6.330e+05
*vfill,exp_J(1,3),data,6.381e+05
*vfill,exp_J(1,4),data,1.000e-20
*vfill,exp_J(1,5),data,9.189e+07
*vfill,exp_J(1,6),data,9.116e+07

/com, Element #80
/com,*************

*vfill,exp_I(2,1),data,3.154e+05
*vfill,exp_I(2,2),data,6.330e+05
*vfill,exp_I(2,3),data,6.382e+05
*vfill,exp_I(2,4),data,2.002e-06
*vfill,exp_I(2,5),data,9.190e+07
*vfill,exp_I(2,6),data,9.116e+07

*vfill,exp_J(2,1),data,3.154e+05
*vfill,exp_J(2,2),data,6.330e+05
*vfill,exp_J(2,3),data,6.382e+05
*vfill,exp_J(2,4),data,2.042e-06
*vfill,exp_J(2,5),data,9.129e-06
*vfill,exp_J(2,6),data,1.546e-05

/com,---------------------------------------------------------------------------

/com, Error computation
/com, ********************

*dim,elem_error_I,,2,6
*dim,elem_error_J,,2,6
*dim,elem_tab,,24,3

/com,============
/com,   Node I
/com,============

*do,i,1,2
 *do,j,1,6
```

```
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,2
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,-----------------------------------------------------------------------

*do,i,1,2
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+12
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3

/com,----------------------------------------------------------------------
/com,

/out,

/com
/com,---------------vm-nr1677-1-4a-a Results Verification---------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-1-4a-a,vrt

/com,
/com, =============================================
/com,    COMPARISON OF MODAL FREQUENCY
/com,   WITH EXPECTED RESULTS
/com, =============================================
/com,

/com,  Mode | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label(1),freq_exp(1),freq_ans(1),freq_err(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,'  ')

/com,

/com,----------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr
```

```
/com,
/com,====================================================
/com,  COMPARISON OF NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,====================================================
/com,

/com,  Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,----------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,===============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,===============================================
/com,

/com,-----------------------------------------------
/com, Note: Element Forces and Moments along Y & Z
/com,       directions are flipped between Mechanical APDL
/com,       and NRC results
/com,-----------------------------------------------


/com,    Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 80
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)
```

```
/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,
/com,

/com,
/com,
/com,*******************************************************************
/com,*******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-1-4a-a,vrt
finish
```

vm-nr1677-1-5a-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-1-5a-a
/title,vm-nr1677-1-5a-a,NRC Piping Benchmark Problems,Volume 1,Problem 5

/com,***********************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,       NUREC/CR--1677-Vol.1
/com,       P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com, Elements used: Pipe16, Pipe18, Combin14 and Mass21 element
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com,
/com,***********************************************************************************

/out,scratch

/prep7
et,1,16       ! Element 1 - PIPE16 (Straight Pipe Element)
et,2,16       ! Element 2 - PIPE16 (Straight Pipe Element)
keyopt,2,4,6      ! Tee Branch
et,3,18       ! Element 3 - PIPE18 (Pipe Bend Element)
keyopt,3,3,1      ! Use ANSYS Flexibility Factor with Pressure Term
et,4,14       ! Element 4 - COMBIN14 (Spring Damper Element)
et,5,21       ! Element 5 - MASS21 (Mass Element)

/com, Real Constants
/com,****************

r, 1, 1.00e7, 0.0,  0.0     ! Real Constant Set 1
r, 2, 450.00, 0.0,  0.0
r, 3, 800.00, 0.0,  0.0
r, 4, 600.00, 0.0,  0.0
r, 5, 14.00, 0.4380, 0.0
r, 6, 14.00, 0.4380, 21.00
r, 7, 12.750, 0.3750, 18.00
r, 8, 12.750, 1.3120, 0.0
r, 9, 12.750, 1.3120, 18.00
r, 10, 12.750, 2.00,  0.0
r, 11, 2.8116, 2.8116, 2.8116
```

```
r, 12, 4.0432, 4.0432, 4.0432
r, 13, 2.5489, 2.5489, 2.5489
r, 14, 1.4063, 1.4063, 1.4063
r, 15, 1.4503, 1.4503, 1.4503
r, 16, 1.8685, 1.8685, 1.8685
r, 17, 2.8566, 2.8566, 2.8566
r, 18, 2.0246, 2.0246, 2.0246
r, 19, 6.7857, 6.7857, 6.7857
r, 20, 0.63406, 0.63406, 0.63406
r, 21, 0.59369, 0.59369, 0.59369
r, 22, 6.95390, 6.95390, 6.95390
r, 23, 3.73960, 3.73960, 3.73960

/com,-----------------------------------------------------------------------

/com, Material Properties
/com,**********************

mp,ex,1,2.62e7
mp,nuxy,1,.3

mp,ex,2,7.56e7
mp,nuxy,2,.3

mp,ex,3,2.52e7
mp,nuxy,3,.3

/com,-----------------------------------------------------------------------

/com, Nodes
/com,*******

n,1,0.0,0.0,0.0
n,2,18.636,0.0,-4.3680
n,3,23.424,0.0,-4.9200
n,4,26.400,0.0,-4.9200
n,5,47.400,0.0,-25.920
n,6,47.400,0.0,-79.920
n,7,68.400,0.0,-100.920
n,8,89.400,0.0,-79.920
n,9,89.400,0.0,-25.920
n,10,110.400,0.0,-4.920
n,11,146.400,0.0,-4.920
n,12,206.400,0.0,-4.920
n,13,245.400,0.0,-4.920
n,14,266.400,0.0,-25.920
n,15,266.400,0.0,-72.480
n,16,266.400,0.0,-87.732
n,17,272.436,-1.452,-102.636
n,18,323.280,-13.680,-154.560
n,19,327.960,-14.760,-159.360
n,20,336.816,-16.944,-168.396
n,21,349.884,-18.264,-173.856
n,22,370.884,-18.264,-173.856
n,23,391.884,-18.264,-173.856
n,24,370.884,30.696,-173.856
n,25,404.844,-18.264,-173.856
n,26,417.804,-18.264,-173.856
n,27,438.804,-18.264,-173.856
n,28,459.804,-18.264,-173.856
n,29,438.804,30.696,-173.856
n,30,472.236,-18.264,-173.856
n,31,485.148,-18.264,-179.316
n,32,507.300,-18.264,-202.128
n,33,519.840,-0.264,-215.040
n,34,245.400,12.000,-4.920
n,35,404.844,12.000,173.856
n,36,485.148,12.000,179.376
n,37,68.400,12.000,-100.920
n,38,323.280,12.000,-154.560
n,39,323.280,-13.680,-166.560
n,52,23.4192,0.000,16.080
```

```
n,53,26.400,0.000,-25.920
n,54,68.400,0.000,-79.920
n,55,68.400,0.000,-79.920
n,56,110.400,0.000,-25.920
n,57,245.400,0.000,-25.920
n,58,286.818,-4.91158,-87.7295
n,59,349.880,-14.0342,-156.360
n,60,472.2350,-18.2640,-191.856
n,61,507.299,-0.2640,-202.127

/com,-----------------------------------------------------------------------

/com, Straight Pipe (Tangent Elements)
/com,*********************************

mat,1
type,1
real,5

en,1,1,2
en,3,3,4
en,5,5,6
en,8,8,9
en,10,10,11
en,11,11,12
en,12,12,13
en,14,14,15
en,15,15,16
en,17,17,18
en,18,18,19
en,19,19,20

/com,----------------

mat,2
type,2
real,8

en,21,21,22
en,22,22,23
en,26,26,27
en,27,27,28

/com,----------------

mat,3
type,1
real,8

en,24,23,25
en,25,25,26
en,29,28,30
en,31,31,32

/com,----------------

mat,3
type,2
real,10

en,23,22,24
en,28,27,29

/com,----------------

type,4
real,1

en,33,7,37

/com,----------------
```

```
type,4
real,1

en,34,18,38

/com,-----------------

type,4
real,1

en,35,18,39

/com,-----------------

type,4
real,2

en,36,13,34

/com,-----------------

type,4
real,3

en,37,25,35

/com,-----------------

type,4
real,4

en,38,31,36

/com,--------------------------------

/com, Pipe Bend Elements
/com,************************

mat,1
type,3
real,6

en,2,2,3,52
en,4,4,5,53
en,6,6,7,54
en,7,7,8,55
en,9,9,10,56
en,13,13,14,57
en,16,16,17,58

/com,-----------------------

mat,1
type,3
real,7

en,20,20,21,59

/com,-----------------------

mat,3
type,3
real,9

en,30,30,31,60
en,32,32,33,61

/com,-----------------------

/com, Mass Elements
/com,***************
```

```
type,5

real,11
en,51,4

real,12
en,52,7

real,13
en,53,10

real,14
en,54,11

real,15
en,55,12

real,16
en,56,13

real,17
en,57,15

real,18
en,58,18

real,19
en,59,22

real,20
en,60,24

real,21
en,61,25

real,22
en,62,27

real,20
en,63,29

real,23
en,64,31

/com,-----------------

/com, Constraints
/com,*************

d,1,all,0.0,0.0
d,33,all,0.0,0.0
d,34,all,0.0,0.0
d,35,all,0.0,0.0
d,36,all,0.0,0.0
d,37,all,0.0,0.0
d,38,all,0.0,0.0
d,39,all,0.0,0.0

save
finish

/com,-----------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,11
```

```
mxpand,,,,yes      ! Expand solutions with Element Calculation ON
solve
save
finish

/com,
/com,==========================
/com, Compare Modal Frequencies
/com,==========================
/com,

*dim,label,,11
*dim,freq_ans,,11
*dim,freq_exp,,11
*dim,freq_err,,11

*do,i,1,11
 label(i)=i
*enddo

*do,i,1,11
 *get,freq_ans(i),mode,i,freq
*enddo

*vfill,freq_exp,data,0.4036e+01,0.4257e+01,0.9116e+01,0.1119e+02,0.1711e+02,0.1817e+02,0.2238e+02,0.2719e+02,0.2801e+02
*vfill,freq_exp(11),data,0.4097e+02
*status,freq_ans
*status,freq_exp

*do,i,1,11
 freq_err(i)=abs(freq_ans(i)/freq_exp(i))
*enddo

*status,freq_err
save,table_1
finish

/com,-------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,sprs      ! Single Point Excitation Response Spectrum
dmprat,0.02      ! Constant Damping Ratio
grp,0.0      ! Group Modes based on significance level
svtyp,2      ! Seismic Acceleration Response Loading
save

sed,1       ! Excitation in X direction
freq
freq,1,1.67,3.03,4,4.25,5,5.26,5.261,6.45
freq,6.451,7.14,10,11.76,15,20,25,30,35
freq,40,100
sv,0.02,4.64,9.27,27.82,46.37,66.83,115.92,185.47,425.04,425.04
sv,0.02,193.2,115.92,65.34,46.37,43.53,40.96,39.41,38.38,37.64
sv,0.02,37.09,37.09
solve

sed,,1      ! Excitation in Y direction
freq
freq,1,1.67,3.03,4,4.25,5,5.26,5.261,6.45
freq,6.451,7.14,10,11.76,15,20,25,30,35
freq,40,100
sv,0.02,3.09,6.18,18.55,30.91,44.55,77.28,123.65,283.36,283.36
sv,0.02,128.8,77.28,43.56,30.91,29.02,27.30,26.27,25.59,25.09
sv,0.02,24.73,24.73
solve
```

```
sed,,,1      ! Excitation in Z direction
freq
freq,1,1.67,3.03,4,4.25,5,5.26,5.261,6.45
freq,6.451,7.14,10,11.76,15,20,25,30,35
freq,40,100
sv,0.02,4.64,9.27,27.82,46.37,66.83,115.92,185.47,425.04,425.04
sv,0.02,193.2,115.92,65.34,46.37,43.53,40.96,39.41,38.38,37.64
sv,0.02,37.09,37.09
solve

/com,------------------------------------------------------------------------------

/post1
/input,,mcom

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1

/com,------------------------

label2(1,1) = 'ux_7'
label2(1,2) = 'uy_13'
label2(1,3) = 'uz_10'
label2(1,4) = 'rotx_14'
label2(1,5) = 'roty_6'
label2(1,6) = 'rotz_8'

/com,----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,----------------------------------

/com, *=====================================================
/com, * Maximum nodal displacements and rotations comparsion
/com, *=======================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,7,U,X
*GET,AdisY,NODE,13,U,Y
*GET,AdisZ,NODE,10,U,Z
*GET,ArotX,NODE,14,ROT,X
*GET,ArotY,NODE,6,ROT,Y
*GET,ArotZ,NODE,8,ROT,Z

/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,9.76006e-02
*SET,EdisY,6.00532e-02
*SET,EdisZ,4.65745e-02
*SET,ErotX,4.42117e-04
*SET,ErotY,1.09853e-03
```

```
*SET,ErotZ,1.95557e-04

/com, Error computation
/com, *********************

ERdisX=ABS((AdisX)/(EdisX))
ERdisY=ABS((AdisY)/(EdisY))
ERdisZ=ABS((AdisZ)/(EdisZ))
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,-----------------------------------------------------------

/com, *========================================================
/com, * Element Forces and Moments Comparison
/com, *==========================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*dim,elem_res_I,,3,6
*dim,elem_res_J,,3,6

*dim,pxi,,3
*dim,vyi,,3
*dim,vzi,,3
*dim,txi,,3
*dim,myi,,3
*dim,mzi,,3

*dim,pxj,,3
*dim,vyj,,3
*dim,vzj,,3
*dim,txj,,3
*dim,myj,,3
*dim,mzj,,3

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========
```

```
/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #31
/com,*************

*get,pxi(2,1),elem,31,smisc,1
*get,vyi(2,1),elem,31,smisc,2
*get,vzi(2,1),elem,31,smisc,3
*get,txi(2,1),elem,31,smisc,4
*get,myi(2,1),elem,31,smisc,5
*get,mzi(2,1),elem,31,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com, Element #20
/com,*************

*get,pxi(3,1),elem,20,smisc,1
*get,vyi(3,1),elem,20,smisc,2
*get,vzi(3,1),elem,20,smisc,3
*get,txi(3,1),elem,20,smisc,4
*get,myi(3,1),elem,20,smisc,5
*get,mzi(3,1),elem,20,smisc,6

*vfill,elem_res_I(3,1),data,pxi(3,1)
*vfill,elem_res_I(3,2),data,vyi(3,1)
*vfill,elem_res_I(3,3),data,vzi(3,1)
*vfill,elem_res_I(3,4),data,txi(3,1)
*vfill,elem_res_I(3,5),data,myi(3,1)
*vfill,elem_res_I(3,6),data,mzi(3,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
```

```
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #31
/com,*************

*get,pxj(2,1),elem,31,smisc,7
*get,vyj(2,1),elem,31,smisc,8
*get,vzj(2,1),elem,31,smisc,9
*get,txj(2,1),elem,31,smisc,10
*get,myj(2,1),elem,31,smisc,11
*get,mzj(2,1),elem,31,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com, Element #20
/com,************

*get,pxj(3,1),elem,20,smisc,7
*get,vyj(3,1),elem,20,smisc,8
*get,vzj(3,1),elem,20,smisc,9
*get,txj(3,1),elem,20,smisc,10
*get,myj(3,1),elem,20,smisc,11
*get,mzj(3,1),elem,20,smisc,12

*vfill,elem_res_J(3,1),data,pxj(3,1)
*vfill,elem_res_J(3,2),data,vyj(3,1)
*vfill,elem_res_J(3,3),data,vzj(3,1)
*vfill,elem_res_J(3,4),data,txj(3,1)
*vfill,elem_res_J(3,5),data,myj(3,1)
*vfill,elem_res_J(3,6),data,mzj(3,1)

/com,----------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,3,6
*dim,exp_J,,3,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,4.736e+02
*vfill,exp_I(1,2),data,1.209e+02
*vfill,exp_I(1,3),data,4.636e+02
*vfill,exp_I(1,4),data,3.979e+03
*vfill,exp_I(1,5),data,5.239e+04
*vfill,exp_I(1,6),data,9.741e+03

*vfill,exp_J(1,1),data,4.736e+02
*vfill,exp_J(1,2),data,1.209e+02
*vfill,exp_J(1,3),data,4.036e+02
*vfill,exp_J(1,4),data,3.479e+03
*vfill,exp_J(1,5),data,4.411e+04
*vfill,exp_J(1,6),data,7.434e+03

/com, Element #31
/com,*************

*vfill,exp_I(2,1),data,5.259e+02
*vfill,exp_I(2,2),data,2.338e+02
*vfill,exp_I(2,3),data,4.972e+02
*vfill,exp_I(2,4),data,1.518e+04
*vfill,exp_I(2,5),data,1.190e+04
*vfill,exp_I(2,6),data,7.325e+03

*vfill,exp_J(2,1),data,5.259e+02
```

```
*vfill,exp_J(2,2),data,2.338e+02
*vfill,exp_J(2,3),data,4.972e+02
*vfill,exp_J(2,4),data,1.518e+04
*vfill,exp_J(2,5),data,1.190e+04
*vfill,exp_j(2,6),data,7.326e+03

/com, Element #20
/com,*************

*vfill,exp_I(3,1),data,4.184e+02
*vfill,exp_I(3,2),data,2.626e+02
*vfill,exp_I(3,3),data,2.154e+02
*vfill,exp_I(3,4),data,9.940e+03
*vfill,exp_I(3,5),data,2.318e+04
*vfill,exp_I(3,6),data,1.200e+04

*vfill,exp_J(3,1),data,3.168e+02
*vfill,exp_J(3,2),data,2.154e+02
*vfill,exp_J(3,3),data,3.462e+02
*vfill,exp_J(3,4),data,1.506e+04
*vfill,exp_J(3,5),data,2.218e+04
*vfill,exp_J(3,6),data,4.918e+03

/com,-----------------------------------------------------------------------

/com, Error computation
/com, ********************

*dim,elem_error_I,,3,6
*dim,elem_error_J,,3,6
*dim,elem_tab,,36,3

/com,============
/com,   Node I
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,----------------------------------------------------------------------

*do,i,1,3
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+18
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3
```

```
/com,-------------------------------------------------------------------------
/com,

/out,

/com
/com,------------------vm-nr1677-1-5a-a Results Verification-------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-1-5a-a,vrt
/com,
/com, =============================================
/com,    COMPARISON OF MODAL FREQUENCY
/com,   WITH EXPECTED RESULTS
/com, =============================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label(1),freq_exp(1),freq_ans(1),freq_err(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,'  ')

/com,

/com,-------------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr

/com,
/com,====================================================
/com,  COMPARISON OF MAXIMUM NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,====================================================
/com,

/com,   Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-------------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,================================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
```

```
/com,       WITH EXPECTED RESULTS
/com,==============================================
/com,

/com,------------------------------------------------
/com, Note: Element Forces and Moments along Y & Z
/com,  directions are flipped between Mechanical APDL
/com,  and NRC results
/com,------------------------------------------------


/com,    Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 31
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(25,1),elem_tab(25,2),elem_tab(25,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 20
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(31,1),elem_tab(31,2),elem_tab(31,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)


/com,
/com,
/com,******************************************************************
/com,******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-1-5a-a,vrt
finish
```

vm-nr1677-1-6a-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-1-6a-a
/title,vm-nr1677-1-6a-a,NRC Piping Benchmark Problems,Volume 1,Problem 6

/com,***************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,       NUREC/CR--1677-Vol.1
/com,       P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com, Elements used: Pipe16, Pipe18, Combin14, Mass21
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com,***************************************************************************

/out,scratch

/prep7

et,1,pipe16     ! Element 1 - PIPE16
et,2,pipe16     ! Element 2 - PIPE16
keyopt,2,1,1    ! Temperatures represent Diametral Gradient
et,3,pipe18     ! Element 3 - PIPE18
keyopt,3,3,1    ! Use ANSYS Flexibility factor with pressure term
et,4,pipe18     ! Element 4 - PIPE18
keyopt,4,1,1    ! Temperatures represent Diametral Gradient
keyopt,4,3,1    ! Use ANSYS Flexibility factor with pressure term
et,5,combin14    ! Element 5 - COMBIN14
et,105,combin14    ! Element 105 - COMBIN14
keyopt,105,3,1    ! Torsional Spring Damper
et,6,mass21     ! Element 6 - MASS21

/com, *Real Constants*
/com,******************

r,       6,         30.0000000,      0.85000000,      0.00000000,
r,       7,         30.0000000,      0.85000000,      45.0000000,
r,       8,         32.0000000,      0.90500000,      0.00000000,
r,       9,         32.0000000,      0.90500000,      45.0000000,
r,      10,         30.0000000,      0.85000000,      150.000000,
r,      11,         9.92500000,      9.92500000,      9.92500000,
r,      12,         5.45300000,      5.45300000,      5.45300000,
r,      13,         4.88800000,      4.88800000,      4.88800000,
r,      14,         5.88800000,      5.88800000,      5.88800000,
r,      15,         5.37300000,      5.37300000,      5.37300000,
r,      16,         3.95000000,      3.95000000,      3.95000000,
r,      17,         2.43000000,      2.43000000,      2.43000000,
r,      18,         3.94100000,      3.94100000,      3.94100000,
r,      19,         7.60920000,      7.60920000,      7.60920000,
r,      20,         7.61200000,      7.61200000,      7.61200000,
r,      21,         7.61110000,      7.61110000,      7.61110000,
r,      22,         7.60100000,      7.60100000,      7.60100000,
r,      23,         10.2930000,      10.2930000,      10.2930000,
r,      24,         7.51800000,      7.51800000,      7.51800000,
r,      25,         3.87700000,      3.87700000,      3.87700000,
r,      26,         10.5280000,      10.5280000,      10.5280000,
r,     101,        0.1000000E20,     0.00000000,      0.00000000,
r,     102,        0.1000000E07,     0.00000000,      0.00000000,
r,     103,        0.2500000E06,     0.00000000,      0.00000000,
r,     104,        0.2000000E07,     0.00000000,      0.00000000,
r,     105,        0.4500000E06,     0.00000000,      0.00000000,
r,     106,        0.8000000E06,     0.00000000,      0.00000000,
```

```
r,     107,        0.1000000E10,     0.00000000,      0.00000000,
r,     108,        0.1000000E12,     0.00000000,      0.00000000,

/com,-------------------------------------------------------------
/com,

/com, *Nodes*
/com,*********

n,       1,                126.000000,      483.996000,      705.840000
n,       2,                126.000000,      483.996000,      704.640000
n,       3,                126.000000,      528.996000,      659.640000
n,       4,                126.000000,      497.176195,      672.820195
n,       5,                126.000000,      567.996000,      659.640000
n,       6,                126.000000,      651.996000,      659.640000
n,       7,                126.000000,      735.996000,      659.640000
n,       8,                126.000000,      802.596000,      659.640000
n,       9,                126.000000,      869.196000,      659.640000
n,      10,                126.000000,      917.196000,      659.640000
n,      11,                126.000000,      965.196000,      659.640000
n,      12,                126.000000,      968.196000,      659.640000
n,      13,                169.860000,     1013.19600,      649.560000
n,      14,                138.846498,     1000.01701,      656.687590
n,      15,                173.928000,     1013.19600,      648.624000
n,      16,                229.836000,     1013.19600,      630.996000
n,      17,                283.992000,     1013.19600,      608.556000
n,      18,                335.988000,     1013.19600,      581.484000
n,      19,                385.428000,     1013.19600,      550.080000
n,      20,                431.940000,     1013.19600,      514.392000
n,      21,                475.164000,     1013.19600,      474.780000
n,      22,                514.776000,     1013.19600,      431.556000
n,      23,                550.464000,     1013.19600,      385.044000
n,      24,                581.964000,     1013.19600,      335.604000
n,      25,                609.036000,     1013.19600,      283.608000
n,      26,                631.474000,     1013.19600,      229.452000
n,      27,                649.104000,     1013.19600,      173.544000
n,      28,                661.788000,     1013.19600,      116.304000
n,      29,                669.444000,     1013.19600,      58.1760000
n,      30,                672.000000,     1013.19600,     -0.39600000
n,      31,                669.444000,     1013.19600,     -58.9680000
n,      32,                661.788000,     1013.19600,     -117.096000
n,      33,                649.104000,     1013.19600,     -174.336000
n,      34,                631.476000,     1013.19600,     -230.244000
n,      35,                609.036000,     1013.19600,     -284.400000
n,      36,                581.964000,     1013.19600,     -336.396000
n,      37,                550.596000,     1013.19600,     -385.572000
n,      38,                375.312000,     1013.19600,     -446.736000
n,      39,                473.553150,     1013.19600,     -446.529080
n,      40,                345.576000,     1013.19600,     -436.500000
n,      41,                262.368000,     1013.19600,     -407.844000
n,      42,                221.700000,     1013.19600,     -393.840000
n,      43,                179.160000,      968.196000,     -379.188000
n,      44,                191.619252,     1000.01318,     -383.479325
n,      45,                179.160000,      968.172000,     -379.188000
n,      76,                126.000000,      528.996000,      704.640000
n,      77,                169.857000,      968.196000,      649.561000
n,      78,                424.134000,     1013.20000,     -304.904000
n,      79,                221.707000,      968.196000,     -393.842000
n,     142,                127.000000,      965.196000,      659.640000
n,     143,                126.000000,      965.196000,      660.640000
n,     144,                515.776000,     1013.19600,      431.556000
n,     145,                514.776000,     1014.19600,      431.556000
n,     146,                514.776000,     1013.19600,      432.556000
n,     147,                662.788000,     1013.19600,      116.304000
n,     148,                661.788000,     1014.19600,      116.304000
n,     149,                661.788000,     1013.19600,      117.304000
n,     150,                661.788000,     1014.19600,     -117.096000
n,     151,                582.223000,     1013.19600,     -337.362000
n,     152,                180.160000,      968.196000,     -379.188000
n,     153,                179.160000,      969.196000,     -379.188000
n,     154,                179.160000,      968.196000,     -378.188000
n,     155,                180.160000,      968.196000,     -379.188000
```

```
n,     156,                179.160000,      969.196000,     -379.188000
n,     157,                179.160000,      968.196000,     -378.188000
n,     158,                127.000000,      483.996000,      705.840000
n,     159,                126.000000,      484.996000,      705.840000
n,     160,                126.000000,      483.996000,      706.840000

/com,------------------------------------------------------------------
/com,

/com, *Material Properties*
/com,**********************

mp,ex,1,29900000
mp,nuxy,1,.3

/com,------------------------------------------------------------------
/com,

/com, *Straight Pipe (Tangent) Elements*
/com,***********************************
/com,

mat,1
type,1
real,6
en,1,1,2
en,4,3,5
en,5,5,6
en,6,6,7
en,7,7,8
en,8,8,9
en,9,9,10
en,10,10,11
en,11,11,12

en,14,13,15
en,15,15,16
en,16,16,17
en,17,17,18
en,18,18,19
en,19,19,20
en,20,20,21
en,21,21,22
en,22,22,23
en,23,23,24
en,24,24,25
en,25,25,26
en,26,26,27
en,27,27,28
en,28,28,29
en,29,29,30
en,30,30,31
en,31,31,32
en,32,32,33
en,33,33,34
en,34,34,35
en,35,35,36
en,36,36,37

en,39,38,40
en,40,40,41
en,41,41,42

/com,---------------

mat,1
type,1
real,8
en,44,43,45

/com,---------------
/com,
```

```
/com, *Pipe Bend Elements*
/com,**********************

mat,1
type,3
real,7
en,2,2,4,76
en,3,4,3,76
en,12,12,14,77
en,13,14,13,77

/com,----------------

mat,1
type,3
real,9
en,42,42,44,79
en,43,44,43,79

/com,----------------

mat,1
type,3
real,10
en,37,37,39,78
en,38,39,38,78

/com,----------------
/com,

/com, *Spring Elements*
/com,********************


mat,1
type,5
real,101
en,158,1,158
en,159,1,159
en,160,1,160

/com,----------------

mat,1
type,5
real,102
en,142,11,142
en,143,11,143

/com,----------------

mat,1
type,5
real,103
en,144,22,144
en,146,22,146

/com,----------------

mat,1
type,5
real,104
en,145,22,145
en,148,28,148
en,150,32,150

/com,----------------

mat,1
type,5
real,105
```

```
en,147,28,147
en,149,28,149

/com,----------------

mat,1
type,5
real,106
en,151,36,151

/com,----------------

mat,1
type,5
real,107
en,152,45,152
en,153,45,153
en,154,45,154

/com,----------------

mat,1
type,105
real,101
en,161,1,158
en,162,1,159
en,163,1,160

/com,----------------

mat,1
type,105
real,108
en,155,45,155
en,156,45,156
en,157,45,157

/com,----------------
/com,

/com, *Mass Elements*
/com,*****************

mat,1
type,6

real,11
en,75,5

real,12
en,76,6

real,13
en,77,7

real,14
en,78,8

real,15
en,79,10

real,16
en,80,12

real,17
en,81,13

real,18
en,82,15

real,19
en,83,17
```

```
real,19
en,84,19

real,20
en,85,21

real,21
en,86,23

real,21
en,87,25

real,21
en,88,27

real,21
en,89,29

real,21
en,90,31

real,21
en,91,33

real,22
en,92,35

real,23
en,93,37

real,24
en,94,38

real,25
en,95,40

real,26
en,96,41

/com,------------------------------------------------------------------
/com,

/com, *Constraints*
/com,***************

d,142,all,0
d,143,all,0
d,144,all,0
d,145,all,0
d,146,all,0
d,147,all,0
d,148,all,0
d,149,all,0
d,150,all,0
d,151,all,0
d,152,all,0
d,153,all,0
d,154,all,0
d,155,all,0
d,156,all,0
d,157,all,0
d,158,all,0
d,159,all,0
d,160,all,0

allsel,all
save
finish

/com,------------------------------------------------------------------
```

```
/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,31
mxpand,,,,yes
solve
save

/com,
/com,===========================
/com, Compare Modal Frequencies
/com,===========================
/com,

*dim,label,,31
*dim,freq_ans,,31
*dim,freq_exp,,31
*dim,freq_err,,31

*do,i,1,31
 label(i)=i
*enddo

*do,i,1,31
 *get,freq_ans(i),mode,i,freq
*enddo

*vfill,freq_exp,data,0.6391e+01,0.9993e+01,0.1327e+02,0.1449e+02,0.1533e+02
*vfill,freq_exp(6),data,0.1750e+02,0.1909e+02,0.1962e+02,0.2144e+02,0.2871e+02
*vfill,freq_exp(11),data,0.2986e+02,0.3148e+02,0.3201e+02,0.3637e+02,0.4098e+02
*vfill,freq_exp(16),data,0.4137e+02,0.4739e+02,0.4977e+02,0.5013e+02,0.5293e+02
*vfill,freq_exp(21),data,0.5690e+02,0.5851e+02,0.6747e+02,0.7046e+02,0.7541e+02
*vfill,freq_exp(26),data,0.7918e+02,0.8074e+02,0.8611e+02,0.8828e+02,0.9274e+02
*vfill,freq_exp(31),data,0.9936e+02

*status,freq_ans
*status,freq_exp

*do,i,1,31
 freq_err(i)=abs(freq_ans(i)/freq_exp(i))
*enddo

*status,freq_err
save,table_1
finish

/com,-----------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,sprs      ! Single Point Excitation Response Spectrum
dmprat,0.02      ! Constant Damping Ratio
grp,0.001      ! Group Modes based on Singificance Level
svtyp,2      ! Seismic Acceleration Response Loading

sed,1       ! Excitation in X direction
freq
freq,0.5,1.1,1.11,8.0,8.01,10,15,20,25
freq,30,35,40,45,50,55,60,65,70
freq,75,80,85,90,95,100,200
sv,0.02,27.05,135.20,649.10,649.10,81.14,75.73,68.52,64.92,62.75
```

```
sv,0.02,61.31,60.28,59.51,58.91,58.43,58.03,57.71,57.43,57.19
sv,0.02,56.98,56.80,56.64,56.50,56.38,56.26,54.53
solve

sed,,1      ! Excitation in Y direction
freq
freq,0.5,1.56,1.563,4.76,4.762,200
sv,0.02,108.2,143,1190,1190,73.42,73.42
solve

sed,,,1      ! Excitation in Z direction
freq
freq,0.5,1.1,1.11,8.0,8.01,10,15,20,25
freq,30,35,40,45,50,55,60,65,70
freq,75,80,85,90,95,100,200
sv,0.02,27.05,135.20,649.10,649.10,81.14,75.73,68.52,64.92,62.75
sv,0.02,61.31,60.28,59.51,58.91,58.43,58.03,57.71,57.43,57.19
sv,0.02,56.98,56.80,56.64,56.50,56.38,56.26,54.53

solve
finish

/com,-------------------------------------------------------------------

/post1
/input,,mcom   ! Compute SSRS

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1

/com,-------------------------

label2(1,1) = 'ux_33'
label2(1,2) = 'uy_39'
label2(1,3) = 'uz_38'
label2(1,4) = 'rotx_37'
label2(1,5) = 'roty_37'
label2(1,6) = 'rotz_41'

/com,-----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,-----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,-----------------------------------

/com, *========================================================
/com, * Maximum nodal displacements and rotations comparsion
/com, *==========================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,33,U,X
*GET,AdisY,NODE,39,U,Y
*GET,AdisZ,NODE,38,U,Z
*GET,ArotX,NODE,37,ROT,X
```

```
*GET,ArotY,NODE,37,ROT,Y
*GET,ArotZ,NODE,41,ROT,Z

/com, Expected results from NRC manual
/com, ********************************

*SET,EdisX,2.35964e-02
*SET,EdisY,0.89428e-01
*SET,EdisZ,1.51271e-02
*SET,ErotX,3.19637e-04
*SET,ErotY,9.58014e-05
*SET,ErotZ,3.10753e-04

/com, Error computation
/com, ********************

ERdisX=ABS((AdisX)/(EdisX))
ERdisY=ABS((AdisY)/(EdisY))
ERdisZ=ABS((AdisZ)/(EdisZ))
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,------------------------------------------------------------

/com, *=========================================================
/com, * Element Forces and Moments Comparison
/com, *===========================================================

/com, Solution obtained from Mechanical APDL
/com, ***************************

*dim,elem_res_I,,3,6
*dim,elem_res_J,,3,6

*dim,pxi,,3
*dim,vyi,,3
*dim,vzi,,3
*dim,txi,,3
*dim,myi,,3
*dim,mzi,,3

*dim,pxj,,3
*dim,vyj,,3
```

```
*dim,vzj,,3
*dim,txj,,3
*dim,myj,,3
*dim,mzj,,3

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #44
/com,*************

*get,pxi(2,1),elem,44,smisc,1
*get,vyi(2,1),elem,44,smisc,2
*get,vzi(2,1),elem,44,smisc,3
*get,txi(2,1),elem,44,smisc,4
*get,myi(2,1),elem,44,smisc,5
*get,mzi(2,1),elem,44,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com, Element #37
/com,*************

*get,pxi(3,1),elem,37,smisc,1
*get,vyi(3,1),elem,37,smisc,2
*get,vzi(3,1),elem,37,smisc,3
*get,txi(3,1),elem,37,smisc,4
*get,myi(3,1),elem,37,smisc,5
*get,mzi(3,1),elem,37,smisc,6

*vfill,elem_res_I(3,1),data,pxi(3,1)
*vfill,elem_res_I(3,2),data,vyi(3,1)
*vfill,elem_res_I(3,3),data,vzi(3,1)
*vfill,elem_res_I(3,4),data,txi(3,1)
*vfill,elem_res_I(3,5),data,myi(3,1)
*vfill,elem_res_I(3,6),data,mzi(3,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
```

```
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #44
/com,*************

*get,pxj(2,1),elem,44,smisc,7
*get,vyj(2,1),elem,44,smisc,8
*get,vzj(2,1),elem,44,smisc,9
*get,txj(2,1),elem,44,smisc,10
*get,myj(2,1),elem,44,smisc,11
*get,mzj(2,1),elem,44,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com, Element #37
/com,*************

*get,pxj(3,1),elem,37,smisc,7
*get,vyj(3,1),elem,37,smisc,8
*get,vzj(3,1),elem,37,smisc,9
*get,txj(3,1),elem,37,smisc,10
*get,myj(3,1),elem,37,smisc,11
*get,mzj(3,1),elem,37,smisc,12

*vfill,elem_res_J(3,1),data,pxj(3,1)
*vfill,elem_res_J(3,2),data,vyj(3,1)
*vfill,elem_res_J(3,3),data,vzj(3,1)
*vfill,elem_res_J(3,4),data,txj(3,1)
*vfill,elem_res_J(3,5),data,myj(3,1)
*vfill,elem_res_J(3,6),data,mzj(3,1)

/com,-----------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,3,6
*dim,exp_J,,3,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,1.171e+03
*vfill,exp_I(1,2),data,2.398e+03
*vfill,exp_I(1,3),data,1.265e+03
*vfill,exp_I(1,4),data,6.826e+04
*vfill,exp_I(1,5),data,4.807e+04
*vfill,exp_I(1,6),data,9.174e+04

*vfill,exp_J(1,1),data,1.171e+03
*vfill,exp_J(1,2),data,2.398e+03
*vfill,exp_J(1,3),data,1.265e+03
*vfill,exp_J(1,4),data,6.826e+04
*vfill,exp_J(1,5),data,4.664e+04
*vfill,exp_J(1,6),data,8.926e+04
```

```
/com, Element #44
/com,*************

*vfill,exp_I(2,1),data,1.749e+03
*vfill,exp_I(2,2),data,1.990e+03
*vfill,exp_I(2,3),data,9.465e+02
*vfill,exp_I(2,4),data,1.004e+05
*vfill,exp_I(2,5),data,1.327e+05
*vfill,exp_I(2,6),data,1.659e+05

*vfill,exp_J(2,1),data,1.749e+03
*vfill,exp_J(2,2),data,1.990e+03
*vfill,exp_J(2,3),data,9.465e+02
*vfill,exp_J(2,4),data,1.004e+05
*vfill,exp_J(2,5),data,1.327e+05
*vfill,exp_j(2,6),data,1.659e+05

/com, Element #37
/com,*************

*vfill,exp_I(3,1),data,6.829e+02
*vfill,exp_I(3,2),data,2.581e+02
*vfill,exp_I(3,3),data,1.2627e+03
*vfill,exp_I(3,4),data,9.236e+04
*vfill,exp_I(3,5),data,4.912e+04
*vfill,exp_I(3,6),data,1.087e+05

*vfill,exp_J(3,1),data,1.187e+03
*vfill,exp_J(3,2),data,2.581e+02
*vfill,exp_J(3,3),data,8.042e+02
*vfill,exp_J(3,4),data,1.948e+04
*vfill,exp_J(3,5),data,7.822e+04
*vfill,exp_J(3,6),data,1.341e+05

/com,------------------------------------------------------------------------

/com, Error computation
/com, *********************

*dim,elem_error_I,,3,6
*dim,elem_error_J,,3,6
*dim,elem_tab,,36,3

/com,============
/com,   Node I
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,-----------------------------------------------------------------------

*do,i,1,3
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
```

```
  *enddo

  *do,j,1,6
   m=cs+j+18
   *vfill,elem_tab(m,1),data,exp_J(i,j)
   *vfill,elem_tab(m,2),data,elem_res_J(i,j)
   *vfill,elem_tab(m,3),data,elem_error_J(i,j)
  *enddo
 *enddo

save,table_3

/com,------------------------------------------------------------------------
/com,

/out,

/com
/com,----------------vm-nr1677-1-6a-a Results Verification---------------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-1-6a-a,vrt
/com,
/com, ============================================
/com,    COMPARISON OF MODAL FREQUENCY
/com,   WITH EXPECTED RESULTS
/com, ============================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label(1),freq_exp(1),freq_ans(1),freq_err(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,'  ')

/com,

/com,------------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr

/com,
/com,==================================================
/com,  COMPARISON OF MAXIMUM NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,==================================================
/com,

/com,   Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
```

```
/com,-------------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,===============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,===============================================
/com,

/com,-----------------------------------------------
/com, Note: Element Forces and Moments along Y & Z
/com,  directions are flipped between Mechanical APDL
/com,  and NRC results
/com,-----------------------------------------------

/com,   Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a5,'   ',f15.3,'  ',f15.3,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a5,'   ',f15.3,'  ',f15.3,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 44
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a5,'   ',f15.3,'  ',f15.3,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(25,1),elem_tab(25,2),elem_tab(25,3)
(1x,a5,'   ',f15.3,'  ',f15.3,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 37
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a5,'   ',f16.3,'  ',f16.3,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(31,1),elem_tab(31,2),elem_tab(31,3)
(1x,a5,'   ',f16.3,'  ',f16.3,'   ',f5.3)


/com,
/com,
```

```
/com,*******************************************************************
/com,*******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-1-6a-a,vrt
finish
```

vm-nr1677-1-7a-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-1-7a-a
/title,vm-nr1677-1-7a-a,NRC Piping Benchmark Problems,Volume 1,Problem 7

/com,****************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,       NUREC/CR--1677-Vol.1
/com,       P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com,
/com, Element used: Pipe16, Pipe18, Mass21 and Combin14
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com,****************************************************************************

/out,scratch

/prep7
et,1,pipe16     ! Element 1 - PIPE16
et,2,pipe16     ! Element 2 - PIPE16
keyopt,2,1,1           ! Diametral Temperature Gradient
et,3,pipe16     ! Element 3 - PIPE16
keyopt,3,4,1           ! Valve
et,4,pipe16     ! Element 4 - PIPE16
keyopt,4,1,1          ! Diametral Temperature Gradient
keyopt,4,4,1           ! Valve
et,5,pipe16     ! Element 5 - PIPE16
keyopt,5,4,6           ! Tee Branch
et,6,pipe16     ! Element 6 - PIPE16
keyopt,6,1,1           ! Diametral Temperature Gradient
keyopt,6,4,6           ! Tee Branch
et,7,pipe18     ! Element 7 - PIPE18
keyopt,7,3,1          ! Use ANSYS Flexibility Factor with pressure term
et,8,pipe18     ! Element 8 - PIPE18
keyopt,8,1,1          ! Diametral Temperature Gradient
keyopt,8,3,1          ! Use ANSYS Flexibility Factor with pressure term
et,9,mass21     ! Element 9 - MASS21
et,10,combin14    ! Element 10 - COMBIN14
et,11,combin14    ! Element 11 - COMBIN14
keyopt,11,3,1           ! Torsional Spring

/com,----------------------------------------------------------------------------

/com, Real Constants
/com,****************

r,       1,         1.00000000,     0.000000000,     0.000000000
r,       2,         4.50000000,     0.337000000,     0.000000000
r,       3,         4.50000000,     0.337000000,     6.000000000
r,       4,         3.50000000,     0.300000000,     0.000000000
r,       5,         3.50000000,     0.300000000,     4.500000000
```

```
r,       6,        0.47179000,     0.471790000,     0.471790000
r,       7,        0.37604000,     0.376040000,     0.376040000
r,       8,        0.40399000,     0.403990000,     0.403990000
r,       9,        0.35016000,     0.350160000,     0.350160000
r,      10,        0.22179000,     0.221790000,     0.221790000
r,      11,        0.33799000,     0.337990000,     0.337990000
r,      12,        0.14441000,     0.144410000,     0.144410000
r,      13,        0.26889000,     0.268890000,     0.268890000
r,      14,        0.29011000,     0.290110000,     0.290110000
r,      15,        0.12733000,     0.127330000,     0.127330000
r,      16,        0.22386000,     0.223860000,     0.223860000
r,      17,        0.20990000,     0.209900000,     0.209900000
r,      18,        0.28620000,     0.286200000,     0.286200000
r,      19,        0.19358000,     0.193580000,     0.193580000
r,      20,        0.18737000,     0.187370000,     0.187370000
r,      21,        0.31366000,     0.313660000,     0.313660000
r,      22,        0.29736000,     0.297360000,     0.297360000
r,      23,        1.00000E09,     0.000000000,     0.000000000
r,      24,        1.00000E11,     0.000000000,     0.000000000

/com,----------------------------------------------------------------------------

/com, Nodes
/com,*******

n,       1,              0.00000000,      0.00000000,      0.00000000
n,       2,              0.00000000,     -6.00000000,      0.00000000
n,       3,              0.00000000,     -12.0000000,     -6.00000000
n,       4,              0.00000000,     -12.0000000,     -38.0400000
n,       5,              0.00000000,     -12.0000000,     -54.0000000
n,       6,              0.00000000,     -18.0000000,     -60.0000000
n,       7,              0.00000000,     -36.0000000,     -60.0000000
n,       8,              0.00000000,     -65.0400000,     -60.0000000
n,       9,              0.00000000,     -71.0400000,     -54.0000000
n,      10,              0.00000000,     -71.0400000,     -36.0000000
n,      11,              0.00000000,     -71.0400000,     -6.00000000
n,      12,             -6.00000000,     -71.0400000,      0.00000000
n,      13,             -21.9600000,     -71.0400000,      0.00000000
n,      14,             -57.9600000,     -71.0400000,      0.00000000
n,      15,             -117.000000,     -71.0400000,      0.00000000
n,      16,             -165.000000,     -71.0400000,      0.00000000
n,      17,             -139.680000,     -71.0400000,     -22.6800000
n,      18,             -141.000000,     -71.0400000,     -25.8600000
n,      19,             -141.000000,     -71.0400000,     -46.5600000
n,      20,             -141.000000,     -71.0400000,     -82.5600000
n,      21,             -141.000000,     -71.0400000,     -102.060000
n,      22,             -136.500000,     -71.0400000,     -106.560000
n,      23,             -122.460000,     -71.0400000,     -106.560000
n,      24,             -97.4400000,     -71.0400000,     -106.560000
n,      25,             -92.9400000,     -75.5400000,     -106.560000
n,      26,             -92.9400000,     -91.0800000,     -106.560000
n,      27,             -92.9400000,     -107.040000,     -106.560000
n,      28,             -213.000000,     -71.0400000,      0.00000000
n,      29,             -255.000000,     -71.0400000,      0.00000000
n,      30,             -259.080000,     -71.0400000,      0.00000000
n,      31,             -277.680000,     -71.0400000,     -22.6800000
n,      32,             -279.000000,     -71.0400000,     -25.8600000
n,      33,             -279.000000,     -71.0400000,     -46.5600000
n,      34,             -279.000000,     -71.0400000,     -82.5600000
n,      35,             -279.000000,     -71.0400000,     -102.060000
n,      36,             -274.500000,     -71.0400000,     -106.560000
n,      37,             -260.460000,     -71.0400000,     -106.560000
n,      38,             -235.440000,     -71.0400000,     -106.560000
n,      39,             -230.940000,     -75.5400000,     -106.560000
n,      40,             -230.940000,     -91.0800000,     -106.560000
n,      41,             -230.940000,     -107.040000,     -106.560000
n,      42,             -263.040000,     -71.0400000,      0.00000000
n,      43,             -315.000000,     -71.0400000,      0.00000000
n,      44,             -375.000000,     -71.0400000,      0.00000000
n,      45,             -412.500000,     -71.0400000,      0.00000000
n,      46,             -417.000000,     -71.0400000,     -4.50000000
n,      47,             -417.000000,     -71.0400000,     -18.1200000
```

```
n,      48,               -417.000000,     -71.0400000,     -78.1200000
n,      49,               -417.000000,     -71.0400000,     -102.180000
n,      50,               -412.500000,     -71.0400000,     -106.680000
n,      51,               -398.460000,     -71.0400000,     -106.680000
n,      52,               -373.440000,     -71.0400000,     -106.680000
n,      53,               -368.940000,     -75.5400000,     -106.680000
n,      54,               -368.940000,     -91.0800000,     -106.680000
n,      55,               -368.940000,     -107.040000,     -106.680000
n,      68,                0.00000000,     -6.00000000,     -6.00000000
n,      69,                0.00000000,     -18.0000000,     -54.0000000
n,      70,                0.00000000,     -65.0400000,     -54.0000000
n,      71,               -6.00000000,     -71.0400000,     -6.00000000
n,      72,               -136.500000,     -71.0400000,     -102.060000
n,      73,               -97.4400000,     -75.5400000,     -106.560000
n,      74,               -136.500000,     -71.0400000,     -25.8640000
n,      75,               -274.500000,     -71.0400000,     -102.060000
n,      76,               -235.440000,     -75.5400000,     -106.560000
n,      77,               -274.500000,     -71.0400000,     -25.8640000
n,      78,               -412.500000,     -71.0400000,     -4.50000000
n,      79,               -412.500000,     -71.0400000,     -102.180000
n,      80,               -373.440000,     -75.5400000,     -106.680000
n,     141,                0.00000000,     -37.0000000,     -60.0000000
n,     142,               -141.000000,     -72.0400000,     -82.5600000
n,     143,               -279.000000,     -72.0400000,     -82.5600000
n,     144,               -417.000000,     -72.0400000,     -78.1200000
n,     145,               -21.9600000,     -72.0400000,      0.00000000
n,     146,               -375.000000,     -72.0400000,      0.00000000
n,     147,               -93.9400000,     -107.040000,     -106.560000
n,     148,               -93.9400000,     -107.040000,     -106.560000
n,     149,               -92.9400000,     -108.040000,     -106.560000
n,     150,               -92.9400000,     -108.040000,     -106.560000
n,     151,               -92.9400000,     -107.040000,     -107.560000
n,     152,               -92.9400000,     -107.040000,     -107.560000
n,     153,               -214.000000,     -71.0400000,      0.00000000
n,     154,               -214.000000,     -71.0400000,      0.00000000
n,     155,               -213.000000,     -72.0400000,      0.00000000
n,     156,               -213.000000,     -72.0400000,      0.00000000
n,     157,               -213.000000,     -71.0400000,     -1.00000000
n,     158,               -213.000000,     -71.0400000,     -1.00000000
n,     159,               -231.940000,     -107.040000,     -106.560000
n,     160,               -231.940000,     -107.040000,     -106.560000
n,     161,               -230.940000,     -108.040000,     -106.560000
n,     162,               -230.940000,     -108.040000,     -106.560000
n,     163,               -230.940000,     -107.040000,     -107.560000
n,     164,               -230.940000,     -107.040000,     -107.560000
n,     165,               -369.940000,     -107.040000,     -106.680000
n,     166,               -369.940000,     -107.040000,     -106.680000
n,     167,               -368.940000,     -108.040000,     -106.680000
n,     168,               -368.940000,     -108.040000,     -106.680000
n,     169,               -368.940000,     -107.040000,     -107.680000
n,     170,               -368.940000,     -107.040000,     -107.680000

/com,---------------------------------------------------------------------------

/com, Material Properties
/com,*********************

mp,ex,1,2.7e7
mp,nuxy,1,.3

mp,ex,2,8.1e7
mp,nuxy,2,.3

/com,---------------------------------------------------------------------------

/com, Straight Pipe (Tangent Elements)
/com,**********************************

mat,1
type,1
real,2
en,1,1,2
```

```
en,3,3,4
en,6,6,7
en,7,7,8
en,9,9,10
en,10,10,11
en,13,13,14
en,27,16,28
en,41,30,42

/com,-----------------

mat,1
type,1
real,4
en,17,18,19
en,18,19,20
en,19,20,21
en,22,23,24
en,24,25,26
en,25,26,27
en,31,32,33
en,32,33,34
en,33,34,35
en,36,37,38
en,38,39,40
en,42,42,43
en,43,43,44
en,44,44,45
en,46,46,47
en,47,47,48
en,48,48,49
en,51,51,52
en,53,53,54

/com,-----------------

mat,1
type,5
real,2
en,14,14,15
en,15,15,16
en,28,28,29
en,29,29,30

/com,-----------------

mat,1
type,5
real,4
en,16,15,17
en,30,29,31

/com,-----------------

mat,2
type,1
real,4
en,25,26,27
en,39,40,41
en,54,54,55

/com,-----------------

mat,2
type,3
real,2
en,4,4,5
en,12,12,13

/com,-----------------

mat,2
```

```
type,3
real,4
en,21,22,23
en,35,36,37
en,50,50,51


/com, Pipe Bend Elements
/com,********************

mat,1
type,7
real,3
en,2,2,3,68
en,5,5,6,69
en,8,8,9,70
en,11,11,12,71

/com,-----------------

mat,1
type,7
real,5
en,20,21,22,72
en,23,24,25,73
en,26,17,18,74
en,34,35,36,75
en,37,38,39,76
en,40,31,32,77
en,45,45,46,78
en,49,49,50,79
en,52,52,53,80


/com, *Spring Elements*
/com,*******************

mat,1
type,10
real,1
en,141,7,141
en,142,20,142
en,143,34,143
en,144,48,144

/com,-----------------

mat,1
type,10
real,23
en,145,13,145
en,146,44,146
en,147,27,147
en,149,27,149
en,151,27,151
en,153,28,153
en,155,28,155
en,157,28,157
en,159,41,159
en,161,41,161
en,163,41,163
en,165,55,165
en,167,55,167
en,169,55,169

/com,-----------------

mat,1
type,11
real,24
en,148,27,148
en,150,27,150
```

```
en,152,27,152
en,154,28,154
en,156,28,156
en,158,28,158
en,160,41,160
en,162,41,162
en,164,41,164
en,166,55,166
en,168,55,168
en,170,55,170


/com, Mass Elements
/com,***************

type,9

real,6
en,67,4

real,7
en,68,7

real,8
en,69,10

real,9
en,70,13

real,10
en,71,14

real,11
en,72,15

real,12
en,73,19

real,13
en,74,20

real,14
en,75,23

real,15
en,76,26

real,16
en,77,16

real,17
en,78,28

real,18
en,79,29

real,12
en,80,33

real,11
en,81,34

real,14
en,82,37

real,15
en,83,40

real,19
en,84,43

real,20
```

```
en,85,44

real,20
en,86,47

real,21
en,87,48

real,22
en,88,51

real,15
en,89,54

/com,------------------------------------------------------------------------

/com, Constraints
/com,*************

d,1,all,0
d,141,all,0
d,142,all,0
d,143,all,0
d,144,all,0
d,145,all,0
d,146,all,0
d,147,all,0
d,148,all,0
d,149,all,0
d,150,all,0
d,151,all,0
d,152,all,0
d,153,all,0
d,154,all,0
d,155,all,0
d,156,all,0
d,157,all,0
d,158,all,0
d,159,all,0
d,160,all,0
d,161,all,0
d,162,all,0
d,163,all,0
d,164,all,0
d,165,all,0
d,166,all,0
d,167,all,0
d,168,all,0
d,169,all,0
d,170,all,0

allsel,all
save
finish

/com,------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,22
mxpand,,,,yes
solve
finish

/com,
/com,===========================
```

```
/com, Compare Modal Frequencies
/com,==========================
/com,

*dim,label,,22
*dim,freq_ans,,22
*dim,freq_exp,,22
*dim,freq_err,,22

*do,i,1,22
 label(i)=i
*enddo

*do,i,1,22
 *get,freq_ans(i),mode,i,freq
*enddo

*vfill,freq_exp,data,0.5034e+01,0.7813e+01,0.8193e+01,0.8977e+01,0.9312e+01,0.9895e+01,0.1322e+02
*vfill,freq_exp(8),data,0.1496e+02,0.1507e+02,0.1775e+02,0.1821e+02,0.2290e+02,0.2502e+02,0.2585e+02
*vfill,freq_exp(15),data,0.2694e+02,0.2813e+02,0.3030e+02,0.3522e+02,0.3710e+02,0.4261e+02,0.4442e+02
*vfill,freq_exp(22),data,0.4809e+02

*status,freq_ans
*status,freq_exp

*do,i,1,22
 freq_err(i)=abs(freq_ans(i)/freq_exp(i))
*enddo

*status,freq_err
save,table_1
finish

/com,--------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,sprs      ! Single Point Excitation Response Spectrum
dmprat,0.02      ! Constant Damping Ratio
grp,0.001      ! Group Modes based on Significance level
svtyp,2      ! Seismic Acceleration Response Loading

sed,1       ! Excitation in X direction
freq
freq,0.83,0.91,1,1.11,1.24,1.72,2,2.86,3.23
freq,5,6,7,7.8,8.2,9,9.3,10,100
sv,0.02,27.05,38.64,69.55,173.88,656.88,734.16,212.52,135.24,637.56
sv,0.02,329.5,236.4,169.9,129.0,111.54,81.26,71.25,50.23,50.23
solve

sed,,1      ! Excitation in Y direction
freq
freq,0.91,1.25,1.43,1.67,1.92,2.38,2.70,3.13,4.55
freq,5,6,7,7.8,8.2,9,9.3,10,100
sv,0.02,46.37,77.28,115.92,231.84,985.32,830.76,830.76,386.4,115.92
sv,0.02,109.48,98.75,91.08,86.36,84.35,80.86,79.70,77.28,77.28
solve

sed,,,1      ! Excitation in Z direction
freq
freq,0.83,0.91,1,1.11,1.24,1.72,2,2.86,3.23
freq,5,6,7,7.8,8.2,9,9.3,10,100
sv,0.02,27.05,38.64,69.55,173.88,656.88,734.16,212.52,135.24,637.56
sv,0.02,329.5,236.4,169.9,129.0,111.54,81.26,71.25,50.23,50.23
solve
fini
```

```
/com,----------------------------------------------------------------------------

/post1
/input,,mcom

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1

/com,------------------------

label2(1,1) = 'ux_8'
label2(1,2) = 'uy_8'
label2(1,3) = 'uz_11'
label2(1,4) = 'rotx_7'
label2(1,5) = 'roty_14'
label2(1,6) = 'rotz_50'

/com,----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,----------------------------------

/com, *=====================================================
/com, * Maximum nodal displacements and rotations comparsion
/com, *=======================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,8,U,X
*GET,AdisY,NODE,8,U,Y
*GET,AdisZ,NODE,11,U,Z
*GET,ArotX,NODE,7,ROT,X
*GET,ArotY,NODE,14,ROT,Y
*GET,ArotZ,NODE,50,ROT,Z

/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,0.84658E-01
*SET,EdisY,0.24339
*SET,EdisZ,0.34208
*SET,ErotX,0.57840E-02
*SET,ErotY,0.21064E-02
*SET,ErotZ,0.12406E-02

/com, Error computation
/com, ********************

ERdisX=ABS((AdisX)/(EdisX))
ERdisY=ABS((AdisY)/(EdisY))
ERdisZ=ABS((AdisZ)/(EdisZ))
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
```

```
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,-----------------------------------------------------------

/com, *========================================================
/com, * Element Forces and Moments Comparison
/com, *==========================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*dim,elem_res_I,,3,6
*dim,elem_res_J,,3,6

*dim,pxi,,3
*dim,vyi,,3
*dim,vzi,,3
*dim,txi,,3
*dim,myi,,3
*dim,mzi,,3

*dim,pxj,,3
*dim,vyj,,3
*dim,vzj,,3
*dim,txj,,3
*dim,myj,,3
*dim,mzj,,3

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6
```

```
*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #38
/com,*************

*get,pxi(2,1),elem,38,smisc,1
*get,vyi(2,1),elem,38,smisc,2
*get,vzi(2,1),elem,38,smisc,3
*get,txi(2,1),elem,38,smisc,4
*get,myi(2,1),elem,38,smisc,5
*get,mzi(2,1),elem,38,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com, Element #49
/com,*************

*get,pxi(3,1),elem,49,smisc,1
*get,vyi(3,1),elem,49,smisc,2
*get,vzi(3,1),elem,49,smisc,3
*get,txi(3,1),elem,49,smisc,4
*get,myi(3,1),elem,49,smisc,5
*get,mzi(3,1),elem,49,smisc,6

*vfill,elem_res_I(3,1),data,pxi(3,1)
*vfill,elem_res_I(3,2),data,vyi(3,1)
*vfill,elem_res_I(3,3),data,vzi(3,1)
*vfill,elem_res_I(3,4),data,txi(3,1)
*vfill,elem_res_I(3,5),data,myi(3,1)
*vfill,elem_res_I(3,6),data,mzi(3,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #38
/com,*************

*get,pxj(2,1),elem,38,smisc,7
*get,vyj(2,1),elem,38,smisc,8
*get,vzj(2,1),elem,38,smisc,9
*get,txj(2,1),elem,38,smisc,10
*get,myj(2,1),elem,38,smisc,11
```

```
*get,mzj(2,1),elem,38,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com, Element #49
/com,*************

*get,pxj(3,1),elem,49,smisc,7
*get,vyj(3,1),elem,49,smisc,8
*get,vzj(3,1),elem,49,smisc,9
*get,txj(3,1),elem,49,smisc,10
*get,myj(3,1),elem,49,smisc,11
*get,mzj(3,1),elem,49,smisc,12

*vfill,elem_res_J(3,1),data,pxj(3,1)
*vfill,elem_res_J(3,2),data,vyj(3,1)
*vfill,elem_res_J(3,3),data,vzj(3,1)
*vfill,elem_res_J(3,4),data,txj(3,1)
*vfill,elem_res_J(3,5),data,myj(3,1)
*vfill,elem_res_J(3,6),data,mzj(3,1)

/com,---------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,3,6
*dim,exp_J,,3,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,2.364e+02
*vfill,exp_I(1,2),data,8.072e+01
*vfill,exp_I(1,3),data,2.605e+02
*vfill,exp_I(1,4),data,4.947e+03
*vfill,exp_I(1,5),data,2.217e+04
*vfill,exp_I(1,6),data,2.106e+03

*vfill,exp_J(1,1),data,2.360e+02
*vfill,exp_J(1,2),data,8.072e+01
*vfill,exp_J(1,3),data,2.665e+02
*vfill,exp_J(1,4),data,4.947e+03
*vfill,exp_J(1,5),data,2.059e+04
*vfill,exp_J(1,6),data,1.656e+03

/com, Element #38
/com,*************

*vfill,exp_I(2,1),data,5.036e+01
*vfill,exp_I(2,2),data,2.762e+01
*vfill,exp_I(2,3),data,2.853e+01
*vfill,exp_I(2,4),data,4.820e+02
*vfill,exp_I(2,5),data,9.669e+01
*vfill,exp_I(2,6),data,1.625e+03

*vfill,exp_J(2,1),data,5.036e+01
*vfill,exp_J(2,2),data,2.762e+01
*vfill,exp_J(2,3),data,2.853e+01
*vfill,exp_J(2,4),data,4.620e+02
*vfill,exp_J(2,5),data,4.280e+02
*vfill,exp_j(2,6),data,1.796e+03

/com, Element #49
/com,*************

*vfill,exp_I(3,1),data,9.427e+01
```

```
*vfill,exp_I(3,2),data,3.529e+01
*vfill,exp_I(3,3),data,2.637e+01
*vfill,exp_I(3,4),data,2.354e+02
*vfill,exp_I(3,5),data,2.491e+03
*vfill,exp_I(3,6),data,4.466e+02

*vfill,exp_J(3,1),data,2.607e+01
*vfill,exp_J(3,2),data,3.529e+01
*vfill,exp_J(3,3),data,9.427e+01
*vfill,exp_J(3,4),data,4.692e+02
*vfill,exp_J(3,5),data,2.176e+03
*vfill,exp_J(3,6),data,1.340e+02

/com,-----------------------------------------------------------------------

/com, Error computation
/com, *********************

*dim,elem_error_I,,3,6
*dim,elem_error_J,,3,6
*dim,elem_tab,,36,3

/com,============
/com,   Node I
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,----------------------------------------------------------------------

*do,i,1,3
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+18
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3

/com,---------------------------------------------------------------------
/com,

/out,

/com
/com,-------------------vm-nr1677-01-7a Results Verification--------------------
/com,
```

```
/nopr
resume,table_1
/gopr

/out,vm-nr1677-1-7a-a,vrt
/com,
/com, =============================================
/com,    COMPARISON OF MODAL FREQUENCY
/com,   WITH EXPECTED RESULTS
/com, =============================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label(1),freq_exp(1),freq_ans(1),freq_err(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,'  ')

/com,

/com,-----------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr

/com,
/com,===================================================
/com,  COMPARISON OF MAXIMUM NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,===================================================
/com,

/com,   Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-----------------------------------------------------------------------

/nopr
resume,table_3
/gopr

/com,
/com,===================================================
/com,   COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,          WITH EXPECTED RESULTS
/com,===================================================
/com,

/com,---------------------------------------------------
/com, Note: 1. Element and Node Numbers are different
/com,     from that in the manual
/com,
/com,  2. Element Forces and Moments along Y & Z
/com,     directions are flipped between Mechanical APDL
/com,     and NRC results
```

```
/com,---------------------------------------------------

/com,   Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 38
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(25,1),elem_tab(25,2),elem_tab(25,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 49
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(31,1),elem_tab(31,2),elem_tab(31,3)
(1x,a5,'   ',f10.4,'  ',f10.4,'   ',f5.3)


/com,
/com,
/com,*******************************************************************
/com,*******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-1-7a-a,vrt
finish
```

vm-nr1677-2-1a-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-2-1a-a
/title,vm-nr1677-2-1a-a,NRC piping benchmarks problems,Volume II,Problem 1a
```

```
/com, ******************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com,  Elements used: Pipe16, Pipe18, Combin14
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, **********************************************************************************

/out,scratch

/PREP7
YoungModulus1 = .258e+8                          ! Young's Modulus
Nu = 0.3                                         ! Poissons ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu))         ! Shear Modulus
WMass=1.042868e-03                               ! Density
WTick=0.216                                      ! Wall Thickness
OD=3.5                                           ! Outer Diameter
RADCUR=48.003                                    ! Radius curvature
temp=60                                          ! Temperature
maxm=15                                          ! Number of modes to extract


et,1,pipe16                                      ! Straight pipe elements
et,2,pipe18                                      ! Curved pipe elements
et,3,combin14                                ! Spring-damper elements
keyopt,3,2,1                                     ! UX Degree Of Freedom
et,4,combin14,                                   ! Spring-damper elements
keyopt,4,2,2                                     ! UY Degree Of Freedom
et,5,combin14                                ! Spring-damper elements
keyopt,5,2,3                                     ! UZ Degree Of Freedom
et,6,combin14                                    ! Spring-damper elements
keyopt,6,2,1                                     ! UX Degree Of Freedom
et,7,combin14                                    ! Spring-damper elements
keyopt,7,2,2                                     ! UY Degree Of Freedom


/com,
/com, Real Constants
/com,****************

r,1,OD,WTick
r,2,OD,WTick,RADCUR
r,3,0.2e+8                                       ! Stiffness
r,4,0.2e+8                                       ! Stiffness
r,5,0.2e+8                                       ! Stiffness
r,6,0.2e+5                                       ! Stiffness
r,7,0.2e+5                                       ! Stiffness


/com,----------------------------------------------------------------------------

/com,
/com, Material Properties
/com,********************

mp,ex,1,YoungModulus1
mp,nuxy,1,Nu
mp,gxy,1,ShearModulus1
mp,dens,1,WMass

mp,ex,2,YoungModulus1
mp,nuxy,2,Nu
mp,gxy,2,ShearModulus1
```

```
mp,dens,2,WMass

/com,----------------------------------------------------------------------------

/com, Nodes
/com,********

n,1,0,0,0
n,2,0,12,0
n,3,35.687,60,32.110
n,4,55,60,49.5
n,5,74.329,60,66.882
n,6,110,12,99
n,7,110,0,99
n,8,110,-24,99,
n,9,110,-48,99,
n,10,110,-72,99
n,11,110,-96,99
n,12,110,-120,99
n,13,110,-144,99
n,14,110,-168,99
n,15,110,-198,99
n,16,110,-228,99
n,17,110,-252,99
n,18,110,-276,99
n,19,110,-300,99
n,20,110,-324,99
n,21,99.6,-349.4,99
n,22,89.2,-374.8,99
n,23,78.8,-400,99
n,24,68.4,-425.6,99
n,25,58,-451,99
n,26,58,-475,99
n,27,58,-487,99
n,28,103.537,-535,114.179
n,29,124.269,-535,121.1
n,30,145,-535,128
n,31,184.975,-535,123.615
n,32,214.8,-536,102.8
n,33,254.585,-535,81.849
n,34,279.312,-535,75
n,35,331,-535,75
n,36,383,-535,75

/com,
/com, Elastic support Nodes
/com,**********************

n,37,10,0,0
n,38,0,10,0
n,39,0,0,10
n,40,55,70,49.5
n,41,110,0,109
n,42,120,0,99
n,43,110,-168,109
n,44,120,-168,109
n,45,110,-324,109
n,46,120,-324,99
n,47,58,-475,109
n,48,68,-475,99
n,49,103.537,-545,114.179
n,50,103.537,-535,104.179
n,51,393,-535,75
n,52,383,-545,75
n,53,383,-535,85

/com,----------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,**********************************
```

```
mat,1        ! Material ID 1
type,1       ! Element Type 1
real,1       ! Real Constant 1

e, 1, 2
e, 3, 4
e, 4, 5
e, 6, 7
e, 7, 8
e, 8, 9
e, 9,10
e,10,11
e,11,12
e,12,13
e,13,14
e,14,15
e,15,16
e,16,17
e,17,18
e,18,19
e,19,20
e,20,21
e,21,22
e,22,23
e,23,24
e,24,25
e,25,26
e,26,27
e,28,29
e,29,30
e,31,32
e,32,33
e,34,35
e,35,36

/com,
/com, Pipe Bend Elements
/com,********************

mat,2
type,2
real,2

e,2,3,4
e,5,6,4
e,27,28,26
e,30,31,29
e,33,34,32


/com, Elastic supports and anchors
/com,******************************

/com, rotate nodes with less than 3 supports
/com,

wplane,,nx(4),ny(4),nz(4),nx(40),ny(40),nz(40),nx(3),ny(3),nz(3)
cswplane,11,0
nrotat,4
nrotat,40
csys,0

wplane,,nx(7),ny(7),nz(7),nx(41),ny(41),nz(41),nx(42),ny(42),nz(42)
cswplane,12,0
nrotat,7
nrotat,41,42
csys,0

wplane,,nx(14),ny(14),nz(14),nx(43),ny(43),nz(43),nx(44),ny(44),nz(44)
cswplane,13,0
nrotat,14
nrotat,43,44
```

```
csys,0

wplane,,nx(20),ny(20),nz(20),nx(45),ny(45),nz(45),nx(46),ny(46),nz(46)
cswplane,14,0
nrotat,20
nrotat,45,46
csys,0

wplane,,nx(26),ny(26),nz(26),nx(47),ny(47),nz(47),nx(48),ny(48),nz(48)
cswplane,15,0
nrotat,26
nrotat,47,48
csys,0

wplane,,nx(28),ny(28),nz(28),nx(49),ny(49),nz(49),nx(50),ny(50),nz(50)
cswplane,16,0
nrotat,28
nrotat,49,50
csys,0

type,3
real,3
e,1,37
e,36,51
e,4,40
e,7,41
e,26,47
e,28,49

type,4
real,4
e,1,38
e,36,52
e,7,42
e,26,48
e,28,50

type,5
real,5
e,1,39
e,36,53

type,6
real,6
e,14,43
e,20,45

type,7
real,7
e,14,44
e,20,46

/com,------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,,node,,37,53
d,all,all
allsel

d,1,rotx,,,,,roty,rotz
d,36,rotx,,,,,roty,rotz
allsel,all
fini

/com,------------------------------------------------------------------------------

/com
/com,==============
/com, Modal solve
```

```
/com,==============
/com,

/solution
antype,modal       ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on        ! Use Lumped Mass Approximation
mxpand,maxm,,,yes       ! Expand solution with Element Calculations ON
solve

/com,========================
/com, Frequency Comparison
/com,========================

*dim,Amode,ARRAY,maxm
*dim,Emode,ARRAY,maxm
*dim,ERmode,ARRAY,maxm
*dim,moden,ARRAY,maxm

*do,i,1,maxm
 *GET, Amode(i), MODE, i, FREQ
*enddo
*VFILL,Emode,DATA,6.042,6.256,7.76,8.943,12.444,12.83,14.303,15.486,16.371,18.543
*VFILL,Emode(11),DATA,19.499,23.243,24.105,32.636,33.837

*do,i,1,maxm
  ERmode(i)=ABS((Amode(i))/(Emode(i)))
  moden(i)=i
*enddo

save,table_1

finish

/com,-------------------------------------------------------------------------------

/com,
/com,==================
/com, Spectrum solve
/com,==================
/com,

/solution
antype,spectrum       ! Perform Spectrum Analysis
spopt,sprs,15       ! Single Point Excitation Response Spectrum
srss,0.0        ! SRSS mode combination

gval = 386.4

svtyp, 2, gval
freq, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83,  23.25,  29.41
sv,,  2.275, 2.275,  1.0,    0.8,  0.925,  0.925,   0.8 ,   1.0 ,    1.0
freq,  34.48
sv,,   0.875
sed,1,0,0        ! Excitation in X direction
SOLVE

svtyp, 2, gval
freq
freq, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83,  23.25,  29.41
sv,, 1.517, 1.517, 0.667,  0.534,  0.617,  0.617,   0.534, 0.667,  0.667
freq,  34.48
sv,,   0.584
sed,0,1,0        ! Excitation in Y direction
SOLVE
fini

/com,-------------------------------------------------------------------------------

/post1
/input,,mcom
```

```
/com,--------------------------------------------------------------------------------

/com, Labels
/com,********

*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1
*dim,label5,char,5,1

/com,-------------------------

label2(1,1) = 'ux_5'
label2(1,2) = 'uy_33'
label2(1,3) = 'uz_15'
label2(1,4) = 'rotx_32'
label2(1,5) = 'roty_32'
label2(1,6) = 'rotz_5'

/com,-------------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,-------------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,-------------------------

label5(1,1)='38'
label5(2,1)='40'
label5(3,1)='46'
label5(4,1)='50'
label5(5,1)='53'


/com,--------------------------------------------------------------------------------


/com, *========================================================
/com, * Maximum nodal displacements and rotations comparison
/com, *==========================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,5,U,X
*GET,AdisY,NODE,33,U,Y
*GET,AdisZ,NODE,15,U,Z
*GET,ArotX,NODE,32,ROT,X
*GET,ArotY,NODE,32,ROT,Y
*GET,ArotZ,NODE,5,ROT,Z

/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,5.86080e-02
*SET,EdisY,1.12744e-01
*SET,EdisZ,1.02848e-02
*SET,ErotX,1.46853e-03
*SET,ErotY,1.09722e-03
*SET,ErotZ,1.27548e-03
```

```
/com, Error computation
/com, ********************

ERdisX=ABS((AdisX)/(EdisX))
ERdisY=ABS((AdisY)/(EdisY))
ERdisZ=ABS((AdisZ)/(EdisZ))
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,-----------------------------------------------------------

/com, *=========================================================
/com, * Element Forces and Moments Comparison
/com, *===========================================================

/com, Solution obtained from Mechanical APDL
/com, ***************************

*dim,elem_res_I,,2,6
*dim,elem_res_J,,2,6

*dim,pxi,,2
*dim,vyi,,2
*dim,vzi,,2
*dim,txi,,2
*dim,myi,,2
*dim,mzi,,2

*dim,pxj,,2
*dim,vyj,,2
*dim,vzj,,2
*dim,txj,,2
*dim,myj,,2
*dim,mzj,,2

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========
```

```
/com, Element #30
/com,************************

*get,pxi(1,1),elem,30,smisc,1
*get,vyi(1,1),elem,30,smisc,2
*get,vzi(1,1),elem,30,smisc,3
*get,txi(1,1),elem,30,smisc,4
*get,myi(1,1),elem,30,smisc,5
*get,mzi(1,1),elem,30,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #33
/com,*************************

*get,pxi(2,1),elem,33,smisc,1
*get,vyi(2,1),elem,33,smisc,2
*get,vzi(2,1),elem,33,smisc,3
*get,txi(2,1),elem,33,smisc,4
*get,myi(2,1),elem,33,smisc,5
*get,mzi(2,1),elem,33,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #30
/com,************************

*get,pxj(1,1),elem,30,smisc,7
*get,vyj(1,1),elem,30,smisc,8
*get,vzj(1,1),elem,30,smisc,9
*get,txj(1,1),elem,30,smisc,10
*get,myj(1,1),elem,30,smisc,11
*get,mzj(1,1),elem,30,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #33
/com,************************

*get,pxj(2,1),elem,33,smisc,7
*get,vyj(2,1),elem,33,smisc,8
*get,vzj(2,1),elem,33,smisc,9
*get,txj(2,1),elem,33,smisc,10
*get,myj(2,1),elem,33,smisc,11
*get,mzj(2,1),elem,33,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)
```

```
allsel,all

/com,--------------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,2,6
*dim,exp_J,,2,6

/com, Element #35
/com,*************

*vfill,exp_I(1,1),data,1.199e+02
*vfill,exp_I(1,2),data,5.663e+01
*vfill,exp_I(1,3),data,5.595e+01
*vfill,exp_I(1,4),data,5.958e+02
*vfill,exp_I(1,5),data,6.750e+02
*vfill,exp_I(1,6),data,6.062e+02

*vfill,exp_J(1,1),data,1.199e+02
*vfill,exp_J(1,2),data,5.663e+01
*vfill,exp_J(1,3),data,5.595e+01
*vfill,exp_J(1,4),data,5.958e+02
*vfill,exp_J(1,5),data,2.685e+03
*vfill,exp_J(1,6),data,3.329e+03

/com, Element #27
/com,*************

*vfill,exp_I(2,1),data,1.837e+02
*vfill,exp_I(2,2),data,2.674e+01
*vfill,exp_I(2,3),data,1.204e+02
*vfill,exp_I(2,4),data,2.658e+02
*vfill,exp_I(2,5),data,1.308e+03
*vfill,exp_I(2,6),data,3.982e+02

*vfill,exp_J(2,1),data,1.204e+02
*vfill,exp_J(2,2),data,2.674e+01
*vfill,exp_J(2,3),data,1.837e+02
*vfill,exp_J(2,4),data,1.123e+03
*vfill,exp_J(2,5),data,3.095e+03
*vfill,exp_J(2,6),data,1.496e+03

/com,-------------------------------------------------------------------------------

/com, Error computation
/com, *********************

*dim,elem_error_I,,2,6
*dim,elem_error_J,,2,6
*dim,elem_tab,,24,3

/com,============
/com,   Node I
/com,============

*do,i,1,2
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,2
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
```

```
*enddo

/com,-------------------------------------------------------------------------

*do,i,1,2
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+12
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3

/com,-----------------------------------------------------------------------------------


/com, *****************************
/com,  Reaction forces comparision
/com, ******************************

*dim,rf_tab,,5,3

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,RFA38,NODE,38,RF,FY
*GET,RFA40,NODE,40,RF,FX
*GET,RFA46,NODE,46,RF,FY
*GET,RFA50,NODE,50,RF,FY
*GET,RFA53,NODE,53,RF,FZ

/com, Expected results from NRC manual
/com, *********************************

*SET,RFE38,107
*SET,RFE40,234
*SET,RFE46,78
*SET,RFE50,89
*SET,RFE53,56

/com, Error computation
/com, *********************

ER38=ABS(RFA38/RFE38)
ER40=ABS(RFA40/RFE40)
ER46=ABS(RFA46/RFE46)
ER50=ABS(RFA50/RFE50)
ER53=ABS(RFA53/RFE53)

*vfill,rf_tab(1,1),data,RFE38
*vfill,rf_tab(1,2),data,RFA38
*vfill,rf_tab(1,3),data,ER38

*vfill,rf_tab(2,1),data,RFE40
*vfill,rf_tab(2,2),data,RFA40
*vfill,rf_tab(2,3),data,ER40

*vfill,rf_tab(3,1),data,RFE46
*vfill,rf_tab(3,2),data,RFA46
*vfill,rf_tab(3,3),data,ER46

*vfill,rf_tab(4,1),data,RFE50
```

```
*vfill,rf_tab(4,2),data,RFA50
*vfill,rf_tab(4,3),data,ER50

*vfill,rf_tab(5,1),data,RFE53
*vfill,rf_tab(5,2),data,RFA53
*vfill,rf_tab(5,3),data,ER53

save,table_4
/com,

/com,
/com, --------------------vm-nr1677-2-1a-a Results Verification---------------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-2-1a-a,vrt

/com, ===========================================
/com,  COMPARISON OF MODAL FREQUENCY
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*VWRITE,moden(1),Emode(1),Amode(1),ERmode(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,' ')

/com,

/com,-------------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr

/com,
/com, ============================================================
/com,  COMPARISON OF NODAL DISPLACEMENTS AND ROTATIONS
/com,    WITH EXPECTED RESULTS
/com, ============================================================
/com,

/com,  Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,--------------------------------------------------------------------------
/com,

/nopr
resume,table_4
/gopr
```

```
/com,
/com, ===========================================
/com,  COMPARISON OF REACTION FORCES
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com,  Node| Expected |  Mechanical APDL  |  Ratio
/com,

*vwrite,label5(1,1),rf_tab(1,1),rf_tab(1,2),rf_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-----------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,==============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,==============================================
/com,

/com,-----------------------------------------------
/com, Note: Element Forces and Moments for some elements
/com,       along Y & Z directions are flipped between Mechanical APDL
/com,  and NRC results
/com,
/com,       Element numbers from Mechanical APDL and NRC are
/com,       different.
/com,       Element 1 (Mechanical APDL) = Element 1 (NRC)
/com,       Element 30 (Mechanical APDL) = Element 35 (NRC)
/com,       Element 33 (Mechanical APDL) = Element 27 (NRC)
/com,-----------------------------------------------
/com,  Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 35
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 27
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
```

```
/com,
/com,
/com,*******************************************************************
/com,*******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-2-1a-a,vrt
finish
```

vm-nr1677-2-1b-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-2-1b-a
/title,vm-nr1677-2-1b-a,NRC piping benchmarks problems,Volume II, Problem 1b

/com, ***************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com, Elements used: Pipe16, Pipe18, Combin14
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, *******************************************************************************

/out,scratch

/prep7
YoungModulus1 = .258e+8                         ! Young's Modulus
Nu = 0.3                                        ! Poissons ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu))        ! Shear Modulus
WMass=1.042868e-03                              ! Density
WTick=0.216                                     ! Wall Thickness
OD=3.5                                          ! Outer Diameter
RADCUR=48.003                                   ! Radius curvature
temp=80                                         ! Temperature
maxm=15                                         ! Number of modes to extract

et,1,pipe16       ! Element 1 - PIPE16
et,2,pipe18       ! Element 2 - PIPE18
et,3,combin14      ! Element 3 - COMBIN14
keyopt,3,2,1      ! UX Degree of Freedom
et,4,combin14      ! Element 4 - COMBIN14
keyopt,4,2,2      ! UY Degree of Freedom
et,5,combin14      ! Element 5 - COMBIN14
keyopt,5,2,3      ! UZ Degree of Freedom
et,6,combin14      ! Element 6 - COMBIN14
keyopt,6,2,1      ! UX Degree of Freedom
et,7,combin14      ! Element 7 - COMBIN14
keyopt,7,2,2      ! UY Degree of Freedom

/com,------------------------------------------------------------------------------------

/com, Real Constants
/com,****************

r,1,od,Wtick      ! Real Constant Set 1
r,2,od,Wtick,RADCUR
```

```
r,3,0.2e+8
r,4,0.2e+8
r,5,0.2e+8
r,6,0.2e+5
r,7,0.2e+5

/com,------------------------------------------------------------------------------------

/com, Material Properties
/com,********************

mp,ex,1,YoungModulus1
mp,nuxy,1,Nu
mp,gxy,1,ShearModulus1
mp,dens,1,WMass

mp,ex,2,YoungModulus1
mp,nuxy,2,Nu
mp,gxy,2,ShearModulus1
mp,dens,2,WMass

/com,------------------------------------------------------------------------------------

/com, Nodes
/com,*******

n,1,0,0,0
n,2,0,12,0
n,3,35.687,60,32.110
n,4,55,60,49.5
n,5,74.329,60,66.882
n,6,110,12,99
n,7,110,0,99
n,8,110,-24,99,
n,9,110,-48,99,
n,10,110,-72,99
n,11,110,-96,99
n,12,110,-120,99
n,13,110,-144,99
n,14,110,-168,99
n,15,110,-198,99
n,16,110,-228,99
n,17,110,-252,99
n,18,110,-276,99
n,19,110,-300,99
n,20,110,-324,99
n,21,99.6,-349.4,99
n,22,89.2,-374.8,99
n,23,78.8,-400,99
n,24,68.4,-425.6,99
n,25,58,-451,99
n,26,58,-475,99
n,27,58,-487,99
n,28,103.537,-535,114.179
n,29,124.269,-535,121.1
n,30,145,-535,128
n,31,184.975,-535,123.615
n,32,214.8,-536,102.8
n,33,254.585,-535,81.849
n,34,279.312,-535,75
n,35,331,-535,75
n,36,383,-535,75

/com,
/com, Elastic Support Nodes
/com,**********************

n,37,10,0,0
n,38,0,10,0
n,39,0,0,10
n,40,55,70,49.5
n,41,110,0,109
```

```
n,42,120,0,99
n,43,110,-168,109
n,44,120,-168,109
n,45,110,-324,109
n,46,120,-324,99
n,47,58,-475,109
n,48,68,-475,99
n,49,103.537,-545,114.179
n,50,103.537,-535,104.179
n,51,393,-535,75
n,52,383,-545,75
n,53,383,-535,85

/com,------------------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,**********************************

mat,1        ! Material ID 1
type,1       ! Element Type 1
real,1       ! Real Constant 1

e, 1, 2
e, 3, 4
e, 4, 5
e, 6, 7
e, 7, 8
e, 8, 9
e, 9,10
e,10,11
e,11,12
e,12,13
e,13,14
e,14,15
e,15,16
e,16,17
e,17,18
e,18,19
e,19,20
e,20,21
e,21,22
e,22,23
e,23,24
e,24,25
e,25,26
e,26,27
e,28,29
e,29,30
e,31,32
e,32,33
e,34,35
e,35,36

/com,
/com, Pipe Bend Elements
/com,********************

mat,2
type,2
real,2

e,2,3,4
e,5,6,4
e,27,28,26
e,30,31,29
e,33,34,32

/com,
/com, Elastic Supports and Anchors
/com,******************************
```

```
! rotate nodes with less than 3 supports
wplane,,nx(4),ny(4),nz(4),nx(40),ny(40),nz(40),nx(3),ny(3),nz(3)
cswplane,11,0
nrotat,4
nrotat,40
csys,0

wplane,,nx(7),ny(7),nz(7),nx(41),ny(41),nz(41),nx(42),ny(42),nz(42)
cswplane,12,0
nrotat,7
nrotat,41,42
csys,0

wplane,,nx(14),ny(14),nz(14),nx(43),ny(43),nz(43),nx(44),ny(44),nz(44)
cswplane,13,0
nrotat,14
nrotat,43,44
csys,0

wplane,,nx(20),ny(20),nz(20),nx(45),ny(45),nz(45),nx(46),ny(46),nz(46)
cswplane,14,0
nrotat,20
nrotat,45,46
csys,0

wplane,,nx(26),ny(26),nz(26),nx(47),ny(47),nz(47),nx(48),ny(48),nz(48)
cswplane,15,0
nrotat,26
nrotat,47,48
csys,0

wplane,,nx(28),ny(28),nz(28),nx(49),ny(49),nz(49),nx(50),ny(50),nz(50)
cswplane,16,0
nrotat,28
nrotat,49,50
csys,0

type,3
real,3
e,1,37
e,36,51
e,4,40
e,7,41
e,26,47
e,28,49

type,4
real,4
e,1,38
e,36,52
e,7,42
e,26,48
e,28,50

type,5
real,5
e,1,39
e,36,53

type,6
real,6
e,14,43
e,20,45

type,7
real,7
e,14,44
e,20,46

/com,
/com, Constraints
/com,*************
```

```
nsel,,node,,37,53
d,all,all
allsel
d,1,rotx,,,,,roty,rotz
d,36,rotx,,,,,roty,rotz

save
finish

/com,------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal      ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on       ! Use Lumped Mass Matrix Approximation
mxpand,maxm,,,yes      ! Expand Solution with Element Calculations ON
solve
save

/com,------------------------------------------------------------------------------------

/com,
/com,===========================
/com, Compare Modal Frequencies
/com,===========================
/com,

*dim,Amode,ARRAY,maxm
*dim,Emode,ARRAY,maxm
*dim,ERmode,ARRAY,maxm
*dim,moden,ARRAY,maxm

*do,i,1,maxm
 *GET, Amode(i), MODE, i, FREQ
*enddo

*VFILL,Emode,DATA,6.042,6.256,7.76,8.943,12.444,12.83,14.303,15.486,16.371,18.543
*VFILL,Emode(11),DATA,19.499,23.243,24.105,32.636,33.837

*do,i,1,maxm
  ERmode(i)=ABS(Amode(i)/Emode(i))
  moden(i)=i
*enddo

save,table_1
finish

/com,------------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,mprs,15     ! Multi Point Excitation Response Spectrum

gval = 386.4

/com,
/com, spectrum 1 (group 1 - upperLevel - X)
/com,**************************************
```

```
spunit,1,accg, gval
spfrq,1, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83
spval,1,,  2.275, 2.275,  1.0,    0.8,  0.925,  0.925,   0.8
spfrq,1,  23.25,  29.41,  34.48
spval,1,,    1.0 ,    1.0, 0.875

/com,
/com, spectrum 2 (group 1 - upperLevel - Y=0.667X)
/com,**********************************************

spunit,2,accg, gval
spfrq,2, 2.5  , 5.0  ,   8.0,  12.35,  13.51,  16.95,  20.83
spval,2,,  1.517, 1.517, 0.667,  0.534,  0.617,  0.617,   0.534
spfrq,2,  23.25,  29.41,  34.48
spval,2,,  0.667 ,  0.667,  0.584

/com,
/com, spectrum 3 (group 2 - lowerLevel - X)
/com,***************************************

spunit, 3,accg, gval
spfrq,3, 3.0  , 4.0  ,  7.0,  12.5,   14.1,  15.87,  21.74
spval,3,,  1.4  , 1.4  , 0.75, 0.875,    0.7,    0.7,   0.8
spfrq,3,  23.25,  27.03,  31.25, 34.48
spval,3,,    0.75,   0.75,    0.7,  0.6

/com,
/com, spectrum 4 (group 2 - lowerLevel - Y=0.667X)
/com,**********************************************

spunit,4,accg, gval
spfrq,4, 3.0  , 4.0  ,  7.0,  12.5,   14.1,  15.87,  21.74
spval,4,,  0.934, 0.934, 0.5 , 0.584,  0.467, 0.467,  0.534
spfrq,4,  23.25,  27.03,  31.25, 34.48
spval,4,,    0.5,     0.5,  0.467,  0.4

/com,
/com, node components for excitation points
/com,***************************************

nsel,,node,,37,42
cm,upperLevel,node
allsel
nsel,,node,,43,53
cm,lowerLevel,node
allsel

/com, -- upper level - spectrum 1
d,37,ux,1,,39
d,41,uy,1,,42
pfact,1
d,upperLevel,all,0

/com, -- upper level - spectrum 2
d,37,uy,1,,39
d,40,ux,1
d,41,uz,1,,42
pfact,2
d,upperLevel,all,0

/com, -- lower level - spectrum 3
d,43,uy,1,,48
d,49,uz,1,,50
d,51,ux,1,,53
pfact,3
d,lowerLevel,all,0

/com, -- lower level - spectrum 4
d,43,uz,1,,48
d,49,ux,-1,,50
d,51,uy,1,,53
pfact,4
```

```
d,lowerLevel,all,0

srss,0.0      ! Combine modes using SRSS mode combination
solve

finish

/com,------------------------------------------------------------------------------------

/post1
/input,,mcom

/com,----------------------------------

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1
*dim,label5,char,5,1

/com,------------------------

label2(1,1) = 'ux_5'
label2(1,2) = 'uy_32'
label2(1,3) = 'uz_32'
label2(1,4) ='rotx_5'
label2(1,5) ='roty_30'
label2(1,6) ='rotz_30'

/com,----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,------------------------

label5(1,1)='37'
label5(2,1)='43'
label5(3,1)='47'
label5(4,1)='50'
label5(5,1)='53'

/com,----------------------------------

/com,------------------------------------------------------------------------------------

/com,
/com,=====================================================
/com, Maximum nodal displacements and rotations comparsion
/com,=====================================================
/com,

/com, Solution obtained from Mechanical APDL
/com, ***************************

*GET,AdisX,NODE,5,U,X
*GET,AdisY,NODE,32,U,Y
*GET,AdisZ,NODE,32,U,Z
*GET,ArotX,NODE,5,ROT,X
```

```
*GET,ArotY,NODE,30,ROT,Y
*GET,ArotZ,NODE,30,ROT,Z

/com,
/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,7.83074e-02
*SET,EdisY,1.89857e-01
*SET,EdisZ,1.98692e-01
*SET,ErotX,1.50690e-03
*SET,ErotY,2.22876e-03
*SET,ErotZ,2.05115e-03

/com,
/com, Error computation
/com,*******************

ERdisX=ABS(AdisX/EdisX)
ERdisY=ABS(AdisY/EdisY)
ERdisZ=ABS(AdisZ/EdisZ)
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,------------------------------------------------------------------------------------

/com, *=====================================================
/com, * Element Forces and Moments Comparison
/com, *=======================================================

/com, Solution obtained from Mechanical APDL
/com, ***************************

*dim,elem_res_I,,3,6
*dim,elem_res_J,,3,6

*dim,pxi,,3
*dim,vyi,,3
*dim,vzi,,3
*dim,txi,,3
*dim,myi,,3
*dim,mzi,,3
```

```
*dim,pxj,,3
*dim,vyj,,3
*dim,vzj,,3
*dim,txj,,3
*dim,myj,,3
*dim,mzj,,3

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #30
/com,*************

*get,pxi(2,1),elem,30,smisc,1
*get,vyi(2,1),elem,30,smisc,2
*get,vzi(2,1),elem,30,smisc,3
*get,txi(2,1),elem,30,smisc,4
*get,myi(2,1),elem,30,smisc,5
*get,mzi(2,1),elem,30,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com, Element #33
/com,*************

*get,pxi(3,1),elem,33,smisc,1
*get,vyi(3,1),elem,33,smisc,2
*get,vzi(3,1),elem,33,smisc,3
*get,txi(3,1),elem,33,smisc,4
*get,myi(3,1),elem,33,smisc,5
*get,mzi(3,1),elem,33,smisc,6

*vfill,elem_res_I(3,1),data,pxi(3,1)
*vfill,elem_res_I(3,2),data,vyi(3,1)
*vfill,elem_res_I(3,3),data,vzi(3,1)
*vfill,elem_res_I(3,4),data,txi(3,1)
*vfill,elem_res_I(3,5),data,myi(3,1)
*vfill,elem_res_I(3,6),data,mzi(3,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************
```

```
*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #30
/com,*************

*get,pxj(2,1),elem,30,smisc,7
*get,vyj(2,1),elem,30,smisc,8
*get,vzj(2,1),elem,30,smisc,9
*get,txj(2,1),elem,30,smisc,10
*get,myj(2,1),elem,30,smisc,11
*get,mzj(2,1),elem,30,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com, Element #33
/com,*************

*get,pxj(3,1),elem,33,smisc,7
*get,vyj(3,1),elem,33,smisc,8
*get,vzj(3,1),elem,33,smisc,9
*get,txj(3,1),elem,33,smisc,10
*get,myj(3,1),elem,33,smisc,11
*get,mzj(3,1),elem,33,smisc,12

*vfill,elem_res_J(3,1),data,pxj(3,1)
*vfill,elem_res_J(3,2),data,vyj(3,1)
*vfill,elem_res_J(3,3),data,vzj(3,1)
*vfill,elem_res_J(3,4),data,txj(3,1)
*vfill,elem_res_J(3,5),data,myj(3,1)
*vfill,elem_res_J(3,6),data,mzj(3,1)

/com,---------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,3,6
*dim,exp_J,,3,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,9.271e+01
*vfill,exp_I(1,2),data,8.643e+01
*vfill,exp_I(1,3),data,8.150e+01
*vfill,exp_I(1,4),data,1.318e+03
*vfill,exp_I(1,5),data,2.885e+03
*vfill,exp_I(1,6),data,2.775e+03

*vfill,exp_J(1,1),data,9.271e+01
*vfill,exp_J(1,2),data,8.643e+01
*vfill,exp_J(1,3),data,8.150e+01
*vfill,exp_J(1,4),data,1.318e+03
*vfill,exp_J(1,5),data,2.041e+03
```

```
*vfill,exp_J(1,6),data,1.907e+03

/com, Element #35
/com,*************

*vfill,exp_I(2,1),data,8.420e+01
*vfill,exp_I(2,2),data,6.672e+01
*vfill,exp_I(2,3),data,7.427e+01
*vfill,exp_I(2,4),data,4.313e+02
*vfill,exp_I(2,5),data,1.169e+03
*vfill,exp_I(2,6),data,1.119e+03

*vfill,exp_J(2,1),data,8.420e+01
*vfill,exp_J(2,2),data,6.672e+01
*vfill,exp_J(2,3),data,7.427e+01
*vfill,exp_J(2,4),data,4.313e+02
*vfill,exp_J(2,5),data,4.724e+03
*vfill,exp_j(2,6),data,4.484e+03

/com, Element #27
/com,*************

*vfill,exp_I(3,1),data,1.217e+02
*vfill,exp_I(3,2),data,3.001e+01
*vfill,exp_I(3,3),data,9.072e+01
*vfill,exp_I(3,4),data,5.562e+02
*vfill,exp_I(3,5),data,1.036e+03
*vfill,exp_I(3,6),data,9.892e+02

*vfill,exp_J(3,1),data,9.072e+01
*vfill,exp_J(3,2),data,3.001e+01
*vfill,exp_J(3,3),data,1.217e+02
*vfill,exp_J(3,4),data,7.557e+02
*vfill,exp_J(3,5),data,2.681e+03
*vfill,exp_J(3,6),data,1.948e+03

/com,-----------------------------------------------------------------------

/com, Error computation
/com, ********************

*dim,elem_error_I,,3,6
*dim,elem_error_J,,3,6
*dim,elem_tab,,36,3

/com,============
/com,   Node I
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,----------------------------------------------------------------------

*do,i,1,3
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
```

```
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+18
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3

/com,------------------------------------------------------------------------------------

/com,*****************************
/com, Reaction forces comparision
/com,******************************

*dim,rf_tab,,5,3

/com, Solution obtained from Mechanical APDL
/com,******************************

*GET,RFA37,NODE,37,RF,FX
*GET,RFA43,NODE,43,RF,FX
*GET,RFA47,NODE,47,RF,FX
*GET,RFA50,NODE,50,RF,FY
*GET,RFA53,NODE,53,RF,FZ

/com, Expected results from NRC manual
/com,**********************************

*SET,RFE37,86
*SET,RFE43,34
*SET,RFE47,53
*SET,RFE50,95
*SET,RFE53,74

/com, Error computation
/com,*******************

ER37=ABS(RFA37/RFE37)
ER43=ABS(RFA43/RFE43)
ER47=ABS(RFA47/RFE47)
ER50=ABS(RFA50/RFE50)
ER53=ABS(RFA53/RFE53)

*vfill,rf_tab(1,1),data,RFE37
*vfill,rf_tab(1,2),data,RFA37
*vfill,rf_tab(1,3),data,ER37

*vfill,rf_tab(2,1),data,RFE43
*vfill,rf_tab(2,2),data,RFA43
*vfill,rf_tab(2,3),data,ER43

*vfill,rf_tab(3,1),data,RFE47
*vfill,rf_tab(3,2),data,RFA47
*vfill,rf_tab(3,3),data,ER47

*vfill,rf_tab(4,1),data,RFE50
*vfill,rf_tab(4,2),data,RFA50
*vfill,rf_tab(4,3),data,ER50

*vfill,rf_tab(5,1),data,RFE53
*vfill,rf_tab(5,2),data,RFA53
*vfill,rf_tab(5,3),data,ER53

save,table_4

/com,
```

```
/com,-------------------------------------------------------------------------------------
/com,

/out,

/com,
/com, ---------------------vm-nr1677-2-1b-a Results Verification---------------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-2-1b-a,vrt

/com,
/com, ===========================================
/com,  COMPARISON OF MODAL FREQUENCY
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,


/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*VWRITE,moden(1),Emode(1),Amode(1),ERmode(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,' ')

/com,

/com,-------------------------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr

/com,
/com,===================================================
/com,  COMPARISON OF NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,===================================================
/com,

/com,  Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-----------------------------------------------------------------------
/com,

/nopr
resume,table_4
/gopr

/com,
```

```
/com, ===========================================
/com,  COMPARISON OF REACTION FORCES
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com, Node | Expected |  Mechanical APDL  |  Ratio
/com,

*vwrite,label5(1,1),rf_tab(1,1),rf_tab(1,2),rf_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-----------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,==============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,==============================================
/com,

/com,-----------------------------------------------
/com, Note: Element Forces and Moments for some elements
/com,       along Y & Z directions are flipped between Mechanical APDL
/com,  and NRC results
/com,
/com,       Element numbers from Mechanical APDL and NRC are
/com,       different.
/com,       Element 1 (Mechanical APDL) = Element 1 (NRC)
/com,       Element 30 (Mechanical APDL) = Element 35 (NRC)
/com,       Element 33 (Mechanical APDL) = Element 27 (NRC)
/com,-----------------------------------------------

/com,  Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 35
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(25,1),elem_tab(25,2),elem_tab(25,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
```

```
/com,
/com,

/com,===============
/com,   Element 27
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(31,1),elem_tab(31,2),elem_tab(31,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)


/com,
/com,
/com,*******************************************************************
/com,*******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-2-1b-a,vrt
finish
```

vm-nr1677-2-1c-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-2-1c-a
/title,vm-nr1677-2-1c-a,NRC piping benchmarks from NUREG/CR1677 VOL II, Problem 1c

/com, ***********************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, August 1985.
/com,
/com,
/com, Elements used: Pipe16, Pipe18, Combin14
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, ***************************************************************************

/out,scratch

/prep7

YoungModulus1 = .258e+8                         ! Young's Modulus
Nu = 0.3                                        ! Poissons ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu))        ! Shear Modulus
WMass=1.042868e-03                              ! Density
WTick=0.216                                     ! Wall Thickness
OD=3.5                                          ! Outer Diameter
RADCUR=48.003                                   ! Radius curvature
temp=80                                         ! Temperature
maxm=15                                         ! Number of modes to extract

et,1,pipe16       ! Element 1 - PIPE16
et,2,pipe18       ! Element 2 - PIPE18
et,3,combin14      ! Element 3 - COMBIN14
```

```
keyopt,3,2,1      ! UX Degree of Freedom
et,4,combin14      ! Element 4 - COMBIN14
keyopt,4,2,2      ! UY Degree of Freedom
et,5,combin14      ! Element 5 - COMBIN14
keyopt,5,2,3      ! UZ Degree of Freedom
et,6,combin14      ! Element 6 - COMBIN14
keyopt,6,2,1      ! UX Degree of Freedom
et,7,combin14      ! Element 7 - COMBIN14
keyopt,7,2,3      ! UZ Degree of Freedom

/com,-----------------------------------------------------------------------------------------

/com, Real Constants
/com,****************

r,1,OD,WTick      ! Real Constant Set 1
r,2,OD,WTick,RADCUR
r,3, 0.2e+8
r,4, 0.2e+8
r,5, 0.2e+8
r,6, 0.2e+5
r,7, 0.2e+5

/com,-----------------------------------------------------------------------------------------

/com, Material Properties
/com,*********************

mp,ex,1,YoungModulus1
mp,nuxy,1,Nu
mp,gxy,1,ShearModulus1
mp,dens,1,WMass

mp,ex,2,YoungModulus1
mp,nuxy,2,Nu
mp,gxy,2,ShearModulus1
mp,dens,2,WMass

/com,-----------------------------------------------------------------------------------------

/com, Nodes
/com,*******

n,1,0,0,0
n,2,0,12,0
n,3,35.687,60,32.110
n,4,55,60,49.5
n,5,74.329,60,66.882
n,6,110,12,99
n,7,110,0,99
n,8,110,-24,99,
n,9,110,-48,99,
n,10,110,-72,99

n,11,110,-96,99
n,12,110,-120,99
n,13,110,-144,99
n,14,110,-168,99
n,15,110,-198,99
n,16,110,-228,99
n,17,110,-252,99
n,18,110,-276,99
n,19,110,-300,99
n,20,110,-324,99

n,21,99.6,-349.4,99
n,22,89.2,-374.8,99
n,23,78.8,-400,99
n,24,68.4,-425.6,99
n,25,58,-451,99
n,26,58,-475,99
n,27,58,-487,99
```

```
n,28,103.537,-535,114.179
n,29,124.269,-535,121.1
n,30,145,-535,128

n,31,184.975,-535,123.615
n,32,214.8,-536,102.8
n,33,254.585,-535,81.849
n,34,279.312,-535,75
n,35,331,-535,75
n,36,383,-535,75

/com,
/com, Elastic Support Nodes
/com,**********************

n,37,10,0,0
n,38,0,10,0
n,39,0,0,10
n,40,55,70,49.5
n,41,110,0,109
n,42,120,0,99
n,43,110,-168,109
n,44,120,-168,99
n,45,110,-324,109
n,46,120,-324,99
n,47,58,-475,109

n,48,68,-475,99
n,49,103.537,-545,114.179
n,50,103.537,-535,104.179
n,51,393,-535,75
n,52,383,-545,75
n,53,383,-535,85

/com,----------------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,*********************************

mat,1        ! Material ID 1
type,1       ! Element Type 1
real,1       ! Real Constant 1

e, 1, 2
e, 3, 4
e, 4, 5
e, 6, 7
e, 7, 8
e, 8, 9
e, 9,10
e,10,11
e,11,12
e,12,13
e,13,14
e,14,15
e,15,16
e,16,17
e,17,18
e,18,19
e,19,20
e,20,21
e,21,22
e,22,23
e,23,24
e,24,25
e,25,26
e,26,27
e,28,29
e,29,30
e,31,32
e,32,33
```

```
e,34,35
e,35,36

/com,
/com, Pipe Bend Elements
/com,********************

mat,2
type,2
real,2

e,2,3,4
e,5,6,4
e,27,28,26
e,30,31,29
e,33,34,32
allsel,all

/com,
/com, Elastic Supports and Anchors
/com,******************************

type,3
real,3
e,1,37
e,7,42
e,26,48
e,36,51

type,4
real,4
e,1,38
e,4,40
e,28,49
e,36,52

type,5
real,5
e,1,39
e,7,41
e,26,47
e,28,50
e,36,53

type,6
real,6
e,14,44
e,20,46

type,7
real,7
e,14,43
e,20,45

/com,-------------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,,node,,37,53
d,all,all
allsel

d,1,rotx,,,,,roty,rotz
d,36,rotx,,,,,roty,rotz

save
finish

/com,-------------------------------------------------------------------------------------
```

```
/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal      ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on       ! Use Lumped Mass Matrix Approximation
mxpand,maxm,,,yes      ! Expand Solution with Element Calculations ON
solve
save

/com,-----------------------------------------------------------------------------------

/com,
/com,==========================
/com, Compare Modal Frequencies
/com,==========================
/com,

*dim,Amode,ARRAY,maxm
*dim,Emode,ARRAY,maxm
*dim,ERmode,ARRAY,maxm
*dim,moden,ARRAY,maxm

*do,i,1,maxm
 *GET, Amode(i), MODE, i, FREQ
*enddo

*VFILL,Emode,DATA,6.042,6.256,7.76,8.943,12.444,12.83,14.303,15.486,16.371,18.543
*VFILL,Emode(11),DATA,19.499,23.243,24.105,32.636,33.837

*do,i,1,maxm
  ERmode(i)=ABS(Amode(i)/Emode(i))
  moden(i)=i
*enddo

save,table_1

finish

/com,-----------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,mprs,15     ! Multi Point Excitation Response Spectrum

gval = 386.4

/com,
/com, spectrum 1 (group 1 - upperLevel - X)
/com,***************************************

spunit,1,accg,gval
spfrq,1, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83
spval,1,,  2.275, 2.275,  1.0,    0.8,  0.925,  0.925,   0.8
spfrq,1,  23.25,  29.41,  34.48
spval,1,,    1.0 ,    1.0, 0.875

/com,
/com, spectrum 2 (group 1 - upperLevel - Y = 0.667X)
/com,************************************************

spunit,2,accg,gval
```

```
spfrq,2, 2.5  , 5.0  ,   8.0,  12.35,  13.51,  16.95,  20.83
spval,2,,  1.517, 1.517, 0.667,  0.534,  0.617,  0.617,   0.534
spfrq,2,  23.25,  29.41,  34.48
spval,2,,  0.667 ,  0.667,  0.584

/com,
/com, spectrum 3 (group 2 - lowerLevel - X)
/com,**************************************

spunit,3,accg,gval
spfrq,3, 3.0  , 4.0  ,  7.0,  12.5,   14.1,  15.87,  21.74
spval,3,,  1.4  , 1.4  , 0.75, 0.875,    0.7,    0.7,   0.8
spfrq,3,  23.25,  27.03,  31.25, 34.48
spval,3,,    0.75,   0.75,    0.7,  0.6

/com,
/com, spectrum 4 (group 2 - lowerLevel - Y = 0.667X)
/com,***********************************************

spunit,4,accg,gval
spfrq,4, 3.0  , 4.0  ,  7.0,  12.5,   14.1,  15.87,  21.74
spval,4,,  0.934, 0.934, 0.5 , 0.584,  0.467, 0.467,  0.534
spfrq,4,  23.25,  27.03,  31.25, 34.48
spval,4,,    0.5,     0.5,  0.467,  0.4

/com,
/com, node components for excitation points
/com,**************************************

nsel,,node,,37,42
cm,upperLevel,node
allsel,all,all

nsel,,node,,43,53
cm,lowerLevel,node
allsel,all

/com, ****************************************************
/com, -- upper level - spectrum 1 (Along X - direction)

sed,1,,,upperLevel
pfact,1
sed,0,,,upperLevel

/com, -- lower level - spectrum 3 (Along X - direction)

sed,1,,,lowerLevel
pfact,3
sed,0,,,lowerLevel

/com, -- upper level - spectrum 2 (Along Y - direction)

sed,,1,,upperLevel
pfact,2
sed,,0,,upperLevel

/com, -- lower level - spectrum 4 (Along Y - direction)

sed,,1,,lowerLevel
pfact,4
sed,,0,,lowerLevel

srss,0.0,,YES ! activate Absolute Sum for MPRS
solve

/com, ****************************************************

/post1

/input,,mcom

/com,----------------------------------
```

```
/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1
*dim,label5,char,17,1

/com,------------------------

label2(1,1) = 'ux_5'
label2(1,2) = 'uy_32'
label2(1,3) = 'uz_32'
label2(1,4) ='rotx_28'
label2(1,5) ='roty_30'
label2(1,6) ='rotz_30'

/com,----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,------------------------

label5(1,1)='37'
label5(2,1)='38'
label5(3,1)='39'
label5(4,1)='40'
label5(5,1)='41'
label5(6,1)='42'
label5(7,1)='43'
label5(8,1)='44'
label5(9,1)='45'
label5(10,1)='46'
label5(11,1)='47'
label5(12,1)='48'
label5(13,1)='49'
label5(14,1)='50'
label5(15,1)='51'
label5(16,1)='52'
label5(17,1)='53'


/com,
/com,=====================================================
/com, Maximum nodal displacements and rotations comparsion
/com,=====================================================
/com,

/com, Solution obtained from Mechanical APDL
/com, ***************************

*GET,AdisX,NODE,5,U,X
*GET,AdisY,NODE,32,U,Y
*GET,AdisZ,NODE,32,U,Z
*GET,ArotX,NODE,28,ROT,X
*GET,ArotY,NODE,30,ROT,Y
*GET,ArotZ,NODE,30,ROT,Z

/com,
```

```
/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,9.08314e-02
*SET,EdisY,2.63393e-01
*SET,EdisZ,2.75874e-01
*SET,ErotX,1.50778e-03
*SET,ErotY,3.09194e-03
*SET,ErotZ,2.84469e-03

/com,
/com, Error computation
/com,*******************

ERdisX=ABS(AdisX/EdisX)
ERdisY=ABS(AdisY/EdisY)
ERdisZ=ABS(AdisZ/EdisZ)
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,-------------------------------------------------------------------------------------

/com, *=========================================================
/com, * Element Forces and Moments Comparison
/com, *===========================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*dim,elem_res_I,,3,6
*dim,elem_res_J,,3,6

*dim,pxi,,3
*dim,vyi,,3
*dim,vzi,,3
*dim,txi,,3
*dim,myi,,3
*dim,mzi,,3

*dim,pxj,,3
*dim,vyj,,3
*dim,vzj,,3
*dim,txj,,3
```

```
*dim,myj,,3
*dim,mzj,,3

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #30
/com,*************

*get,pxi(2,1),elem,30,smisc,1
*get,vyi(2,1),elem,30,smisc,2
*get,vzi(2,1),elem,30,smisc,3
*get,txi(2,1),elem,30,smisc,4
*get,myi(2,1),elem,30,smisc,5
*get,mzi(2,1),elem,30,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com, Element #33
/com,*************

*get,pxi(3,1),elem,33,smisc,1
*get,vyi(3,1),elem,33,smisc,2
*get,vzi(3,1),elem,33,smisc,3
*get,txi(3,1),elem,33,smisc,4
*get,myi(3,1),elem,33,smisc,5
*get,mzi(3,1),elem,33,smisc,6

*vfill,elem_res_I(3,1),data,pxi(3,1)
*vfill,elem_res_I(3,2),data,vyi(3,1)
*vfill,elem_res_I(3,3),data,vzi(3,1)
*vfill,elem_res_I(3,4),data,txi(3,1)
*vfill,elem_res_I(3,5),data,myi(3,1)
*vfill,elem_res_I(3,6),data,mzi(3,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
```

```
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #30
/com,*************

*get,pxj(2,1),elem,30,smisc,7
*get,vyj(2,1),elem,30,smisc,8
*get,vzj(2,1),elem,30,smisc,9
*get,txj(2,1),elem,30,smisc,10
*get,myj(2,1),elem,30,smisc,11
*get,mzj(2,1),elem,30,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com, Element #33
/com,*************

*get,pxj(3,1),elem,33,smisc,7
*get,vyj(3,1),elem,33,smisc,8
*get,vzj(3,1),elem,33,smisc,9
*get,txj(3,1),elem,33,smisc,10
*get,myj(3,1),elem,33,smisc,11
*get,mzj(3,1),elem,33,smisc,12

*vfill,elem_res_J(3,1),data,pxj(3,1)
*vfill,elem_res_J(3,2),data,vyj(3,1)
*vfill,elem_res_J(3,3),data,vzj(3,1)
*vfill,elem_res_J(3,4),data,txj(3,1)
*vfill,elem_res_J(3,5),data,myj(3,1)
*vfill,elem_res_J(3,6),data,mzj(3,1)

/com,------------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,3,6
*dim,exp_J,,3,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,1.277e+02
*vfill,exp_I(1,2),data,1.165e+02
*vfill,exp_I(1,3),data,1.090e+02
*vfill,exp_I(1,4),data,1.522e+03
*vfill,exp_I(1,5),data,3.548e+03
*vfill,exp_I(1,6),data,3.503e+03

*vfill,exp_J(1,1),data,1.277e+02
*vfill,exp_J(1,2),data,1.165e+02
*vfill,exp_J(1,3),data,1.090e+02
*vfill,exp_J(1,4),data,1.522e+03
*vfill,exp_J(1,5),data,2.450e+03
*vfill,exp_J(1,6),data,2.316e+03

/com, Element #35
/com,*************
```

```
*vfill,exp_I(2,1),data,1.156e+02
*vfill,exp_I(2,2),data,9.181e+01
*vfill,exp_I(2,3),data,1.026e+02
*vfill,exp_I(2,4),data,5.825e+02
*vfill,exp_I(2,5),data,1.615e+03
*vfill,exp_I(2,6),data,1.544e+03

*vfill,exp_J(2,1),data,1.156e+02
*vfill,exp_J(2,2),data,9.181e+01
*vfill,exp_J(2,3),data,1.026e+02
*vfill,exp_J(2,4),data,5.825e+02
*vfill,exp_J(2,5),data,6.548e+03
*vfill,exp_j(2,6),data,6.198e+03

/com, Element #27
/com,*************

*vfill,exp_I(3,1),data,1.639e+02
*vfill,exp_I(3,2),data,4.134e+01
*vfill,exp_I(3,3),data,1.233e+02
*vfill,exp_I(3,4),data,7.691e+02
*vfill,exp_I(3,5),data,1.399e+03
*vfill,exp_I(3,6),data,1.365e+03

*vfill,exp_J(3,1),data,1.233e+02
*vfill,exp_J(3,2),data,4.134e+01
*vfill,exp_J(3,3),data,1.639e+02
*vfill,exp_J(3,4),data,1.034e+03
*vfill,exp_J(3,5),data,3.666e+03
*vfill,exp_J(3,6),data,2.692e+03

/com,------------------------------------------------------------------------------

/com, Error computation
/com, *********************

*dim,elem_error_I,,3,6
*dim,elem_error_J,,3,6
*dim,elem_tab,,36,3

/com,============
/com,   Node I
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,-----------------------------------------------------------------------------

*do,i,1,3
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo
```

```
 *do,j,1,6
  m=cs+j+18
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3

/com,-------------------------------------------------------------------------------------

/com,
/com,*****************************
/com, Reaction forces comparision
/com,******************************
/com,

*dim,rf_ans,,17,1
*dim,rf_exp,,17,1
*dim,rf_err,,17,1
*dim,rf_tab,,17,3

/com,
/com, Solution obtained from Mechanical APDL
/com,******************************

*GET,RFA37,NODE,37,RF,FX
*GET,RFA38,NODE,38,RF,FY
*GET,RFA39,NODE,39,RF,FZ
*GET,RFA40,NODE,40,RF,FY
*GET,RFA41,NODE,41,RF,FZ
*GET,RFA42,NODE,42,RF,FX
*GET,RFA43,NODE,43,RF,FZ
*GET,RFA44,NODE,44,RF,FX
*GET,RFA45,NODE,45,RF,FZ
*GET,RFA46,NODE,46,RF,FX
*GET,RFA47,NODE,47,RF,FZ
*GET,RFA48,NODE,48,RF,FX
*GET,RFA49,NODE,49,RF,FY
*GET,RFA50,NODE,50,RF,FZ
*GET,RFA51,NODE,51,RF,FX
*GET,RFA52,NODE,52,RF,FY
*GET,RFA53,NODE,53,RF,FZ

*vfill,rf_ans(1,1),data,RFA37
*vfill,rf_ans(2,1),data,RFA38
*vfill,rf_ans(3,1),data,RFA39
*vfill,rf_ans(4,1),data,RFA40
*vfill,rf_ans(5,1),data,RFA41
*vfill,rf_ans(6,1),data,RFA42
*vfill,rf_ans(7,1),data,RFA43
*vfill,rf_ans(8,1),data,RFA44
*vfill,rf_ans(9,1),data,RFA45
*vfill,rf_ans(10,1),data,RFA46
*vfill,rf_ans(11,1),data,RFA47
*vfill,rf_ans(12,1),data,RFA48
*vfill,rf_ans(13,1),data,RFA49
*vfill,rf_ans(14,1),data,RFA50
*vfill,rf_ans(15,1),data,RFA51
*vfill,rf_ans(16,1),data,RFA52
*vfill,rf_ans(17,1),data,RFA53

/com,
/com, Expected results from NRC manual
/com,**********************************

*vfill,rf_exp(1,1),data,117
*vfill,rf_exp(2,1),data,128
*vfill,rf_exp(3,1),data,109
*vfill,rf_exp(4,1),data,278
*vfill,rf_exp(5,1),data,100
```

```
*vfill,rf_exp(6,1),data,113
*vfill,rf_exp(7,1),data,44
*vfill,rf_exp(8,1),data,65
*vfill,rf_exp(9,1),data,35
*vfill,rf_exp(10,1),data,63
*vfill,rf_exp(11,1),data,72
*vfill,rf_exp(12,1),data,185
*vfill,rf_exp(13,1),data,204
*vfill,rf_exp(14,1),data,131
*vfill,rf_exp(15,1),data,116
*vfill,rf_exp(16,1),data,92
*vfill,rf_exp(17,1),data,103

/com,
/com, Error computation
/com,*******************


*do,i,1,17
 rf_err(i,1) = abs((rf_ans(i,1))/(rf_exp(i,1)))
*enddo


*do,i,1,17
 *vfill,rf_tab(i,1),data,rf_exp(i,1)
 *vfill,rf_tab(i,2),data,rf_ans(i,1)
 *vfill,rf_tab(i,3),data,rf_err(i,1)
*enddo

save,table_4

/com,

/com,------------------------------------------------------------------------------------
/com,

/out,

/com,
/com, -----------------------vm-nr1677-2-1c-a Results Verification-------------------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-2-1c-a,vrt

/com,
/com, ===========================================
/com,  COMPARISON OF MODAL FREQUENCY
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*VWRITE,moden(1),Emode(1),Amode(1),ERmode(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,' ')

/com,

/com,------------------------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr

/com,
/com,====================================================
```

```
/com,  COMPARISON OF NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,==================================================
/com,

/com,  Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-----------------------------------------------------------------------
/com,

/nopr
resume,table_4
/gopr

/com,
/com, ===========================================
/com,  COMPARISON OF REACTION FORCES
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com, Node | Expected |  Mechanical APDL  |  Error
/com,

*vwrite,label5(1,1),rf_tab(1,1),rf_tab(1,2),rf_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,------------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,==============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,==============================================
/com,

/com,-----------------------------------------------
/com, Note: Element Forces and Moments for some elements
/com,       along Y & Z directions are flipped between Mechanical APDL
/com,  and NRC results
/com,
/com,       Element numbers from Mechanical APDL and NRC are
/com,       different.
/com,       Element 1 (Mechanical APDL) = Element 1 (NRC)
/com,       Element 30 (Mechanical APDL) = Element 35 (NRC)
/com,       Element 33 (Mechanical APDL) = Element 27 (NRC)
/com,-----------------------------------------------

/com,  Result | Expected | Mechanical APDL |  Ratio
```

```
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 35
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(25,1),elem_tab(25,2),elem_tab(25,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 27
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(31,1),elem_tab(31,2),elem_tab(31,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-------------------------------------------------------------------------
/com,


/out,
*list,vm-nr1677-2-1c-a,vrt
finish
```

vm-nr1677-2-2a-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-2-2a-a
/title,vm-nr1677-2-2a-a,NRC piping benchmarks problems,Volume II, Problem 2a

/com, ***************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
```

```
/com,
/com, Elements used: Pipe16, Pipe18, Combin14 and Mass21
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, ******************************************************************************

/out,scratch

/prep7

YoungModulus1 = .240e+8    ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu)) ! Shear Modulus
WMass=0.001056893     ! Density
WTick=0.241      ! Wall Thickness
k=0.71e-5
OD=7.288      ! Outer Diameter
RADCUR=36.30     ! Radius of Curvature
temp=80      ! Temperature
maxm=25      ! No. of Modes to Extract

et,1,pipe16      ! Element 1 - PIPE16
et,2,pipe18      ! Element 2 - PIPE18
et,3,combin14     ! Element 3 - COMBIN14
keyopt,3,2,1     ! X Degree of Freedom
et,4,combin14     ! Element 4 - COMBIN14
keyopt,4,2,2     ! Y Degree of Freedom
et,5,combin14     ! Element 5 - COMBIN14
keyopt,5,2,3     ! Z Degree of Freedom
et,6,mass21      ! Element 6 - MASS21
keyopt,6,3,2     ! 3D mass without inertia

/com,------------------------------------------------------------------------------------

/com, Real Constants
/com,****************

r,  1,  OD,  WTick
r,  2,  OD,  WTick, RADCUR
r,  3,  0.1e+5
r,  4,  0.1e+9
r,  5,  0.1e+11
r,  6,  1.518

/com,------------------------------------------------------------------------------------

/com, Material Properties
/com,********************

mp,ex,  1, YoungModulus1
mp,nuxy,1, Nu
mp,gxy ,1, ShearModulus1
mp,dens,1, WMass
mp,kxx,1, k

mp,ex,  2, YoungModulus1
mp,nuxy,2, Nu
mp,gxy ,2, ShearModulus1
mp,dens,2, WMass
mp,kxx,2, K

/com,------------------------------------------------------------------------------------

/com, Nodes
/com,*******
```

```
n,1,0,0,0
n,2,0,54.45,0
n,3,0,108.9,0
n,4,10.632,134.568,0
n,5,36.3,145.2,0
n,6,54.15,145.2,0
n,7,72.0,145.2,0
n,8,97.668,145.2,10.632
n,9,108.3,145.2,36.3
n,10,108.3,145.2,56.8
n,11,108.3,145.2,77.3
n,12,108.3,145.2,97.8
n,13,108.3,145.2,118.3
n,14,108.3,145.2,188.8
n,15,108.3,181.5,225.1
n,16,108.3,236,225.1
n,17,108.3,290,225.1
n,18,148.3,145.2,97.8
n,19,188.3,145.2,97.8
n,20,224.6,145.2,61.5
n,21,224.6,145.2,20

/com,
/com, Elastic Support Nodes
/com,**********************

n,22,1,0,0
n,23,0,1,0
n,24,0,0,1
n,25,72,145.2,-1
n,26,109.3,145.2,36.3
n,27,108.3,146.2,77.3
n,28,108.3,146.2,118.3
n,29,107.3,182.5,226.5
n,30,109.3,290,225.1
n,31,108.3,291,225.1
n,32,108.3,290,226.1
n,33,225.6,145.2,20
n,34,224.6,146.2,20
n,35,224.6,145.2,21

/com,---------------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,*********************************

mat,1       ! Material ID 1
type,1      ! Element Type 1
real,1      ! Real Constant Set 1

en, 1, 1, 2
en, 2, 2, 3
en, 5, 5, 6
en, 6, 6, 7
en, 9, 9,10
en,10,10,11
en,11,11,12
en,12,12,13
en,13,13,14
en,15,15,16
en,16,16,17
en,17,12,18
en,18,18,19
en,20,20,21

/com,
/com, Pipe Bend Elements
/com,*******************

mat,2
type,2
```

```
real,2

en, 3, 3, 4, 2
en, 4, 4, 5, 6
en, 7, 7, 8, 6
en, 8, 8, 9,10
en,14,14,15,16
en,19,19,20,18

/com,
/com, Elastic Supports and Anchors
/com,*****************************

! rotate nodes with less than 3 supports
wplane,,nx(15),ny(15),nz(15),nx(29),ny(29),nz(29),nx(16),ny(16),nz(16)
cswplane,11,0
nrotat,15
nrotat,29
csys,0

real,3     ! 0.1e+5
type,4     ! local y
e,11,27
e,13,28

real,4     ! 0.1e+9
type,3     !local x
e,9,26
e,15,29

type,5     !local z
e,7,25

real,5     ! 0.1e+11
type,3     !local x
e,1,22
e,17,30
e,21,33

type,4     ! local y
e,1,23
e,17,31
e,21,34

type,5     ! local z
e,1,24
e,17,32
e,21,35

/com
/com, Mass Elements
/com,***************

type,6
real,6
e,18

/com,------------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,,node,,22,35
d,all,all
allsel
d,1,rotx,,,,,roty,rotz
d,21,rotx,,,,,roty,rotz

allsel,all

/com, Loading
```

```
/com,*********

/com, **Internal Pressure on PIPE elements**
esel,s,ename,,18
esel,a,ename,,16
sfe,all,1,pres,,350
allsel,all
save
finish

/com,-------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal    ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on     ! Use Lumped Mass Matrix Approximation
mxpand,maxm,,,yes    ! Expand Solutions with Element Calculations ON
solve
save

/com,
/com,==========================
/com, Compare Modal Frequencies
/com,==========================
/com,

*dim,Amode,ARRAY,maxm
*dim,Emode,ARRAY,maxm
*dim,ERmode,ARRAY,maxm
*dim,moden,ARRAY,maxm

*do,i,1,maxm
 *GET, Amode(i), MODE, i, FREQ
*enddo
*VFILL,Emode,DATA,9.36,12.706,15.377,17.797,21.603,25.098,32.035,38.069,40.293,48.898
*VFILL,Emode(11),DATA,57.515,61.5,62.541,69.348,77.444,78.881,101.715,103.583,107.966,115.098
*VFILL,Emode(21),DATA,135.244,155.22,160.601,203.789,209.925,

*do,i,1,maxm
  ERmode(i)=ABS(Amode(i)/Emode(i))
  moden(i)=i
*enddo

save,table_1
finish

/com,-------------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,sprs,maxm     ! Single Point Excitation Response Spectrum
srss,0.0

gval = 386.4

/com,
/com, spectrum 1 (X)
/com,***************

svtyp, 2, gval
```

```
freq,0.4,0.630119723,0.64516129,1.124985938,1.374948439,1.705029838,2.420135528,2.750275028,3.41997264
SV,,2.7,0.814,0.81,4.15,4.15,2.4,1.7,1.46,1.6,
freq,4.679457183,5.720823799,6.600660066,9.900990099,15.12859304,16.50165017,39.0625
sv,,2.05,2.05,1.75,0.9,0.77,0.65,0.65,,
sed,1,0,0      ! Excitation in X direction
solve

/com,
/com, spectrum 2 (Y) - coef 1
/com,*************************

svtyp, 2, gval
freq
FREQ,0.4,0.740740741,1.124985938,1.374948439,1.759943682,2.474634991,3.571428571,5.399568035,6.600660066
SV,,0.34,1.15,2.87,2.87,1.5,0.9,0.87,1.32,1.32
FREQ,8.802816901,10.20408163,15.50387597,39.0625
Sv,,0.73,0.55,0.37,0.37
sed,0,1,0      ! Excitation in Y direction
solve

/com
/com, spectrum 2 (Z) - coef 1
/com,*************************

svtyp, 2, gval
freq
FREQ,0.4,0.689655172,1.124985938,1.374948439,1.766160367,2.699784017,4.500450045,5.500550055,6.501950585
SV,,0.34,1.06,3.55,3.55,1.95,1.08,1.38,1.38,1.3
FREQ,7.974481659,13.00390117,17.51313485,39.0625
SV,,1,0.65,0.55,0.55
sed,0,0,1      ! Excitation in Z direction
solve

finish

/com,-----------------------------------------------------------------------------------

/post1
/input,,mcom

/com,----------------------------------

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1
*dim,label5,char,5,1

/com,-------------------------

label2(1,1) = 'ux_14'
label2(1,2) = 'uy_8'
label2(1,3) = 'uz_4'
label2(1,4) ='rotx_3'
label2(1,5) ='roty_7'
label2(1,6) ='rotz_17'

/com,-----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,-----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
```

```
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,-------------------------

label5(1,1)='23'
label5(2,1)='26'
label5(3,1)='28'
label5(4,1)='33'
label5(5,1)='34'

/com,----------------------------------

/com,-------------------------------------------------------------------------------------

/com,
/com,=========================================================
/com, Maximum nodal displacements and rotations comparsion
/com,=========================================================
/com,

/com, Solution obtained from Mechanical APDL
/com, ***************************

*GET,AdisX,NODE,14,U,X
*GET,AdisY,NODE,8,U,Y
*GET,AdisZ,NODE,4,U,Z
*GET,ArotX,NODE,3,ROT,X
*GET,ArotY,NODE,7,ROT,Y
*GET,ArotZ,NODE,17,ROT,Z

/com,
/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,8.49378e-02
*SET,EdisY,3.79278e-02
*SET,EdisZ,9.07052e-02
*SET,ErotX,1.02681e-03
*SET,ErotY,1.89200e-03
*SET,ErotZ,9.07075e-04

/com,
/com, Error computation
/com,*******************

ERdisX=ABS(AdisX/EdisX)
ERdisY=ABS(AdisY/EdisY)
ERdisZ=ABS(AdisZ/EdisZ)
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
```

```
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,-------------------------------------------------------------------------------------

/com,==========================================================
/com, Element Forces and Moments Comparison
/com,==========================================================

/com, Solution obtained from Mechanical APDL
/com,******************************

*dim,elem_res_I,,3,6
*dim,elem_res_J,,3,6

*dim,pxi,,3
*dim,vyi,,3
*dim,vzi,,3
*dim,txi,,3
*dim,myi,,3
*dim,mzi,,3

*dim,pxj,,3
*dim,vyj,,3
*dim,vzj,,3
*dim,txj,,3
*dim,myj,,3
*dim,mzj,,3

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #20
/com,*************

*get,pxi(2,1),elem,20,smisc,1
*get,vyi(2,1),elem,20,smisc,2
*get,vzi(2,1),elem,20,smisc,3
*get,txi(2,1),elem,20,smisc,4
*get,myi(2,1),elem,20,smisc,5
*get,mzi(2,1),elem,20,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
```

```
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com, Element #8
/com,*************

*get,pxi(3,1),elem,8,smisc,1
*get,vyi(3,1),elem,8,smisc,2
*get,vzi(3,1),elem,8,smisc,3
*get,txi(3,1),elem,8,smisc,4
*get,myi(3,1),elem,8,smisc,5
*get,mzi(3,1),elem,8,smisc,6

*vfill,elem_res_I(3,1),data,pxi(3,1)
*vfill,elem_res_I(3,2),data,vyi(3,1)
*vfill,elem_res_I(3,3),data,vzi(3,1)
*vfill,elem_res_I(3,4),data,txi(3,1)
*vfill,elem_res_I(3,5),data,myi(3,1)
*vfill,elem_res_I(3,6),data,mzi(3,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #20
/com,*************

*get,pxj(2,1),elem,20,smisc,7
*get,vyj(2,1),elem,20,smisc,8
*get,vzj(2,1),elem,20,smisc,9
*get,txj(2,1),elem,20,smisc,10
*get,myj(2,1),elem,20,smisc,11
*get,mzj(2,1),elem,20,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com, Element #8
/com,*************

*get,pxj(3,1),elem,8,smisc,7
*get,vyj(3,1),elem,8,smisc,8
*get,vzj(3,1),elem,8,smisc,9
*get,txj(3,1),elem,8,smisc,10
*get,myj(3,1),elem,8,smisc,11
*get,mzj(3,1),elem,8,smisc,12

*vfill,elem_res_J(3,1),data,pxj(3,1)
*vfill,elem_res_J(3,2),data,vyj(3,1)
```

```
*vfill,elem_res_J(3,3),data,vzj(3,1)
*vfill,elem_res_J(3,4),data,txj(3,1)
*vfill,elem_res_J(3,5),data,myj(3,1)
*vfill,elem_res_J(3,6),data,mzj(3,1)

/com,-------------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,3,6
*dim,exp_J,,3,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,6.496e+01
*vfill,exp_I(1,2),data,9.050e+01
*vfill,exp_I(1,3),data,1.774e+02
*vfill,exp_I(1,4),data,5.110e+03
*vfill,exp_I(1,5),data,1.635e+04
*vfill,exp_I(1,6),data,7.002e+03

*vfill,exp_J(1,1),data,6.496e+01
*vfill,exp_J(1,2),data,9.050e+01
*vfill,exp_J(1,3),data,1.774e+02
*vfill,exp_J(1,4),data,5.110e+03
*vfill,exp_J(1,5),data,7.138e+03
*vfill,exp_J(1,6),data,3.188e+03

/com, Element #20
/com,*************

*vfill,exp_I(2,1),data,2.451e+02
*vfill,exp_I(2,2),data,1.916e+02
*vfill,exp_I(2,3),data,3.779e+02
*vfill,exp_I(2,4),data,2.314e+03
*vfill,exp_I(2,5),data,3.823e+03
*vfill,exp_I(2,6),data,3.268e+03

*vfill,exp_J(2,1),data,2.451e+02
*vfill,exp_J(2,2),data,1.916e+02
*vfill,exp_J(2,3),data,3.779e+02
*vfill,exp_J(2,4),data,2.314e+03
*vfill,exp_J(2,5),data,1.660e+04
*vfill,exp_j(2,6),data,1.114e+04

/com, Element #8
/com,*************

*vfill,exp_I(3,1),data,4.463e+02
*vfill,exp_I(3,2),data,3.256e+01
*vfill,exp_I(3,3),data,5.178e+02
*vfill,exp_I(3,4),data,2.967e+03
*vfill,exp_I(3,5),data,1.202e+04
*vfill,exp_I(3,6),data,7.986e+02

*vfill,exp_J(3,1),data,6.648e+02
*vfill,exp_J(3,2),data,3.256e+01
*vfill,exp_J(3,3),data,1.591e+02
*vfill,exp_J(3,4),data,2.021e+03
*vfill,exp_J(3,5),data,2.052e+04
*vfill,exp_J(3,6),data,2.487e+03

/com,------------------------------------------------------------------------------

/com, Error computation
/com, ********************

*dim,elem_error_I,,3,6
*dim,elem_error_J,,3,6
*dim,elem_tab,,36,3
```

```
/com,============
/com,   Node I
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,------------------------------------------------------------------------

*do,i,1,3
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+18
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3

/com,----------------------------------------------------------------------------------

/com,*****************************
/com, Reaction forces comparision
/com,******************************

*dim,rf_tab,,5,3

/com, Solution obtained from Mechanical APDL
/com,******************************

*GET,RFA23,NODE,23,RF,FY
*GET,RFA26,NODE,26,RF,FX
*GET,RFA28,NODE,28,RF,FY
*GET,RFA33,NODE,33,RF,FX
*GET,RFA34,NODE,34,RF,FY

/com, Expected results from NRC manual
/com,**********************************

*SET,RFE23,65
*SET,RFE26,446
*SET,RFE28,164
*SET,RFE33,378
*SET,RFE34,192

/com, Error computation
/com,******************

ER23=ABS(RFA23/RFE23)
```

```
ER26=ABS(RFA26/RFE26)
ER28=ABS(RFA28/RFE28)
ER33=ABS(RFA33/RFE33)
ER34=ABS(RFA34/RFE34)

*vfill,rf_tab(1,1),data,RFE23
*vfill,rf_tab(1,2),data,RFA23
*vfill,rf_tab(1,3),data,ER23

*vfill,rf_tab(2,1),data,RFE26
*vfill,rf_tab(2,2),data,RFA26
*vfill,rf_tab(2,3),data,ER26

*vfill,rf_tab(3,1),data,RFE28
*vfill,rf_tab(3,2),data,RFA28
*vfill,rf_tab(3,3),data,ER28

*vfill,rf_tab(4,1),data,RFE33
*vfill,rf_tab(4,2),data,RFA33
*vfill,rf_tab(4,3),data,ER33

*vfill,rf_tab(5,1),data,RFE34
*vfill,rf_tab(5,2),data,RFA34
*vfill,rf_tab(5,3),data,ER34

save,table_4

/com,


/com,------------------------------------------------------------------------------------
/com,

/out,

/com,
/com, ----------------------vm-nr1677-2-2a-a Results Verification---------------------------
/com,

/nopr
resume,table_1
/gopr,

/out,vm-nr1677-2-2a-a,vrt

/com,
/com, ===========================================
/com,  COMPARISON OF MODAL FREQUENCY
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*VWRITE,moden(1),Emode(1),Amode(1),ERmode(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,' ')

/com,

/com,------------------------------------------------------------------------------------
/com,


/nopr
resume,table_2
/gopr

/com,
/com,=====================================================
/com,  COMPARISON OF NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
```

```
/com,====================================================
/com,

/com,  Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-----------------------------------------------------------------------
/com,

/nopr
resume,table_4
/gopr

/com,
/com, ===========================================
/com,  COMPARISON OF REACTION FORCES
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com, Node | Expected |  Mechanical APDL  |  Ratio
/com,

*vwrite,label5(1,1),rf_tab(1,1),rf_tab(1,2),rf_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,------------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,===============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,===============================================
/com,

/com,----------------------------------------------------
/com, Note: Element Forces and Moments for some elements
/com,       along Y & Z directions are flipped between Mechanical APDL
/com,  and NRC results
/com,------------------------------------------------------

/com,  Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
```

```
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 20
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(25,1),elem_tab(25,2),elem_tab(25,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 8
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(31,1),elem_tab(31,2),elem_tab(31,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)


/com,
/com,
/com,*******************************************************************
/com,*******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-2-2a-a,vrt
finish
```

vm-nr1677-2-2b-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-2-2b-a
/title,vm-nr1677-2-2b-a,NRC piping benchmarks problems,Volume II,Problem 2b

/com, ***************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com, Elements used: Pipe16, Pipe18, Combin14, Mass21
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
```

```
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, ********************************************************************************

/out,scratch

/prep7

YoungModulus1 = .240e+8    ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu)) ! Shear Modulus
WMass=0.001056893     ! Density
WTick=0.241      ! Wall Thickness
k=0.71e-5
OD=7.288      ! Outer Diameter
RADCUR=36.30     ! Radius of Curvature
temp=80      ! Temperature
maxm=25      ! No. of Modes to Extract

et,1,pipe16      ! Element 1 - PIPE16
et,2,pipe18      ! Element 2 - PIPE18
et,3,combin14     ! Element 3 - COMBIN14
keyopt,3,2,1     ! X Degree of Freedom
et,4,combin14     ! Element 4 - COMBIN14
keyopt,4,2,2     ! Y Degree of Freedom
et,5,combin14     ! Element 5 - COMBIN14
keyopt,5,2,3     ! Z Degree of Freedom
et,6,mass21      ! Element 6 - MASS21
keyopt,6,3,2     ! 3D mass without inertia

/com,------------------------------------------------------------------------------------

/com, Real Constants
/com,****************

r,  1,  OD,  WTick
r,  2,  OD,  WTick, RADCUR
r,  3,  0.1e+5
r,  4,  0.1e+9
r,  5,  0.1e+11
r,  6,  1.518

/com,------------------------------------------------------------------------------------

/com, Material Properties
/com,********************

mp,ex,  1, YoungModulus1
mp,nuxy,1, Nu
mp,gxy ,1, ShearModulus1
mp,dens,1, WMass
mp,kxx,1, k

mp,ex,  2, YoungModulus1
mp,nuxy,2, Nu
mp,gxy ,2, ShearModulus1
mp,dens,2, WMass
mp,kxx,2, K

/com,------------------------------------------------------------------------------------

/com, Nodes
/com,*******

n,1,0,0,0
n,2,0,54.45,0
n,3,0,108.9,0
n,4,10.632,134.568,0
n,5,36.3,145.2,0
n,6,54.15,145.2,0
```

```
n,7,72.0,145.2,0
n,8,97.668,145.2,10.632
n,9,108.3,145.2,36.3
n,10,108.3,145.2,56.8
n,11,108.3,145.2,77.3
n,12,108.3,145.2,97.8
n,13,108.3,145.2,118.3
n,14,108.3,145.2,188.8
n,15,108.3,181.5,225.1
n,16,108.3,236,225.1
n,17,108.3,290,225.1
n,18,148.3,145.2,97.8
n,19,188.3,145.2,97.8
n,20,224.6,145.2,61.5
n,21,224.6,145.2,20

/com,
/com, Elastic Support Nodes
/com,**********************

n,22,1,0,0
n,23,0,1,0
n,24,0,0,1
n,25,72,145.2,-1
n,26,109.3,145.2,36.3
n,27,108.3,146.2,77.3
n,28,108.3,146.2,118.3
n,29,107.3,182.5,226.5
n,30,109.3,290,225.1
n,31,108.3,291,225.1
n,32,108.3,290,226.1
n,33,225.6,145.2,20
n,34,224.6,146.2,20
n,35,224.6,145.2,21

/com,--------------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,*********************************

mat,1       ! Material ID 1
type,1      ! Element Type 1
real,1      ! Real Constant Set 1

en, 1, 1, 2
en, 2, 2, 3
en, 5, 5, 6
en, 6, 6, 7
en, 9, 9,10
en,10,10,11
en,11,11,12
en,12,12,13
en,13,13,14
en,15,15,16
en,16,16,17
en,17,12,18
en,18,18,19
en,20,20,21

/com,
/com, Pipe Bend Elements
/com,*******************

mat,2
type,2
real,2

en, 3, 3, 4, 2
en, 4, 4, 5, 6
en, 7, 7, 8, 6
en, 8, 8, 9,10
```

```
en,14,14,15,16
en,19,19,20,18

/com,
/com, Elastic Supports and Anchors
/com,******************************

! rotate nodes with less than 3 supports
wplane,,nx(15),ny(15),nz(15),nx(29),ny(29),nz(29),nx(16),ny(16),nz(16)
cswplane,11,0
nrotat,15
nrotat,29
csys,0

real,3     ! 0.1e+5
type,4     ! local y
e,11,27
e,13,28

real,4     ! 0.1e+9
type,3     !local x
e,9,26
e,15,29

type,5     !local z
e,7,25

real,5     ! 0.1e+11
type,3     !local x
e,1,22
e,17,30
e,21,33

type,4     ! local y
e,1,23
e,17,31
e,21,34

type,5     ! local z
e,1,24
e,17,32
e,21,35

/com
/com, Mass Elements
/com,***************

type,6
real,6
e,18

/com,------------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,,node,,22,35
d,all,all
allsel
d,1,rotx,,,,,roty,rotz
d,21,rotx,,,,,roty,rotz

allsel,all

/com, Loading
/com,*********

/com, **Internal Pressure on PIPE elements**
esel,s,ename,,18
esel,a,ename,,16
sfe,all,1,pres,,350
```

```
allsel,all
save
finish

/com,-------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,maxm
lumpm,on     ! Use Lumped Mass Matrix Approximation
mxpand,maxm,,,yes    ! Expand Solutions with Element Calculations ON
solve
save

/com,
/com,===========================
/com, Compare Modal Frequencies
/com,===========================
/com,

*dim,Amode,ARRAY,maxm
*dim,Emode,ARRAY,maxm
*dim,ERmode,ARRAY,maxm
*dim,moden,ARRAY,maxm

*do,i,1,maxm
 *GET, Amode(i), MODE, i, FREQ
*enddo
*VFILL,Emode,DATA,9.36,12.706,15.377,17.797,21.603,25.098,32.035,38.069,40.293,48.898
*VFILL,Emode(11),DATA,57.515,61.5,62.541,69.348,77.444,78.881,101.715,103.583,107.966,115.098
*VFILL,Emode(21),DATA,135.244,155.22,160.601,203.789,209.925,

*do,i,1,maxm
 ERmode(i)=ABS(Amode(i)/Emode(i))
 moden(i)=i
*enddo
save,table_1
finish

/com,-------------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,mprs,maxm     ! Multi Point Excitation Response Spectrum

gval = 386.4

/com,
/com, spectrum 1 (group 1 - X)
/com,*************************

spunit,1,accg, gval

spfrq,1,0.4,0.719942405,0.900090009,1.099989,1.350074254,1.800180018,2.200220022
spval,1,, 0.13,0.22,0.57,0.57,0.38,0.63,0.63

spfrq,1,2.699784017,3.51000351,4.679457183,5.720823799,6.600660066,8.576329331,11.00110011
spval,1,, 0.75,1.15,1.42,1.42,1.29,0.85,0.42

spfrq,1,33.00330033,34.96503497,39.0625
```

```
spval,1,,0.25,0.22,0.22

/com,
/com, spectrum 2 (group 1 - Y)
/com,**************************

spunit,2,accg, gval
spfrq,2,0.4,0.639795266,0.900090009,1.099989,1.43000143,1.649892757,1.800180018
spval,2,,0.18,0.18,0.995,0.995,0.715,0.35,0.42,

spfrq,2, 3.500175009,4.500450045,5.500550055,6.600660066,8.703220191,9.35453695,15.40832049
spval,2,,0.77,0.998,0.998,0.9,0.68,0.42,0.22

spfrq,2,16,28.49002849,31.94888179,39.0625
spval,2,,0.205,0.205,0.19,0.19

/com,
/com, spectrum 3 (group 1 - Z)
/com,**************************

spunit,3,accg, gval

spfrq,3,0.4,0.599880024,1.124985938,1.374948439,1.539882969,2.200220022,2.5
spval,3,, 0.17,0.17,1.6,1.6,0.78,0.3,0.3

spfrq,3,3.599712023,4.500450045,5.500550055,8.051529791,14.30615165,21.97802198,25.97402597
spval,3,,0.51,0.63,0.63,0.47,0.24,0.2,0.17

spfrq,3,39.0625
spval,3,,0.17

/com,
/com, spectrum 4 (group 2 - X)
/com,**************************

spunit,4,accg, gval

spfrq,4,0.4,0.480076812,0.539956803,1.17000117,1.43000143,1.649892757,2
spval,4,,0.17,0.17,0.23,2.25,2.25,1.07,0.75

spfrq,4,3.300330033,17.6056338,21.97802198,39.0625
spval,4,,0.38,0.03,0.23,0.23

/com,
/com, spectrum 5 (group 2 - Y)
/com,**************************

spunit,5,accg, gval

spfrq,5,0.4,0.610128127,1.124985938,1.374948439,1.759943682,2.474634991,4.500450045
spval,5,,0.17,0.3,2.87,2.87,1.5,0.9,0.85

spfrq,5,5.500550055,8,15.50387597,39.0625
spval,5,,0.85,0.65,0.37,0.37

/com,
/com, spectrum 6 (group 2 - Z)
/com,**************************

spunit,6,accg, gval

spfrq,6,0.4,0.5,0.599880024,1.124985938,1.374948439,1.700102006,2.699784017
spval,6,,0.2,0.2,0.362,3.55,3.55,1.95,1.08

spfrq,6,4.500450045,5.500550055,6.501950585,7.974481659,13.00390117,17.51313485,39.0625
spval,6,,1.38,1.38,1.3,1,0.65,0.55,0.55

/com,
/com, spectrum 7 (group 3 - X)
/com,**************************

spunit,7,accg, gval
```



```
spfrq,7,0.4,0.60204696,1.124985938,1.374948439,1.705029838,2.420135528,2.750275028
spval,7,,0.18,0.42,4.15,4.15,2.4,1.7,1.46

spfrq,7,3.41997264,4.679457183,5.720823799,6.600660066,9.900990099,15.12859304,16.50165017
spval,7,,1.6,2.05,2.05,1.75,0.9,0.77,0.65

spfrq,7,39.0625
spval,7,,0.65

/com,
/com, spectrum 8 (group 3 - Y)
/com,**************************

spunit,8,accg, gval

spfrq,8,0.4,0.576036866,0.704225352,0.900090009,1.080030241,1.800180018,2.610284521
spval,8,,0.14,0.28,0.28,0.17,0.28,0.53,0.56

spfrq,8,5.399568035,6.600660066,8.802816901,11.00110011,24.75247525,27.47252747,40
spval,8,,1.32,1.32,0.73,0.42,0.25,0.23,0.23

/com,
/com, spectrum 9 (group 3 - Z)
/com,**************************

spunit,9,accg, gval

spfrq,9,0.4,0.603136309,0.736919676,0.934579439,1.099989,1.374948439,1.425110446
spval,9,,0.224,0.535,0.535,0.498,0.25,0.195,0.125

spfrq,9,1.619957881,2.66028199,3.599712023,5.399568035,6.600660066,8.802816901,14.02524544
spval,9,,0.17,0.214,0.33,0.55,0.55,0.346,0.18

spfrq,9,17.00680272,28.65329513,31.94888179,39.0625
spval,9,,0.135,0.125,0.112,0.112

/com,
/com, spectrum 10 (group 4 - X)
/com,***************************

spunit,10,accg, gval

spfrq,10,0.4,0.630119723,0.765110941,0.934579439,1.319957761,2.035002035,2.699784017
spval,10,, 0.27,0.814,0.85,0.85,0.536,0.335,0.265

spfrq,10,5.399568035,6.600660066,8.802816901,14.85884101,18.01801802,39.0625
spval,10,, 0.31,0.31,0.215,0.14,0.126,0.126

/com,
/com, spectrum 11 (group 4 - Y)
/com,***************************

spunit,11,accg, gval

spfrq,11,0.4,0.765110941,0.934579439,1.374948439,1.665001665,2.035002035,4.319654428
spval,11,,0.34,1.2,1.2,0.85,0.68,0.68,0.85

spfrq,11,5.399568035,6.600660066,8.250825083,9.68054211,14.85884101,18.48428835,28.01120448
spval,11,,1.02,1.02,0.73,0.42,0.36,0.26,0.21

spfrq,11,39.0625
spval,11,,0.21

/com,
/com, spectrum 12 (group 4 - Z)
/com,***************************

spunit,12,accg, gval

spfrq,12,0.4,0.765110941,0.934579439,1.374948439,1.665001665,2.035002035,4.319654428
spval,12,,0.34,1.2,1.2,0.85,0.68,0.68,0.85
```

```
spfrq,12,5.399568035,6.600660066,8.250825083,9.68054211,14.85884101,18.48428835,28.01120448
spval,12,,1.02,1.02,0.73,0.42,0.36,0.26,0.21

spfrq,12,39.0625
spval,12,,0.21


/com,
/com, node components for excitation points
/com,*************************************

nsel,,node,,22,24
cm,gp1,node
allsel

nsel,,node,,25,29
cm,gp2,node
allsel


nsel,,node,,30,32
cm,gp3,node
allsel

nsel,,node,,33,35
cm,gp4,node
allsel

/com,---------------------------------------------------------------------------------

/com, -- level #1 - spectrum 1
d,gp1,ux,1
pfact,1
d,gp1,all,0

/com, -- level #1 - spectrum 2
d,gp1,uy,1
pfact,2
d,gp1,all,0

/com, -- level #1 - spectrum 3
d,gp1,uz,1
pfact,3
d,gp1,all,0

/com, -- level #2 - spectrum 4
d,26,ux,-1
d,29,ux,0.5025
pfact,4
d,26,all,0
d,29,all,0

/com, -- level #2 - spectrum 5
d,27,uy,-1
d,28,uy,-1
d,29,ux,-0.5025
pfact,5
d,27,all,0
d,28,all,0
d,29,all,0

/com, -- level #2 - spectrum 6
d,25,uz,1
d,29,ux,0.7035
pfact,6
d,25,all,0
d,29,all,0

/com, -- level #3 - spectrum 7
d,gp3,ux,1
pfact,7
```

```
d,gp3,all,0

/com, -- level #3 - spectrum 8
d,gp3,uy,1
pfact,8
d,gp3,all,0

/com, -- level #3 - spectrum 9
d,gp3,uz,1
pfact,9
d,gp3,all,0


/com, -- level #4 - spectrum 10
d,gp4,ux,1
pfact,10
d,gp4,all,0

/com, -- level #4 - spectrum 11
d,gp4,uy,1
pfact,11
d,gp4,all,0

/com, -- level #4 - spectrum 12
d,gp4,uz,1
pfact,12
d,gp4,all,0

srss,0.0     ! Combine modes using SRSS combination
solve

/com,------------------------------------------------------------------------------------------


/post1
/input,,mcom

/com,-----------------------------------

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1
*dim,label5,char,3,1

/com,------------------------

label2(1,1) = 'ux_14'
label2(1,2) = 'uy_7'
label2(1,3) = 'uz_4'
label2(1,4) ='rotx_3'
label2(1,5) ='roty_7'
label2(1,6) ='rotz_17'

/com,----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'
```

```
/com,-------------------------

label5(1,1)='23'
label5(2,1)='28'
label5(3,1)='35'

/com,-----------------------------------

/com,-------------------------------------------------------------------------------------

/com,
/com,========================================================
/com, Maximum nodal displacements and rotations comparsion
/com,========================================================
/com,

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,14,U,X
*GET,AdisY,NODE,8,U,Y
*GET,AdisZ,NODE,4,U,Z
*GET,ArotX,NODE,3,ROT,X
*GET,ArotY,NODE,7,ROT,Y
*GET,ArotZ,NODE,17,ROT,Z

/com,
/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,5.30455e-02
*SET,EdisY,2.41779e-02
*SET,EdisZ,5.73824e-02
*SET,ErotX,6.49739e-04
*SET,ErotY,1.19820e-03
*SET,ErotZ,5.72329e-04

/com,
/com, Error computation
/com,********************

ERdisX=ABS(AdisX/EdisX)
ERdisY=ABS(AdisY/EdisY)
ERdisZ=ABS(AdisZ/EdisZ)
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
```

```
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,----------------------------------------------------------------------------------

/com,========================================================
/com, Element Forces and Moments Comparison
/com,========================================================

/com, Solution obtained from Mechanical APDL
/com,*****************************

*dim,elem_res_I,,3,6
*dim,elem_res_J,,3,6

*dim,pxi,,3
*dim,vyi,,3
*dim,vzi,,3
*dim,txi,,3
*dim,myi,,3
*dim,mzi,,3

*dim,pxj,,3
*dim,vyj,,3
*dim,vzj,,3
*dim,txj,,3
*dim,myj,,3
*dim,mzj,,3

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #20
/com,*************

*get,pxi(2,1),elem,20,smisc,1
*get,vyi(2,1),elem,20,smisc,2
*get,vzi(2,1),elem,20,smisc,3
*get,txi(2,1),elem,20,smisc,4
*get,myi(2,1),elem,20,smisc,5
*get,mzi(2,1),elem,20,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com, Element #8
```

```
/com,*************

*get,pxi(3,1),elem,8,smisc,1
*get,vyi(3,1),elem,8,smisc,2
*get,vzi(3,1),elem,8,smisc,3
*get,txi(3,1),elem,8,smisc,4
*get,myi(3,1),elem,8,smisc,5
*get,mzi(3,1),elem,8,smisc,6

*vfill,elem_res_I(3,1),data,pxi(3,1)
*vfill,elem_res_I(3,2),data,vyi(3,1)
*vfill,elem_res_I(3,3),data,vzi(3,1)
*vfill,elem_res_I(3,4),data,txi(3,1)
*vfill,elem_res_I(3,5),data,myi(3,1)
*vfill,elem_res_I(3,6),data,mzi(3,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #20
/com,*************

*get,pxj(2,1),elem,20,smisc,7
*get,vyj(2,1),elem,20,smisc,8
*get,vzj(2,1),elem,20,smisc,9
*get,txj(2,1),elem,20,smisc,10
*get,myj(2,1),elem,20,smisc,11
*get,mzj(2,1),elem,20,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com, Element #8
/com,*************

*get,pxj(3,1),elem,8,smisc,7
*get,vyj(3,1),elem,8,smisc,8
*get,vzj(3,1),elem,8,smisc,9
*get,txj(3,1),elem,8,smisc,10
*get,myj(3,1),elem,8,smisc,11
*get,mzj(3,1),elem,8,smisc,12

*vfill,elem_res_J(3,1),data,pxj(3,1)
*vfill,elem_res_J(3,2),data,vyj(3,1)
*vfill,elem_res_J(3,3),data,vzj(3,1)
*vfill,elem_res_J(3,4),data,txj(3,1)
*vfill,elem_res_J(3,5),data,myj(3,1)
*vfill,elem_res_J(3,6),data,mzj(3,1)
```

```
/com,--------------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,3,6
*dim,exp_J,,3,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,4.616e+01
*vfill,exp_I(1,2),data,5.305e+01
*vfill,exp_I(1,3),data,1.129e+02
*vfill,exp_I(1,4),data,3.230e+03
*vfill,exp_I(1,5),data,1.034e+04
*vfill,exp_I(1,6),data,4.209e+03

*vfill,exp_J(1,1),data,4.616e+01
*vfill,exp_J(1,2),data,5.305e+01
*vfill,exp_J(1,3),data,1.129e+02
*vfill,exp_J(1,4),data,3.230e+03
*vfill,exp_J(1,5),data,4.529e+03
*vfill,exp_J(1,6),data,2.005e+03

/com, Element #20
/com,*************

*vfill,exp_I(2,1),data,1.155e+02
*vfill,exp_I(2,2),data,1.140e+02
*vfill,exp_I(2,3),data,1.032e+02
*vfill,exp_I(2,4),data,1.361e+03
*vfill,exp_I(2,5),data,2.302e+03
*vfill,exp_I(2,6),data,1.960e+03

*vfill,exp_J(2,1),data,1.155e+02
*vfill,exp_J(2,2),data,1.140e+02
*vfill,exp_J(2,3),data,1.032e+02
*vfill,exp_J(2,4),data,1.361e+03
*vfill,exp_J(2,5),data,4.038e+03
*vfill,exp_j(2,6),data,6.632e+03

/com, Element #8
/com,*************

*vfill,exp_I(3,1),data,2.650e+02
*vfill,exp_I(3,2),data,2.282e+01
*vfill,exp_I(3,3),data,3.272e+02
*vfill,exp_I(3,4),data,1.884e+03
*vfill,exp_I(3,5),data,7.379e+03
*vfill,exp_I(3,6),data,7.638e+02

*vfill,exp_J(3,1),data,4.116e+02
*vfill,exp_J(3,2),data,2.282e+01
*vfill,exp_J(3,3),data,8.904e+01
*vfill,exp_J(3,4),data,1.346e+03
*vfill,exp_J(3,5),data,1.288e+04
*vfill,exp_J(3,6),data,1.569e+03

/com,-------------------------------------------------------------------------------

/com, Error computation
/com, ********************

*dim,elem_error_I,,3,6
*dim,elem_error_J,,3,6
*dim,elem_tab,,36,3

/com,============
/com,   Node I
/com,============
```

```
*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,-----------------------------------------------------------------------

*do,i,1,3
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+18
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3

/com,---------------------------------------------------------------------------------

/com,*****************************
/com, Reaction forces comparision
/com,******************************

*dim,rf_tab,,3,3

/com, Solution obtained from Mechanical APDL
/com,******************************

*GET,RFA23,NODE,23,RF,FY
*GET,RFA28,NODE,28,RF,FY
*GET,RFA35,NODE,35,RF,FZ

/com, Expected results from NRC manual
/com,**********************************

*SET,RFE23,46
*SET,RFE28,98
*SET,RFE35,116

/com, Error computation
/com,******************

ER23=ABS(RFA23/RFE23)
ER28=ABS(RFA28/RFE28)
ER35=ABS(RFA35/RFE35)

*vfill,rf_tab(1,1),data,RFE23
*vfill,rf_tab(1,2),data,RFA23
*vfill,rf_tab(1,3),data,ER23

*vfill,rf_tab(2,1),data,RFE28
*vfill,rf_tab(2,2),data,RFA28
```

```
*vfill,rf_tab(2,3),data,ER28

*vfill,rf_tab(3,1),data,RFE35
*vfill,rf_tab(3,2),data,RFA35
*vfill,rf_tab(3,3),data,ER35

save,table_4

/com,

/com,------------------------------------------------------------------------------------
/com,

/out,

/com,
/com, -------------------------vm-nr1677-2-2b-a Results Verification----------------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-2-2b-a,vrt

/com,
/com, ===========================================
/com,  COMPARISON OF MODAL FREQUENCY
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*VWRITE,moden(1),Emode(1),Amode(1),ERmode(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,' ')

/com,

/com,------------------------------------------------------------------------------------
/com,
/nopr
resume,table_2
/gopr

/com,
/com,====================================================
/com,  COMPARISON OF NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,====================================================
/com,

/com,  Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-------------------------------------------------------------------------
```

```
/com,

/nopr
resume,table_4
/gopr

/com,
/com, ==========================================
/com,  COMPARISON OF REACTION FORCES
/com,      WITH EXPECTED RESULTS
/com, ==========================================
/com,

/com, Node | Expected |  Mechanical APDL  |  Ratio
/com,

*vwrite,label5(1,1),rf_tab(1,1),rf_tab(1,2),rf_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,------------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,=============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,=============================================
/com,

/com,-------------------------------------------------------
/com, Note: Element Forces and Moments for some elements
/com,       along Y & Z directions are flipped between Mechanical APDL
/com,  and NRC results
/com,
/com,--------------------------------------------------------

/com,  Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 20
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(25,1),elem_tab(25,2),elem_tab(25,3)
```

```
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 8
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(31,1),elem_tab(31,2),elem_tab(31,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)


/com,
/com,
/com,*******************************************************************
/com,*******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-2-2b-a,vrt
finish
```

vm-nr1677-2-2c-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-2-2c-a
/title,vm-nr1677-2-2c-a,NRC piping benchmarks problems,Volume II,Problem 2c

/com, ******************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com, Elements used: Pipe16, Pipe18, Combin14 and Mass21
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, ******************************************************************************

/out,scratch

/prep7

YoungModulus1 = .240e+8    ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu)) ! Shear Modulus
WMass=0.001056893     ! Density
WTick=0.241      ! Wall Thickness
k=0.71e-5
OD=7.288      ! Outer Diameter
RADCUR=36.30      ! Radius of Curvature
temp=80      ! Temperature
maxm=25      ! No. of Modes to Extract
```

```
et,1,pipe16      ! Element 1 - PIPE16
et,2,pipe18      ! Element 2 - PIPE18
et,3,combin14     ! Element 3 - COMBIN14
keyopt,3,2,1     ! X Degree of Freedom
et,4,combin14     ! Element 4 - COMBIN14
keyopt,4,2,2     ! Y Degree of Freedom
et,5,combin14     ! Element 5 - COMBIN14
keyopt,5,2,3     ! Z Degree of Freedom
et,6,mass21      ! Element 6 - MASS21
keyopt,6,3,2     ! 3D mass without inertia

/com,-------------------------------------------------------------------------------------

/com, Real Constants
/com,****************

r,  1,  OD,  WTick
r,  2,  OD,  WTick, RADCUR
r,  3,  0.1e+5
r,  4,  0.1e+9
r,  5,  0.1e+11
r,  6,  1.518

/com,-------------------------------------------------------------------------------------

/com, Material Properties
/com,*********************

mp,ex,  1, YoungModulus1
mp,nuxy,1, Nu
mp,gxy ,1, ShearModulus1
mp,dens,1, WMass
mp,kxx,1, k

mp,ex,  2, YoungModulus1
mp,nuxy,2, Nu
mp,gxy ,2, ShearModulus1
mp,dens,2, WMass
mp,kxx,2, K

/com,-------------------------------------------------------------------------------------

/com, Nodes
/com,*******

n,1,0,0,0
n,2,0,54.45,0
n,3,0,108.9,0
n,4,10.632,134.568,0
n,5,36.3,145.2,0
n,6,54.15,145.2,0
n,7,72.0,145.2,0
n,8,97.668,145.2,10.632
n,9,108.3,145.2,36.3
n,10,108.3,145.2,56.8
n,11,108.3,145.2,77.3
n,12,108.3,145.2,97.8
n,13,108.3,145.2,118.3
n,14,108.3,145.2,188.8
n,15,108.3,181.5,225.1
n,16,108.3,236,225.1
n,17,108.3,290,225.1
n,18,148.3,145.2,97.8
n,19,188.3,145.2,97.8
n,20,224.6,145.2,61.5
n,21,224.6,145.2,20

/com,
/com, Elastic Support Nodes
/com,**********************

n,22,1,0,0
```

```
n,23,0,1,0
n,24,0,0,1
n,25,72,145.2,-1
n,26,109.3,145.2,36.3
n,27,108.3,146.2,77.3
n,28,108.3,146.2,118.3
n,29,107.3,182.5,226.5
n,30,109.3,290,225.1
n,31,108.3,291,225.1
n,32,108.3,290,226.1
n,33,225.6,145.2,20
n,34,224.6,146.2,20
n,35,224.6,145.2,21

/com,-----------------------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,**********************************

mat,1       ! Material ID 1
type,1      ! Element Type 1
real,1      ! Real Constant Set 1

en, 1, 1, 2
en, 2, 2, 3
en, 5, 5, 6
en, 6, 6, 7
en, 9, 9,10
en,10,10,11
en,11,11,12
en,12,12,13
en,13,13,14
en,15,15,16
en,16,16,17
en,17,12,18
en,18,18,19
en,20,20,21

/com,
/com, Pipe Bend Elements
/com,********************

mat,2
type,2
real,2

en, 3, 3, 4, 2
en, 4, 4, 5, 6
en, 7, 7, 8, 6
en, 8, 8, 9,10
en,14,14,15,16
en,19,19,20,18

/com,
/com, Elastic Supports and Anchors
/com,******************************

! rotate nodes with less than 3 supports
wplane,,nx(15),ny(15),nz(15),nx(29),ny(29),nz(29),nx(16),ny(16),nz(16)
cswplane,11,0
nrotat,15
nrotat,29
csys,0

real,3     ! 0.1e+5
type,4     ! local y
e,11,27
e,13,28

real,4     ! 0.1e+9
type,3     !local x
```

```
e,9,26
e,15,29

type,5     !local z
e,7,25

real,5     ! 0.1e+11
type,3     !local x
e,1,22
e,17,30
e,21,33

type,4     ! local y
e,1,23
e,17,31
e,21,34

type,5     ! local z
e,1,24
e,17,32
e,21,35

/com
/com, Mass Elements
/com,***************

type,6
real,6
e,18

/com,------------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,,node,,22,35
d,all,all
allsel
d,1,rotx,,,,,roty,rotz
d,21,rotx,,,,,roty,rotz

allsel,all

/com, Loading
/com,*********

/com, **Internal Pressure on PIPE elements**
esel,s,ename,,18
esel,a,ename,,16
sfe,all,1,pres,,350
allsel,all
save
finish

/com,------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal    ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on     ! Use Lumped Mass Matrix Approximation
mxpand,maxm,,,yes    ! Expand Solutions with Element Calculations ON
solve
save

/com,
```

```
/com,=========================
/com, Compare Modal Frequencies
/com,=========================
/com,

*dim,Amode,ARRAY,maxm
*dim,Emode,ARRAY,maxm
*dim,ERmode,ARRAY,maxm
*dim,moden,ARRAY,maxm

*do,i,1,maxm
 *GET, Amode(i), MODE, i, FREQ
*enddo
*VFILL,Emode,DATA,9.36,12.706,15.377,17.797,21.603,25.098,32.035,38.069,40.293,48.898
*VFILL,Emode(11),DATA,57.515,61.5,62.541,69.348,77.444,78.881,101.715,103.583,107.966,115.098
*VFILL,Emode(21),DATA,135.244,155.22,160.601,203.789,209.925,

*do,i,1,maxm
 ERmode(i)=ABS(Amode(i)/Emode(i))
 moden(i)=i
*enddo

save,table_1

finish

/com,------------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,mprs,maxm     ! Multi Point Excitation Response Spectrum

gval = 386.4

/com,------------------------------------------------------------------------------------

/com,
/com, spectrum 1 (group 1 - X)
/com,**************************

spunit,1,accg, gval

spfrq,1,0.4,0.719942405,0.900090009,1.099989,1.350074254,1.800180018,2.200220022
spval,1,, 0.13,0.22,0.57,0.57,0.38,0.63,0.63

spfrq,1,2.699784017,3.51000351,4.679457183,5.720823799,6.600660066,8.576329331,11.00110011
spval,1,, 0.75,1.15,1.42,1.42,1.29,0.85,0.42

spfrq,1,33.00330033,34.96503497,39.0625
spval,1,,0.25,0.22,0.22

/com,
/com, spectrum 2 (group 1 - Y)
/com,**************************

spunit,2,accg, gval
spfrq,2,0.4,0.639795266,0.900090009,1.099989,1.43000143,1.649892757,1.800180018
spval,2,,0.18,0.18,0.995,0.995,0.715,0.35,0.42,

spfrq,2, 3.500175009,4.500450045,5.500550055,6.600660066,8.703220191,9.35453695,15.40832049
spval,2,,0.77,0.998,0.998,0.9,0.68,0.42,0.22

spfrq,2,16,28.49002849,31.94888179,39.0625
spval,2,,0.205,0.205,0.19,0.19

/com,
```

```
/com, spectrum 3 (group 1 - Z)
/com,**************************

spunit,3,accg, gval

spfrq,3,0.4,0.599880024,1.124985938,1.374948439,1.539882969,2.200220022,2.5
spval,3,, 0.17,0.17,1.6,1.6,0.78,0.3,0.3

spfrq,3,3.599712023,4.500450045,5.500550055,8.051529791,14.30615165,21.97802198,25.97402597
spval,3,,0.51,0.63,0.63,0.47,0.24,0.2,0.17

spfrq,3,39.0625
spval,3,,0.17

/com,
/com, spectrum 4 (group 2 - X)
/com,**************************

spunit,4,accg, gval

spfrq,4,0.4,0.480076812,0.539956803,1.17000117,1.43000143,1.649892757,2
spval,4,,0.17,0.17,0.23,2.25,2.25,1.07,0.75

spfrq,4,3.300330033,17.6056338,21.97802198,39.0625
spval,4,,0.38,0.03,0.23,0.23

/com,
/com, spectrum 5 (group 2 - Y)
/com,**************************

spunit,5,accg, gval

spfrq,5,0.4,0.610128127,1.124985938,1.374948439,1.759943682,2.474634991,4.500450045
spval,5,,0.17,0.3,2.87,2.87,1.5,0.9,0.85

spfrq,5,5.500550055,8,15.50387597,39.0625
spval,5,,0.85,0.65,0.37,0.37

/com,
/com, spectrum 6 (group 2 - Z)
/com,**************************

spunit,6,accg, gval

spfrq,6,0.4,0.5,0.599880024,1.124985938,1.374948439,1.700102006,2.699784017
spval,6,,0.2,0.2,0.362,3.55,3.55,1.95,1.08

spfrq,6,4.500450045,5.500550055,6.501950585,7.974481659,13.00390117,17.51313485,39.0625
spval,6,,1.38,1.38,1.3,1,0.65,0.55,0.55

/com,
/com, spectrum 7 (group 3 - X)
/com,**************************

spunit,7,accg, gval

spfrq,7,0.4,0.60204696,1.124985938,1.374948439,1.705029838,2.420135528,2.750275028
spval,7,,0.18,0.42,4.15,4.15,2.4,1.7,1.46

spfrq,7,3.41997264,4.679457183,5.720823799,6.600660066,9.900990099,15.12859304,16.50165017
spval,7,,1.6,2.05,2.05,1.75,0.9,0.77,0.65

spfrq,7,39.0625
spval,7,,0.65

/com,
/com, spectrum 8 (group 3 - Y)
/com,**************************

spunit,8,accg, gval

spfrq,8,0.4,0.576036866,0.704225352,0.900090009,1.080030241,1.800180018,2.610284521
```

```
spval,8,,0.14,0.28,0.28,0.17,0.28,0.53,0.56

spfrq,8,5.399568035,6.600660066,8.802816901,11.00110011,24.75247525,27.47252747,40
spval,8,,1.32,1.32,0.73,0.42,0.25,0.23,0.23

/com,
/com, spectrum 9 (group 3 - Z)
/com,**************************

spunit,9,accg, gval

spfrq,9,0.4,0.603136309,0.736919676,0.934579439,1.099989,1.374948439,1.425110446
spval,9,,0.224,0.535,0.535,0.498,0.25,0.195,0.125

spfrq,9,1.619957881,2.66028199,3.599712023,5.399568035,6.600660066,8.802816901,14.02524544
spval,9,,0.17,0.214,0.33,0.55,0.55,0.346,0.18

spfrq,9,17.00680272,28.65329513,31.94888179,39.0625
spval,9,,0.135,0.125,0.112,0.112

/com,
/com, spectrum 10 (group 4 - X)
/com,***************************

spunit,10,accg, gval

spfrq,10,0.4,0.630119723,0.765110941,0.934579439,1.319957761,2.035002035,2.699784017
spval,10,, 0.27,0.814,0.85,0.85,0.536,0.335,0.265

spfrq,10,5.399568035,6.600660066,8.802816901,14.85884101,18.01801802,39.0625
spval,10,, 0.31,0.31,0.215,0.14,0.126,0.126

/com,
/com, spectrum 11 (group 4 - Y)
/com,***************************

spunit,11,accg, gval

spfrq,11,0.4,0.765110941,0.934579439,1.374948439,1.665001665,2.035002035,4.319654428
spval,11,,0.34,1.2,1.2,0.85,0.68,0.68,0.85

spfrq,11,5.399568035,6.600660066,8.250825083,9.68054211,14.85884101,18.48428835,28.01120448
spval,11,,1.02,1.02,0.73,0.42,0.36,0.26,0.21

spfrq,11,39.0625
spval,11,,0.21

/com,
/com, spectrum 12 (group 4 - Z)
/com,***************************

spunit,12,accg, gval

spfrq,12,0.4,0.765110941,0.934579439,1.374948439,1.665001665,2.035002035,4.319654428
spval,12,,0.34,1.2,1.2,0.85,0.68,0.68,0.85

spfrq,12,5.399568035,6.600660066,8.250825083,9.68054211,14.85884101,18.48428835,28.01120448
spval,12,,1.02,1.02,0.73,0.42,0.36,0.26,0.21

spfrq,12,39.0625
spval,12,,0.21

/com,
/com, node components for excitation points
/com,***************************************

nsel,,node,,22,24
cm,gp1,node
allsel

nsel,,node,,25,29
cm,gp2,node
```

```
allsel

nsel,,node,,30,32
cm,gp3,node
allsel

nsel,,node,,33,35
cm,gp4,node
allsel

/com,----------------------------------------------------------------------------------

! -- level #1 - spectrum 1 (Along X - Direction)

sed,1,,,gp1
dlist,all
pfact,1
sed,0,,,gp1

! -- level #1 - spectrum 2 (Along Y - Direction)

sed,,1,,gp1
dlist,all
pfact,2
sed,,0,,gp1

! -- level #1 - spectrum 3 (Along Z - Direction)

sed,,,1,gp1
dlist,all
pfact,3
sed,,,0,gp1

! -- level #2 - spectrum 4 (Along X - Direction)

sed,1,,,gp2
dlist,all
pfact,4
sed,0,,,gp2

! -- level #2 - spectrum 5 (Along Y - Direction)

sed,,1,,gp2
dlist,all
pfact,5
sed,,0,,gp2

! -- level #2 - spectrum 6 (Along Z - Direction)

sed,,,1,gp2
dlist,all
pfact,6
sed,,,0,gp2

! -- level #3 - spectrum 7 (Along X - Direction)

sed,1,,,gp3
dlist,all
pfact,7
sed,0,,,gp3

! -- level #3 - spectrum 8 (Along Y - Direction)

sed,,1,,gp3
dlist,all
pfact,8
sed,,0,,gp3

! -- level #3 - spectrum 9 (Along Z - Direction)

sed,,,1,gp3
dlist,all
```

```
pfact,9
sed,,,0,gp3

! -- level #4 - spectrum 10 (Along X - Direction)

sed,1,,,gp4
dlist,all
pfact,10
sed,0,,,gp4

! -- level #4 - spectrum 11 (Along Y - Direction)

sed,,1,,gp4
dlist,all
pfact,11
sed,,0,,gp4

! -- level #4 - spectrum 12 (Along Z - Direction)

sed,,,1,gp4
dlist,all
pfact,12
sed,,,0,gp4

srss,0.0,,YES ! activate Absolute Sum for MPRS
solve

finish
/com,------------------------------------------------------------------------------------

/post1

/input,,mcom

/com,-----------------------------------

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1
*dim,label5,char,3,1

/com,-------------------------

label2(1,1) = 'ux_14'
label2(1,2) = 'uy_8'
label2(1,3) = 'uz_4'
label2(1,4) ='rotx_3'
label2(1,5) ='roty_7'
label2(1,6) ='rotz_17'

/com,-----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,-----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,-----------------------------------

/com,------------------------------------------------------------------------------------
```

```
/com,
/com,=========================================================
/com, Maximum nodal displacements and rotations comparsion
/com,=========================================================
/com,

/com, Solution obtained from Mechanical APDL
/com, ***************************

*GET,AdisX,NODE,14,U,X
*GET,AdisY,NODE,8,U,Y
*GET,AdisZ,NODE,4,U,Z
*GET,ArotX,NODE,3,ROT,X
*GET,ArotY,NODE,7,ROT,Y
*GET,ArotZ,NODE,17,ROT,Z

/com,
/com, Expected results from NRC manual
/com, ********************************

*SET,EdisX,7.40647e-02
*SET,EdisY,3.55177e-02
*SET,EdisZ,8.00211e-02
*SET,ErotX,9.06483e-04
*SET,ErotY,1.67234e-03
*SET,ErotZ,7.98620e-04

/com,
/com, Error computation
/com,*******************

ERdisX=ABS(AdisX/EdisX)
ERdisY=ABS(AdisY/EdisY)
ERdisZ=ABS(AdisZ/EdisZ)
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,-------------------------------------------------------------------------------------------

/com,=========================================================
/com, Element Forces and Moments Comparison
/com,=========================================================
```

```
/com, Solution obtained from Mechanical APDL
/com,******************************

*dim,elem_res_I,,3,6
*dim,elem_res_J,,3,6

*dim,pxi,,3
*dim,vyi,,3
*dim,vzi,,3
*dim,txi,,3
*dim,myi,,3
*dim,mzi,,3

*dim,pxj,,3
*dim,vyj,,3
*dim,vzj,,3
*dim,txj,,3
*dim,myj,,3
*dim,mzj,,3

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #20
/com,*************

*get,pxi(2,1),elem,20,smisc,1
*get,vyi(2,1),elem,20,smisc,2
*get,vzi(2,1),elem,20,smisc,3
*get,txi(2,1),elem,20,smisc,4
*get,myi(2,1),elem,20,smisc,5
*get,mzi(2,1),elem,20,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com, Element #8
/com,*************

*get,pxi(3,1),elem,8,smisc,1
*get,vyi(3,1),elem,8,smisc,2
*get,vzi(3,1),elem,8,smisc,3
*get,txi(3,1),elem,8,smisc,4
*get,myi(3,1),elem,8,smisc,5
*get,mzi(3,1),elem,8,smisc,6
```

```
*vfill,elem_res_I(3,1),data,pxi(3,1)
*vfill,elem_res_I(3,2),data,vyi(3,1)
*vfill,elem_res_I(3,3),data,vzi(3,1)
*vfill,elem_res_I(3,4),data,txi(3,1)
*vfill,elem_res_I(3,5),data,myi(3,1)
*vfill,elem_res_I(3,6),data,mzi(3,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #20
/com,*************

*get,pxj(2,1),elem,20,smisc,7
*get,vyj(2,1),elem,20,smisc,8
*get,vzj(2,1),elem,20,smisc,9
*get,txj(2,1),elem,20,smisc,10
*get,myj(2,1),elem,20,smisc,11
*get,mzj(2,1),elem,20,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com, Element #8
/com,*************

*get,pxj(3,1),elem,8,smisc,7
*get,vyj(3,1),elem,8,smisc,8
*get,vzj(3,1),elem,8,smisc,9
*get,txj(3,1),elem,8,smisc,10
*get,myj(3,1),elem,8,smisc,11
*get,mzj(3,1),elem,8,smisc,12

*vfill,elem_res_J(3,1),data,pxj(3,1)
*vfill,elem_res_J(3,2),data,vyj(3,1)
*vfill,elem_res_J(3,3),data,vzj(3,1)
*vfill,elem_res_J(3,4),data,txj(3,1)
*vfill,elem_res_J(3,5),data,myj(3,1)
*vfill,elem_res_J(3,6),data,mzj(3,1)

/com,-------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,3,6
*dim,exp_J,,3,6

/com, Element #1
```

```
/com,************

*vfill,exp_I(1,1),data,6.961e+01
*vfill,exp_I(1,2),data,7.639e+01
*vfill,exp_I(1,3),data,1.556e+02
*vfill,exp_I(1,4),data,4.498e+03
*vfill,exp_I(1,5),data,1.438e+04
*vfill,exp_I(1,6),data,5.959e+03

*vfill,exp_J(1,1),data,6.961e+01
*vfill,exp_J(1,2),data,7.639e+01
*vfill,exp_J(1,3),data,1.556e+02
*vfill,exp_J(1,4),data,4.498e+03
*vfill,exp_J(1,5),data,6.317e+03
*vfill,exp_J(1,6),data,2.787e+03

/com, Element #20
/com,*************

*vfill,exp_I(2,1),data,1.576e+02
*vfill,exp_I(2,2),data,1.699e+02
*vfill,exp_I(2,3),data,1.517e+02
*vfill,exp_I(2,4),data,2.041e+03
*vfill,exp_I(2,5),data,3.192e+03
*vfill,exp_I(2,6),data,2.935e+03

*vfill,exp_J(2,1),data,1.576e+02
*vfill,exp_J(2,2),data,1.699e+02
*vfill,exp_J(2,3),data,1.517e+02
*vfill,exp_J(2,4),data,2.041e+03
*vfill,exp_J(2,5),data,6.079e+03
*vfill,exp_j(2,6),data,9.904e+03

/com, Element #8
/com,*************

*vfill,exp_I(3,1),data,3.686e+02
*vfill,exp_I(3,2),data,3.377e+01
*vfill,exp_I(3,3),data,4.532e+02
*vfill,exp_I(3,4),data,2.643e+03
*vfill,exp_I(3,5),data,1.031e+04
*vfill,exp_I(3,6),data,1.268e+03

*vfill,exp_J(3,1),data,5.717e+02
*vfill,exp_J(3,2),data,3.377e+01
*vfill,exp_J(3,3),data,1.200e+02
*vfill,exp_J(3,4),data,1.937e+03
*vfill,exp_J(3,5),data,1.794e+04
*vfill,exp_J(3,6),data,2.187e+03

/com,-----------------------------------------------------------------------

/com, Error computation
/com, *********************

*dim,elem_error_I,,3,6
*dim,elem_error_J,,3,6
*dim,elem_tab,,36,3

/com,============
/com,   Node I
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============
```

```
*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,--------------------------------------------------------------------------

*do,i,1,3
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+18
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3

/com,-----------------------------------------------------------------------------------

/com,*****************************
/com, Reaction forces comparision
/com,******************************

*dim,Areac,,14
*dim,Ereac,,14
*dim,ERreac,,14
*dim,Nreac,STRING,8,14

Nreac(1,1) = 'FX1'
Nreac(1,2) = 'FY1'
Nreac(1,3) = 'FZ1'

Nreac(1,4) = 'FZ7'
Nreac(1,5) = 'FX9'

Nreac(1,6) = 'FY11'
Nreac(1,7) = 'FY13'
Nreac(1,8) = 'FX15'

Nreac(1,9) = 'FX17'
Nreac(1,10) = 'FY17'
Nreac(1,11) = 'FZ17'

Nreac(1,12) = 'FX21'
Nreac(1,13) = 'FY21'
Nreac(1,14) = 'FZ21'

*GET,Areac(1),NODE,22,RF,FX
*GET,Areac(2),NODE,23,RF,FY
*GET,Areac(3),NODE,24,RF,FZ

*GET,Areac(4),NODE,25,RF,FZ
*GET,Areac(5),NODE,26,RF,FX

*GET,Areac(6),NODE,27,RF,FY
*GET,Areac(7),NODE,28,RF,FY
*GET,Areac(8),NODE,29,RF,FX

*GET,Areac(9),NODE,30,RF,FX
*GET,Areac(10),NODE,31,RF,FY
*GET,Areac(11),NODE,32,RF,FZ
```

```
*GET,Areac(12),NODE,33,RF,FX
*GET,Areac(13),NODE,34,RF,FY
*GET,Areac(14),NODE,35,RF,FZ

*VFILL,Ereac,DATA,76,70,156,607,350,184,146,301,45,169
*VFILL,Ereac(11),DATA,91,152,170,158

*do,i,1,14
   ERreac(i) = abs(Areac(i)/Ereac(i))
*enddo

save,table_4

finish

/com,------------------------------------------------------------------------------------
/com,

/out,

/com,
/com, -------------------------vm-nr1677-2-2c-a Results Verification---------------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-2-2c-a,vrt

/com,
/com, ===========================================
/com,  COMPARISON OF MODAL FREQUENCY
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*VWRITE,moden(1),Emode(1),Amode(1),ERmode(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,' ')

/com,

/com,------------------------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr

/com,
/com,=====================================================
/com,  COMPARISON OF NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,=====================================================
/com,

/com,  Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
```

```
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-------------------------------------------------------------------------
/com,

/nopr
resume,table_4
/gopr

/com,
/com, ===========================================
/com,  COMPARISON OF REACTION FORCES
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com, Node | Expected |  Mechanical APDL  |  Ratio
/com,

*VWRITE,Nreac(1),Ereac(1),Areac(1),ERreac(1)
(5X,a,2X,F12.4,3X,F12.4,3X,F8.2,' ')

/com,

/com,--------------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,==============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,==============================================
/com,

/com,---------------------------------------------------------
/com, Note: Element Forces and Moments for some elements
/com,       along Y & Z directions are flipped between Mechanical APDL
/com,  and NRC results
/com,
/com,----------------------------------------------------------


/com,  Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 20
/com,===============
```

```
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'    ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(25,1),elem_tab(25,2),elem_tab(25,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'    ',f5.3)

/com,
/com,

/com,===============
/com,   Element 8
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'    ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(31,1),elem_tab(31,2),elem_tab(31,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'    ',f5.3)


/com,
/com,
/com,*******************************************************************
/com,*******************************************************************
/com,
/com,
/out,
*list,vm-nr1677-2-2c-a,vrt
finish
```

vm-nr1677-2-3a-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-2-3a-a
/title,vm-nr1677-2-3a-a,NRC piping benchmarks problems,Volume II,Problem 3a

/com, ***************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com, Elements used: Pipe16, Pipe18, Combin14
/com,
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, *******************************************************************************

/out,scratch

/prep7

YoungModulus1 = 0.277e+08   ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu)) ! Shear Modulus
```

```
WMass = 1.546e-03     ! Density
WTick=0.3750     ! Wall Thickness
OD=12.750      ! Outer Diameter
RADCUR1 = 60     ! Radius of Curvature
RADCUR2 = 18
Temperature = 400
Pressue = 615
maxm=15      ! No. of Modes to Extract


/com,------------------------------------------------------------------------------------

et, 1,pipe16     ! Element 1 - PIPE16
et, 2,pipe18     ! Element 2 - PIPE18
keyopt,2,3,1     ! Use ANSYS Flexibility term with pressure item
et, 3,pipe18     ! Element 3 - PIPE18
keyopt,3,3,1     ! Use ANSYS Flexibility term with pressure item
et, 4,combin14     ! Element 4 - COMBIN14
keyopt,4,2,2     ! Y Degree of Freedom
et, 5,combin14     ! Element 5 - COMBIN14
keyopt,5,2,1     ! X Degree of Freedom
et, 6,combin14     ! Element 6 - COMBIN14
keyopt,6,2,2     ! Y Degree of Freedom
et, 7,combin14     ! Element 7 - COMBIN14
keyopt,7,2,3     ! Z Degree of Freedom
et, 8,combin14     ! Element 8 - COMBIN14
keyopt,8,2,4     ! ROT-X Degree of Freedom
et, 9,combin14     ! Element 9 - COMBIN14
keyopt,9,2,5     ! ROT-Y Degree of Freedom
et,10,combin14     ! Element 10 - COMBIN14
keyopt,10,2,6     ! ROT-Z Degree of Freedom

/com,------------------------------------------------------------------------------------

/com, Real Constants
/com,****************

r, 1, OD,WTick
r, 2, OD,WTick,RADCUR1
r, 3, OD,WTick,RADCUR2
r, 4, 0.1e+2
r, 5, 0.1e+13
r, 6, 0.1e+13
r, 7, 0.1e+13
r, 8, 0.1e+13
r, 9, 0.1e+13
r,10, 0.1e+13

/com, ------------------------------------------------------------------------------------

/com, Material Properties
/com,********************

mp,ex,  1, YoungModulus1
mp,nuxy,1, Nu
mp,gxy ,1, ShearModulus1
mp,dens,1, WMass

mp,ex,  2, YoungModulus1
mp,nuxy,2, Nu
mp,gxy ,2, ShearModulus1
mp,dens,2, WMass

mp,ex,  3, YoungModulus1
mp,nuxy,3, Nu
mp,gxy ,3, ShearModulus1
mp,dens,3, WMass

/com,------------------------------------------------------------------------------------

/com, Nodes
/com,*******
```

```
n,1,0,1226.875,0
n,2,30.021,1226.875,30.550
n,3,60.042,1226.875,61.100
n,4,90.064,1226.875,91.651
n,5,105.154,1226.875,102.817
n,6,139.302,1226.875,120.593
n,7,181.878,1226.875,142.757
n,8,224.435,1226.875,164.922
n,9,243.383,1226.875,174.774
n,10,262.311,1226.875,184.628
n,11,292.798,1226.875,191.342

n,12,334.171,1226.875,189.421
n,120,334.171,1226.875,189.421

n,13,375.543,1226.875,187.500

n,14,405.511,1226.875,186.110
n,140,431.483,1226.875,184.904

n,15,501.172,1226.875,181.669
n,16,570.860,1226.875,178.433
n,17,579.777,1226.875,178.683
n,18,615.118,1226.875,182.316
n,20,633.028,1226.875,184.156

n,21,678.227,1226.875,188.802
n,22,723.426,1226.875,193.448
n,23,768.625,1226.875,198.095
n,24,809.602,1226.875,187.256
n,25,814.057,1226.875,184.079
n,26,852.626,1226.875,156.568
n,27,891.195,1226.875,129.058
n,28,929.764,1226.875,101.547

n,29,968.332,1226.875,74.036
n,290,978.101,1226.875,67.067

n,31,1012.600,1226.875,42.430
n,310,1012.600,1226.875,42.430

n,32,1047.098,1226.875,17.793
n,34,1061.752,1244.875,7.340
n,35,1061.752,1272.375,7.340
n,36,1072.214,1290.375,-7.307
n,37,1081.623,1290.375,-20.48
n,38,1108.85,1290.375,-58.399
n,39,1136.077,1290.375,-96.317
n,40,1163.304,1290.375,-134.236
n,41,1190.531,1290.375,-172.154

/com,
/com, Elastic Support Nodes
/com,**********************

n,410,1190.531,1290.375,-172.154

n,43,1197.006,1290.375,-182.019
n,44,1207.729,1290.375,-209.536
n,45,1211.63,1290.375,-241.111
n,46,1215.531,1290.375,-272.687
n,47,1219.432,1290.375,-304.262
n,48,1223.333,1290.375,-335.873
n,49,1227.234,1290.375,-367.413

n,51,1232.114,1290.375,-407.115
n,52,1233.704,1295.647,-419.787
n,53,1234.945,1305.772,-429.836

n,55,1254.329,1318.500,-439.952
n,56,1279.579,1318.500,-436.387
```

```
n,57,1304.829,1318.500,-432.823
n,58,1330.078,1318.500,-429.258
n,59,1355.328,1318.500,-425.693

n,61,431.943,1226.875,194.899
n,62,616.14,1226.875,172.368
n,63,974.139,1226.875,82.176
n,65,1227.234,1300.375,-367.413
n,66,1255.726,1318.500,-449.852

n,67,1182.401,1290.375,-177.966
n,68,105.154,1236.875,102.817
n,69,224.435,1236.875,164.922
n,70,405.511,1236.875,186.110
n,71,633.028,1236.875,184.156
n,72,814.057,1236.875,184.079
n,73,978.101,1236.875,67.067
n,74,1081.623,1300.375,-20.48
n,75,1190.531,1300.375,-172.154

n,101,10,1226.875,0
n,102,0,1236.875,0
n,103,0,1226.875,10

n,591,1345.328,1318.5,-425.693
n,592,1355.328,1328.5,-425.693
n,593,1355.328,1318.5,-415.693

n,601,93.495,1226.9,94.879
n,602,97.170,1226.9,97.828
n,603,101.06,1226.9,100.48

/com,------------------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,**********************************

mat,1       ! Material ID 1
type,1      ! Element Type 1
real,1      ! Real Constant Set 1

e,1,2
e,2,3
e,3,4

e,5,6
e,6,7
e,7,8

e,8,9
e,9,10

e,11,12
e,12,13
e,13,14
e,14,140
e,140,15
e,15,16

e,17,18

e,18,20
e,20,21
e,21,22
e,22,23

e,24,25
e,25,26
e,26,27
e,27,28
e,28,29
```

```
e,29,290
e,290,31
e,31,32

e,34,35

e,36,37
e,37,38
e,38,39
e,39,40
e,40,41
e,41,43

e,44,45
e,45,46
e,46,47
e,47,48
e,48,49
e,49,51

e,52,53

e,55,56
e,56,57
e,57,58
e,58,59

/com,
/com, Pipe Bend Elements
/com,*******************

type,2
real,2
e,4,601,3
e,601,602,603
e,602,603,5
e,603,5,6
e,10,11,9
e,16,17,15
e,23,24,25
e,43,44,45

type,3
real,3
e,32,34,35
e,35,36,37
e,51,52,53
e,53,55,56

/com,
/com, Spring Elements
/com,****************

type,4
real,4
e,49,65

type,6
real,6
e,5,68
e,8,69
e,14,70
e,20,71
e,25,72
e,290,73
e,37,74
e,410,75

type,5
real,5
n1 = 55
n2 = 66
```

```
n3 = 56

ics = 11
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 41
n2 = 67
n3 = 40

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

/com,
/com, Snubber Elements
/com,******************

n1 = 13
n2 = 120
n3 = 59

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 140
n2 = 61
n3 = 15

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 18
n2 = 62
n3 = 17

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 29
n2 = 63
n3 = 28

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
```

```
e,n1,n2

n1 = 32
n2 = 310
n3 = 34
!n3 = 59

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

/com,
/com, 3D Support at both ends
/com,************************

type,5
real,5
e,1,101
e,59,591

type,6
real,6
e,1,102
e,59,592

type,7
real,7
e,1,103
e,59,593

type,8
real,8
e,1,101
e,59,591

type,9
real,9
e,1,102
e,59,592

type,10
real,10
e,1,103
e,59,593

/com,--------------------------------------------------------------------------------

/com,
/com, Model Rigid Region
/com,*******************

cerig,41,410,uy

/com,--------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,s,node,,61,63
nsel,a,node,,65,75
nsel,a,node,,101,103
nsel,a,node,,120
nsel,a,node,,310
nsel,a,node,,591,593
d,all,all,0

nsel,all
```

```
/com,-------------------------------------------------------------------------------------

/com,
/com, Loads
/com,*******

/com, Temperature Input
/com,*******************

bf,all,temp,Temperature

esel,r,type,,1
esel,a,type,,2
esel,a,type,,3

/com, Pressure Input
/com,****************

sfe,all,1,pres,,Pressue,,,

allsel,all,all
save
finish

/com,-------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal       ! Perform modal solve
modopt,lanb,maxm
lump,on        ! Lumped mass formulation
mxpand,maxm,,,yes       ! Expand the modes with stress calculation
solve


/com,
/com,===========================
/com, Compare Modal Frequencies
/com,===========================
/com,

*dim,Amode,ARRAY,maxm
*dim,Emode,ARRAY,maxm
*dim,ERmode,ARRAY,maxm
*dim,moden,ARRAY,maxm

*do,i,1,maxm
 *GET, Amode(i), MODE, i, FREQ
*enddo

*VFILL,Emode,DATA,7.238,10.145,14.579,15.991,17.198,17.987,22.282,23.632,27.864,29.211
*VFILL,Emode(11),DATA,29.514,31.554,34.018,34.778,35.122

*do,i,1,maxm
  ERmode(i) = ABS(Amode(i)/Emode(i))
  moden(i) = i
*enddo
save,table_1
finish

/com,-------------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
```

```
/com,

/solution
gvalue = 386.4

sfedele,all,1,pres,,,
bfdele,all,temp,,,

antype,spectrum      ! Perform Spectrum Analysis
spopt,sprs,maxm      ! Single Point Excitation Response System

srss,,,       ! SRSS mode combination method

/com,
/com,  Excitation in X - Direction
/com,*******************************

svtyp,2,gvalue           ! Acceleration Response Spectrum

freq,1.000,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937,1.3423,1.3889
sv,,1.1620,1.2820,1.3990,1.5490,1.6060,1.6760,1.7040,1.7740,1.8390

freq,1.4104,1.4347,1.5552,1.6949,1.7825,1.9305,2.0747,2.2779,2.4752
sv,,1.8690,1.9040,2.0840,2.2460,2.3040,2.3830,2.4790,2.5920,2.6440

freq,2.6042,2.6596,2.9499,3.2362,3.3898,3.4965,3.5714,3.6101,3.6630
sv,,2.6400,2.6390,2.7820,2.9510,3.0660,3.2150,3.3840,3.5320,3.7660

freq,3.7313,3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505,5.0761
sv,,4.1890,4.7930,5.1890,5.2240,5.2320,5.2270,5.1520,3.0020,2.9230

freq,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627,7.8125,7.8740,7.9365
sv,,2.9000,2.8730,2.8490,2.8440,2.7610,2.6670,2.6350,2.7850,2.7550

freq,8.3333,8.9286,9.5238,9.6154,9.7087,10.4167,10.8696,11.6279,11.7647
sv,,2.8070,2.7970,2.7440,2.6740,2.6270,2.7810,2.9310,3.0770,3.1120

freq,12.1951,12.5000,12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
sv,,3.1340,3.1340,3.1160,2.9750,2.6870,2.5600,2.3990,2.0640,1.8550


freq,15.3846,15.6250,17.8571,18.8679,22.7273,23.8095,24.3902,25.6410,26.3158
sv,,1.5240,1.5120,1.4720,1.3350,1.0900,1.0730,1.0700,1.0490,1.0040


freq,27.0270,27.7778,28.5714,40.000,76.9231,1000.0000
sv,,0.9823,0.9669,0.9560,0.8930,0.8300,0.7710

sed,1,0,0       ! Excitation in X - Direction
solve

/com,
/com, Excitation in Y - Direction
/com,******************************

svtyp,2,gvalue
freq,,

freq,0.5,2,2.100,2.898,4,5,7.692,8.474,10.309
sv,,0.380,2.050,2.750,2.750,3.500,3.500,5.800,12.100,12.100

freq,11.494,14.104,15.384,17.605,23.255,50
sv,,10.700,10.700,5.900,5.900,2.050,1.570

sed,0,1,0       ! Excitation in Y - Direction
solve

/com,
/com, Excitation in Z - Direction
/com,******************************

svtyp,2,gvalue
```

```
freq,,,

freq,1,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937,1.3423,1.3889
sv,,1.1620,1.2820,1.3990,1.5490,1.6060,1.6760,1.7040,1.7740,1.8390

freq,1.4104,1.4347,1.5552,1.6949,1.7825,1.9305,2.0747,2.2779,2.4752
sv,,1.8690,1.9040,2.0840,2.2460,2.3040,2.3820,2.4790,2.5920,2.6440

freq,2.6042,2.6596,2.9499,3.2362,3.3898,3.4965,3.5714,3.6101,3.6630
sv,,2.6400,2.6390,2.7820,2.9510,3.0660,3.2150,3.3840,3.5320,3.7660

freq,3.7313,3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505,5.0761
sv,,4.1890,4.7930,5.1890,5.2240,5.2320,5.2270,5.1520,3.0020,2.9230

freq,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627,7.8125,7.8740,7.9365
sv,,2.900,2.8730,2.8490,2.8440,2.7610,2.6670,2.6350,2.6850,2.7550

freq,8.333,8.9286,9.5238,9.6154,9.7087,10.4167,10.8696,11.6279,11.7647
sv,,2.8070,2.7970,2.7440,2.6740,2.6270,2.7810,2.9310,3.0770,3.1120

freq,12.1951,12.5000,12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
sv,,3.1340,3.1340,3.1160,2.9750,2.6870,2.5600,2.3990,2.0640,1.8550

freq,15.3846,15.6250,17.8571,18.8679,22.7273,23.8095,24.3902,25.6410,26.3158
sv,,1.5240,1.5120,1.4720,1.3350,1.0900,1.0730,1.0700,1.0490,1.0040

freq,27.0270,27.7778,28.5714,40.000,76.9231,1000.000
sv,,0.9823,0.9669,0.9560,0.8930,0.8300,0.7710

sed,0,0,1       ! Excitation in Z - Direction
solve

finish

/com,------------------------------------------------------------------------------------------

/post1
/input,,mcom

/com,-----------------------------------

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1
*dim,label5,char,22,1

/com,-------------------------

label2(1,1) = 'ux_36'
label2(1,2) = 'uy_51'
label2(1,3) = 'uz_20'
label2(1,4) ='rotx_44'
label2(1,5) ='roty_31'
label2(1,6) ='rotz_53'

/com,-----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,-----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
```

```
label4(6,1)='MZ(J)'

/com,-------------------------

label5(1,1)='65'
label5(2,1)='66'
label5(3,1)='67'
label5(4,1)='75'
label5(5,1)='68'
label5(6,1)='69'
label5(7,1)='70'
label5(8,1)='71'
label5(9,1)='72'
label5(10,1)='73'
label5(11,1)='74'
label5(12,1)='101'
label5(13,1)='102'
label5(14,1)='103'
label5(15,1)='591'
label5(16,1)='592'
label5(17,1)='593'
label5(18,1)='120'
label5(19,1)='310'
label5(20,1)='61'
label5(21,1)='62'
label5(22,1)='63'

/com,-------------------------------------------------------------------------------------

/com,
/com,==========================================================
/com, Maximum nodal displacements and rotations comparsion
/com,==========================================================
/com,

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,36,U,X
*GET,AdisY,NODE,51,U,Y
*GET,AdisZ,NODE,20,U,Z
*GET,ArotX,NODE,44,ROT,X
*GET,ArotY,NODE,31,ROT,Y
*GET,ArotZ,NODE,53,ROT,Z

/com,
/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,6.11356e-01
*SET,EdisY,1.10350e+00
*SET,EdisZ,6.21499e-03
*SET,ErotX,9.30337e-03
*SET,ErotY,6.00114e-03
*SET,ErotZ,1.33137e-02

/com,
/com, Error computation
/com,********************

ERdisX=ABS(AdisX/EdisX)
ERdisY=ABS(AdisY/EdisY)
ERdisZ=ABS(AdisZ/EdisZ)
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX
```

```
*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,------------------------------------------------------------------------------------

/com,===========================================================
/com, Element Forces and Moments Comparison
/com,===========================================================

/com, Solution obtained from Mechanical APDL
/com,******************************

*dim,elem_res_I,,3,6
*dim,elem_res_J,,3,6

*dim,pxi,,3
*dim,vyi,,3
*dim,vzi,,3
*dim,txi,,3
*dim,myi,,3
*dim,mzi,,3

*dim,pxj,,3
*dim,vyj,,3
*dim,vzj,,3
*dim,txj,,3
*dim,myj,,3
*dim,mzj,,3

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)
```

```
/com, Element #17
/com,*************

*get,pxi(2,1),elem,17,smisc,1
*get,vyi(2,1),elem,17,smisc,2
*get,vzi(2,1),elem,17,smisc,3
*get,txi(2,1),elem,17,smisc,4
*get,myi(2,1),elem,17,smisc,5
*get,mzi(2,1),elem,17,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com, Element #50
/com,*************

*get,pxi(3,1),elem,50,smisc,1
*get,vyi(3,1),elem,50,smisc,2
*get,vzi(3,1),elem,50,smisc,3
*get,txi(3,1),elem,50,smisc,4
*get,myi(3,1),elem,50,smisc,5
*get,mzi(3,1),elem,50,smisc,6

*vfill,elem_res_I(3,1),data,pxi(3,1)
*vfill,elem_res_I(3,2),data,vyi(3,1)
*vfill,elem_res_I(3,3),data,vzi(3,1)
*vfill,elem_res_I(3,4),data,txi(3,1)
*vfill,elem_res_I(3,5),data,myi(3,1)
*vfill,elem_res_I(3,6),data,mzi(3,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #17
/com,*************

*get,pxj(2,1),elem,17,smisc,7
*get,vyj(2,1),elem,17,smisc,8
*get,vzj(2,1),elem,17,smisc,9
*get,txj(2,1),elem,17,smisc,10
*get,myj(2,1),elem,17,smisc,11
*get,mzj(2,1),elem,17,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
```

```
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com, Element #50
/com,*************

*get,pxj(3,1),elem,50,smisc,7
*get,vyj(3,1),elem,50,smisc,8
*get,vzj(3,1),elem,50,smisc,9
*get,txj(3,1),elem,50,smisc,10
*get,myj(3,1),elem,50,smisc,11
*get,mzj(3,1),elem,50,smisc,12

*vfill,elem_res_J(3,1),data,pxj(3,1)
*vfill,elem_res_J(3,2),data,vyj(3,1)
*vfill,elem_res_J(3,3),data,vzj(3,1)
*vfill,elem_res_J(3,4),data,txj(3,1)
*vfill,elem_res_J(3,5),data,myj(3,1)
*vfill,elem_res_J(3,6),data,mzj(3,1)

/com,-----------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,3,6
*dim,exp_J,,3,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,2.014e+03
*vfill,exp_I(1,2),data,8.689e+01
*vfill,exp_I(1,3),data,8.132e+02
*vfill,exp_I(1,4),data,1.413e+04
*vfill,exp_I(1,5),data,5.834e+04
*vfill,exp_I(1,6),data,3.861e+03

*vfill,exp_J(1,1),data,2.014e+03
*vfill,exp_J(1,2),data,8.689e+01
*vfill,exp_J(1,3),data,8.132e+02
*vfill,exp_J(1,4),data,1.413e+04
*vfill,exp_J(1,5),data,2.443e+04
*vfill,exp_J(1,6),data,5.350e+02

/com, Element #17
/com,*************

*vfill,exp_I(2,1),data,6.286e+03
*vfill,exp_I(2,2),data,7.523e+02
*vfill,exp_I(2,3),data,8.733e+02
*vfill,exp_I(2,4),data,2.243e+04
*vfill,exp_I(2,5),data,8.460e+03
*vfill,exp_I(2,6),data,2.959e+04

*vfill,exp_J(2,1),data,6.286e+03
*vfill,exp_J(2,2),data,7.523e+02
*vfill,exp_J(2,3),data,8.733e+02
*vfill,exp_J(2,4),data,2.243e+04
*vfill,exp_J(2,5),data,4.353e+04
*vfill,exp_j(2,6),data,2.350e+04

/com, Element #48
/com,*************

*vfill,exp_I(3,1),data,1.739e+03
*vfill,exp_I(3,2),data,3.953e+02
*vfill,exp_I(3,3),data,7.730e+02
*vfill,exp_I(3,4),data,1.464e+04
*vfill,exp_I(3,5),data,2.224e+04
*vfill,exp_I(3,6),data,1.652e+04

*vfill,exp_J(3,1),data,1.879e+03
```

```
*vfill,exp_J(3,2),data,3.953e+02
*vfill,exp_J(3,3),data,3.000e+02
*vfill,exp_J(3,4),data,2.026e+04
*vfill,exp_J(3,5),data,2.947e+04
*vfill,exp_J(3,6),data,1.633e+04

/com,------------------------------------------------------------------------

/com, Error computation
/com, ********************

*dim,elem_error_I,,3,6
*dim,elem_error_J,,3,6
*dim,elem_tab,,36,3

/com,============
/com,   Node I
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,-----------------------------------------------------------------------

*do,i,1,3
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+18
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3

/com,-----------------------------------------------------------------------------------------

/com,*****************************
/com, Reaction forces comparision
/com,******************************

*dim,rf_tab,,22,3

/com, Solution obtained from Mechanical APDL
/com,******************************

*GET,RFA65,NODE,65,RF,FY
*GET,RFA66,NODE,66,RF,FX
*GET,RFA67,NODE,67,RF,FX
*GET,RFA75,NODE,75,RF,FY
*GET,RFA68,NODE,68,RF,FY
```

```
*GET,RFA69,NODE,69,RF,FY
*GET,RFA70,NODE,70,RF,FY
*GET,RFA71,NODE,71,RF,FY
*GET,RFA72,NODE,72,RF,FY
*GET,RFA73,NODE,73,RF,FY

*GET,RFA74,NODE,74,RF,FY
*GET,RFA101,NODE,101,RF,FX
*GET,RFA102,NODE,102,RF,FY
*GET,RFA103,NODE,103,RF,FZ

*GET,RFA591,NODE,591,RF,FX
*GET,RFA592,NODE,592,RF,FY
*GET,RFA593,NODE,593,RF,FZ

*GET,RFA120,NODE,120,RF,FX
*GET,RFA310,NODE,310,RF,FX

*GET,RFA61,NODE,61,RF,FX
*GET,RFA62,NODE,62,RF,FX
*GET,RFA63,NODE,63,RF,FX

/com, Expected results from NRC manual
/com,**********************************

*SET,RFE65,11
*SET,RFE66,7837
*SET,RFE67,4472
*SET,RFE75,8931
*SET,RFE68,359

*SET,RFE69,729
*SET,RFE70,784
*SET,RFE71,1043
*SET,RFE72,1378
*SET,RFE73,3408

*SET,RFE74,1448
*SET,RFE101,1685
*SET,RFE102,87
*SET,RFE103,1370

*SET,RFE591,3031
*SET,RFE592,15859
*SET,RFE593,896

*SET,RFE120,6792
*SET,RFE310,11991

*SET,RFE61,801
*SET,RFE62,303
*SET,RFE63,7447

/com, Error computation
/com,*******************

ER65 = ABS(RFA65/RFE65)
ER66 = ABS(RFA66/RFE66)
ER67 = ABS(RFA67/RFE67)
ER75 = ABS(RFA75/RFE75)
ER68 = ABS(RFA68/RFE68)

ER69 = ABS(RFA69/RFE69)
ER70 = ABS(RFA70/RFE70)
ER71 = ABS(RFA71/RFE71)
ER72 = ABS(RFA72/RFE72)
ER73 = ABS(RFA73/RFE73)

ER74  = ABS(RFA74/RFE74)
ER101 = ABS(RFA101/RFE101)
ER102 = ABS(RFA102/RFE102)
```

```
ER103 = ABS(RFA103/RFE103)

ER591 = ABS(RFA591/RFE591)
ER592 = ABS(RFA592/RFE592)
ER593 = ABS(RFA593/RFE593)

ER120 = ABS(RFA120/RFE120)
ER310 = ABS(RFA310/RFE310)

ER61 = ABS(RFA61/RFE61)
ER62 = ABS(RFA62/RFE62)
ER63 = ABS(RFA63/RFE63)

*vfill,rf_tab(1,1),data,RFE65
*vfill,rf_tab(1,2),data,RFA65
*vfill,rf_tab(1,3),data,ER65

*vfill,rf_tab(2,1),data,RFE66
*vfill,rf_tab(2,2),data,RFA66
*vfill,rf_tab(2,3),data,ER66

*vfill,rf_tab(3,1),data,RFE67
*vfill,rf_tab(3,2),data,RFA67
*vfill,rf_tab(3,3),data,ER67

*vfill,rf_tab(4,1),data,RFE75
*vfill,rf_tab(4,2),data,RFA75
*vfill,rf_tab(4,3),data,ER75

*vfill,rf_tab(5,1),data,RFE68
*vfill,rf_tab(5,2),data,RFA68
*vfill,rf_tab(5,3),data,ER68

*vfill,rf_tab(6,1),data,RFE69
*vfill,rf_tab(6,2),data,RFA69
*vfill,rf_tab(6,3),data,ER69

*vfill,rf_tab(7,1),data,RFE70
*vfill,rf_tab(7,2),data,RFA70
*vfill,rf_tab(7,3),data,ER70

*vfill,rf_tab(8,1),data,RFE71
*vfill,rf_tab(8,2),data,RFA71
*vfill,rf_tab(8,3),data,ER71

*vfill,rf_tab(9,1),data,RFE72
*vfill,rf_tab(9,2),data,RFA72
*vfill,rf_tab(9,3),data,ER72

*vfill,rf_tab(10,1),data,RFE73
*vfill,rf_tab(10,2),data,RFA73
*vfill,rf_tab(10,3),data,ER73

*vfill,rf_tab(11,1),data,RFE74
*vfill,rf_tab(11,2),data,RFA74
*vfill,rf_tab(11,3),data,ER74

*vfill,rf_tab(12,1),data,RFE101
*vfill,rf_tab(12,2),data,RFA101
*vfill,rf_tab(12,3),data,ER101

*vfill,rf_tab(13,1),data,RFE102
*vfill,rf_tab(13,2),data,RFA102
*vfill,rf_tab(13,3),data,ER102

*vfill,rf_tab(14,1),data,RFE103
*vfill,rf_tab(14,2),data,RFA103
*vfill,rf_tab(14,3),data,ER103

*vfill,rf_tab(15,1),data,RFE591
*vfill,rf_tab(15,2),data,RFA591
*vfill,rf_tab(15,3),data,ER591
```

```
*vfill,rf_tab(16,1),data,RFE592
*vfill,rf_tab(16,2),data,RFA592
*vfill,rf_tab(16,3),data,ER592

*vfill,rf_tab(17,1),data,RFE593
*vfill,rf_tab(17,2),data,RFA593
*vfill,rf_tab(17,3),data,ER593

*vfill,rf_tab(18,1),data,RFE120
*vfill,rf_tab(18,2),data,RFA120
*vfill,rf_tab(18,3),data,ER120

*vfill,rf_tab(19,1),data,RFE310
*vfill,rf_tab(19,2),data,RFA310
*vfill,rf_tab(19,3),data,ER310

*vfill,rf_tab(20,1),data,RFE61
*vfill,rf_tab(20,2),data,RFA61
*vfill,rf_tab(20,3),data,ER61

*vfill,rf_tab(21,1),data,RFE62
*vfill,rf_tab(21,2),data,RFA62
*vfill,rf_tab(21,3),data,ER62

*vfill,rf_tab(22,1),data,RFE63
*vfill,rf_tab(22,2),data,RFA63
*vfill,rf_tab(22,3),data,ER63

save,table_4

/com,-----------------------------------------------------------------------------------
/com,

/out,

/com,
/com, ------------------------vm-nr1677-2-3a-a Results Verification------------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-2-3a-a,vrt

/com,
/com, ===========================================
/com,  COMPARISON OF MODAL FREQUENCY
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*VWRITE,moden(1),Emode(1),Amode(1),ERmode(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,' ')

/com,

/com,-----------------------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr

/com,
/com,====================================================
/com,  COMPARISON OF NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
```

```
/com,====================================================
/com,

/com,  Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,------------------------------------------------------------------------
/com,

/nopr
resume,table_4
/gopr

/com,
/com, ===========================================
/com,  COMPARISON OF REACTION FORCES
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com,  Node | Expected |  Mechanical APDL  |  Ratio
/com,

*vwrite,label5(1,1),rf_tab(1,1),rf_tab(1,2),rf_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-------------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,=============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,=============================================
/com,

/com,------------------------------------------------
/com, Note: Element Forces and Moments for some elements
/com,       along Y & Z directions are flipped between Mechanical APDL
/com,  and NRC results
/com,
/com,       Element numbers from Mechanical APDL and NRC are
/com,       different.
/com,       Element 1 (Mechanical APDL) = Element 1 (NRC)
/com,       Element 17 (Mechanical APDL) = Element 17 (NRC)
/com,       Element 50 (Mechanical APDL) = Element 48 (NRC)
/com,------------------------------------------------


/com,  Result | Expected | Mechanical APDL |  Ratio
/com,
```

```
/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 17
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(25,1),elem_tab(25,2),elem_tab(25,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 50
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(31,1),elem_tab(31,2),elem_tab(31,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,
/com,
/com,******************************************************************
/com,******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-2-3a-a,vrt
finish
```

vm-nr1677-2-3b-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-2-3b-a
/title,vm-nr1677-2-3b-a,NRC piping benchmarks problems,Volume II,Problem 3b

/com, ***************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
```

```
/com,
/com, Elements used: Pipe16, Pipe18, Combin14,
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, ********************************************************************************

/out,scratch

/prep7

YoungModulus1 = 0.277e+08   ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu)) ! Shear Modulus
WMass = 1.546e-03     ! Density
WTick=0.3750     ! Wall Thickness
OD=12.750      ! Outer Diameter
RADCUR1 = 60     ! Radius of Curvature
RADCUR2 = 18
Temperature = 400
Pressue = 615
maxm=15      ! No. of Modes to Extract


/com,-------------------------------------------------------------------------------------

et, 1,pipe16     ! Element 1 - PIPE16
et, 2,pipe18     ! Element 2 - PIPE18
keyopt,2,3,1     ! Use ANSYS Flexibility term with pressure item
et, 3,pipe18     ! Element 3 - PIPE18
keyopt,3,3,1     ! Use ANSYS Flexibility term with pressure item
et, 4,combin14     ! Element 4 - COMBIN14
keyopt,4,2,2     ! Y Degree of Freedom
et, 5,combin14     ! Element 5 - COMBIN14
keyopt,5,2,1     ! X Degree of Freedom
et, 6,combin14     ! Element 6 - COMBIN14
keyopt,6,2,2     ! Y Degree of Freedom
et, 7,combin14     ! Element 7 - COMBIN14
keyopt,7,2,3     ! Z Degree of Freedom
et, 8,combin14     ! Element 8 - COMBIN14
keyopt,8,2,4     ! ROT-X Degree of Freedom
et, 9,combin14     ! Element 9 - COMBIN14
keyopt,9,2,5     ! ROT-Y Degree of Freedom
et,10,combin14     ! Element 10 - COMBIN14
keyopt,10,2,6     ! ROT-Z Degree of Freedom

/com,-------------------------------------------------------------------------------------


/com, Real Constants
/com,****************

r, 1, OD,WTick
r, 2, OD,WTick,RADCUR1
r, 3, OD,WTick,RADCUR2
r, 4, 0.1e+2
r, 5, 0.1e+13
r, 6, 0.1e+13
r, 7, 0.1e+13
r, 8, 0.1e+13
r, 9, 0.1e+13
r,10, 0.1e+13

/com, -------------------------------------------------------------------------------------

/com, Material Properties
/com,********************
```

```
mp,ex,  1, YoungModulus1
mp,nuxy,1, Nu
mp,gxy ,1, ShearModulus1
mp,dens,1, WMass

mp,ex,  2, YoungModulus1
mp,nuxy,2, Nu
mp,gxy ,2, ShearModulus1
mp,dens,2, WMass

mp,ex,  3, YoungModulus1
mp,nuxy,3, Nu
mp,gxy ,3, ShearModulus1
mp,dens,3, WMass

/com,-----------------------------------------------------------------------------------

/com, Nodes
/com,*******

n,1,0,1226.875,0
n,2,30.021,1226.875,30.550
n,3,60.042,1226.875,61.100
n,4,90.064,1226.875,91.651
n,5,105.154,1226.875,102.817
n,6,139.302,1226.875,120.593
n,7,181.878,1226.875,142.757
n,8,224.435,1226.875,164.922
n,9,243.383,1226.875,174.774
n,10,262.311,1226.875,184.628

n,11,292.798,1226.875,191.342

n,12,334.171,1226.875,189.421
n,120,334.171,1226.875,189.421

n,13,375.543,1226.875,187.500

n,14,405.511,1226.875,186.110
n,140,431.483,1226.875,184.904

n,15,501.172,1226.875,181.669
n,16,570.860,1226.875,178.433
n,17,579.777,1226.875,178.683
n,18,615.118,1226.875,182.316
n,20,633.028,1226.875,184.156

n,21,678.227,1226.875,188.802
n,22,723.426,1226.875,193.448
n,23,768.625,1226.875,198.095
n,24,809.602,1226.875,187.256
n,25,814.057,1226.875,184.079
n,26,852.626,1226.875,156.568
n,27,891.195,1226.875,129.058
n,28,929.764,1226.875,101.547

n,29,968.332,1226.875,74.036
n,290,978.101,1226.875,67.067

n,31,1012.600,1226.875,42.430
n,310,1012.600,1226.875,42.430

n,32,1047.098,1226.875,17.793
n,34,1061.752,1244.875,7.340
n,35,1061.752,1272.375,7.340
n,36,1072.214,1290.375,-7.307
n,37,1081.623,1290.375,-20.48
n,38,1108.85,1290.375,-58.399
n,39,1136.077,1290.375,-96.317
n,40,1163.304,1290.375,-134.236
n,41,1190.531,1290.375,-172.154
```

```
/com,
/com, Elastic Support Nodes
/com,***********************

n,410,1190.531,1290.375,-172.154

n,43,1197.006,1290.375,-182.019
n,44,1207.729,1290.375,-209.536
n,45,1211.63,1290.375,-241.111
n,46,1215.531,1290.375,-272.687
n,47,1219.432,1290.375,-304.262
n,48,1223.333,1290.375,-335.873
n,49,1227.234,1290.375,-367.413

n,51,1232.114,1290.375,-407.115
n,52,1233.704,1295.647,-419.787
n,53,1234.945,1305.772,-429.836

n,55,1254.329,1318.500,-439.952
n,56,1279.579,1318.500,-436.387
n,57,1304.829,1318.500,-432.823
n,58,1330.078,1318.500,-429.258
n,59,1355.328,1318.500,-425.693

n,61,431.943,1226.875,194.899
n,62,616.14,1226.875,172.368
n,63,974.139,1226.875,82.176
n,65,1227.234,1300.375,-367.413
n,66,1255.726,1318.500,-449.852

n,67,1182.401,1290.375,-177.966
n,68,105.154,1236.875,102.817
n,69,224.435,1236.875,164.922
n,70,405.511,1236.875,186.110
n,71,633.028,1236.875,184.156
n,72,814.057,1236.875,184.079
n,73,978.101,1236.875,67.067
n,74,1081.623,1300.375,-20.48
n,75,1190.531,1300.375,-172.154

n,101,10,1226.875,0
n,102,0,1236.875,0
n,103,0,1226.875,10

n,591,1345.328,1318.5,-425.693
n,592,1355.328,1328.5,-425.693
n,593,1355.328,1318.5,-415.693

n,601,93.495,1226.9,94.879
n,602,97.170,1226.9,97.828
n,603,101.06,1226.9,100.48

/com,-----------------------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,**********************************

mat,1       ! Material ID 1
type,1      ! Element Type 1
real,1      ! Real Constant Set 1

e,1,2
e,2,3
e,3,4

e,5,6
e,6,7
e,7,8

e,8,9
```

```
e,9,10

e,11,12
e,12,13
e,13,14
e,14,140
e,140,15
e,15,16

e,17,18

e,18,20
e,20,21
e,21,22
e,22,23

e,24,25
e,25,26
e,26,27
e,27,28
e,28,29
e,29,290
e,290,31
e,31,32

e,34,35

e,36,37
e,37,38
e,38,39
e,39,40
e,40,41
e,41,43

e,44,45
e,45,46
e,46,47
e,47,48
e,48,49
e,49,51

e,52,53

e,55,56
e,56,57
e,57,58
e,58,59

/com,
/com, Pipe Bend Elements
/com,********************

type,2
real,2
e,4,601,3
e,601,602,603
e,602,603,5
e,603,5,6
e,10,11,9
e,16,17,15
e,23,24,25
e,43,44,45

type,3
real,3
e,32,34,35
e,35,36,37
e,51,52,53
e,53,55,56

/com,
/com, Spring Elements
```

```
/com,*****************

type,4
real,4
e,49,65

type,6
real,6
e,5,68
e,8,69
e,14,70
e,20,71
e,25,72
e,290,73
e,37,74
e,410,75

type,5
real,5
n1 = 55
n2 = 66
n3 = 56

ics = 11
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 41
n2 = 67
n3 = 40

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

/com,
/com, Snubber Elements
/com,*****************

n1 = 13
n2 = 120
n3 = 59

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 140
n2 = 61
n3 = 15

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 18
```

```
n2 = 62
n3 = 17

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 29
n2 = 63
n3 = 28

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 32
n2 = 310
n3 = 34
!n3 = 59

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

/com,
/com, 3D Support at both ends
/com,*************************

type,5
real,5
e,1,101
e,59,591

type,6
real,6
e,1,102
e,59,592

type,7
real,7
e,1,103
e,59,593

type,8
real,8
e,1,101
e,59,591

type,9
real,9
e,1,102
e,59,592

type,10
real,10
e,1,103
e,59,593

/com,-------------------------------------------------------------------------------------
```

```
/com,
/com, Model Rigid Region
/com,********************

cerig,41,410,uy

/com,------------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,s,node,,61,63
nsel,a,node,,65,75
nsel,a,node,,101,103
nsel,a,node,,120
nsel,a,node,,310
nsel,a,node,,591,593
d,all,all,0

nsel,all

/com,------------------------------------------------------------------------------------

/com,
/com, Loads
/com,*******

/com, Temperature Input
/com,*******************

bf,all,temp,Temperature

eplo
esel,r,type,,1
esel,a,type,,2
esel,a,type,,3

/com, Pressure Input
/com,****************

sfe,all,1,pres,,Pressue,,,

allsel,all,all
save
finish

/com,------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,maxm
lump,on
mxpand,maxm,,,yes
solve


/com,
/com,==========================
/com, Compare Modal Frequencies
/com,==========================
/com,

*dim,Amode,ARRAY,maxm
*dim,Emode,ARRAY,maxm
*dim,ERmode,ARRAY,maxm
```

```
*dim,moden,ARRAY,maxm

*do,i,1,maxm
 *GET, Amode(i), MODE, i, FREQ
*enddo

*VFILL,Emode,DATA,7.238,10.145,14.579,15.991,17.198,17.987,22.282,23.632,27.864,29.211
*VFILL,Emode(11),DATA,29.514,31.554,34.018,34.778,35.122

*do,i,1,maxm
  ERmode(i) = ABS(Amode(i)/Emode(i))
  moden(i) = i
*enddo

save,table_1
finish

/com,-----------------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
sfedele,all,1,pres,,,
bfdele,all,temp,,,

antype,spectrum
spopt,mprs,maxm      ! Multi-point response spectrum analysis

gval = 386.4

/com,-----------------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 1 (Group 1 - X - Direction Excitation)
/com,*************************************************

spunit,1,accg, gval

spfrq,1, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,1,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,1, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,1,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,1, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,1,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,1, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,1,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,1, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,1,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,1, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,1,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,1, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,1,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,1, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,1,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,1, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,1,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,1, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,1,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07
```

```
spfrq,1, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,1,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,1, 1000.0
spval,1,, 0.771

/com,
/com, Spectrum 2 (Group 1 - Y - Direction Excitation)
/com,*************************************************

spunit,2,accg, gval

spfrq,2, 0.5,1.4993,1.6207,1.9011,2.0704,3.8023,4.2553,
spval,2,,  0.35,1.45,1.8,1.8,2.61,2.61,2.78,

spfrq,2, 5.1813,5.4054,7.8125,8.1301,9.901,11.5207,14.1044,
spval,2,,  2.78,2.58,2.58,3.25,3.25,3.62,3.62,

spfrq,2, 14.4928,17.6991,23.9981,59.988
spval,2,,  3.05,3.05,1.20,0.75

/com,
/com, Spectrum 3 (Group 1 - Z - Direction Excitation)
/com,*************************************************

spunit,3,accg, gval

spfrq,3, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,3,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,3, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,3,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,3, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,3,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782,

spfrq,3, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
spval,3,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,3, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
spval,3,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,3, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,3,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,3, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,3,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,3, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,3,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,3, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,3,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,3, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,3,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,3, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,3,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,3, 1000.0
spval,3,, 0.771


/com,--------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 4 (Group 2 - X - Direction Excitation)
/com,*************************************************
```

```
spunit,4,accg, gval

spfrq,4, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,4,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,4, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,4,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,4, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,4,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,4, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
spval,4,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,4, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
spval,4,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,4, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,4,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,4, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,4,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,4, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,4,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,4, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,4,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,4, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,4,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,4, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,4,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,4, 1000.0
spval,4,, 0.771

/com,
/com, Spectrum 5 (Group 2 - Y - Direction Excitation)
/com,*************************************************

spunit,5,accg, gval

spfrq,5, 0.50,1.4556,1.9011,2.0704,2.907,4.065,4.9603
spval,5,,  1.45,1.8,1.8,2.68,2.68,3.17,3.17

spfrq,5, 5.0,7.5988,8.5034,10.9051,11.5207,14.0845,16.0
spval,5,,  3.03,3.03,4.82,4.82,5.95,5.95,4.49

spfrq,5, 19.1205,21.0084,50.0
spval,5,,  4.49,1.85,1.05

/com,
/com, Spectrum 6 (Group 2 - Z - Direction Excitation)
/com,*************************************************

spunit,6,accg, gval

spfrq,6, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,6,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,6, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,6,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,6, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,6,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,6, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
spval,6,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,6, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
```

```
spval,6,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,6, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,6,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,6, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,6,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,6, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,6,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,6, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,6,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,6, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,6,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,6, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,6,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,6, 1000.0
spval,6,, 0.771

/com,-------------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 7 (Group 3 - X - Direction Excitation)
/com,**************************************************

spunit,7,accg, gval

spfrq,7, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,7,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,7, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,7,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,7, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,7,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,7, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
spval,7,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,7, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
spval,7,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,7, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,7,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,7, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,7,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,7, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,7,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,7, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,7,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,7, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,7,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,7, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,7,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,7, 1000.0
spval,7,, 0.771

/com,
/com, Spectrum 8 (Group 3 - Y - Direction Excitation)
/com,**************************************************
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```
spunit,8,accg, gval

spfrq,8, 0.5,1.9011,2.0704,3.003,4.0486,4.9505,7.1942
spval,8,,  0.4,1.88,2.72,2.72,3.42,3.42,3.82

spfrq,8, 8.1301,9.5238,10.352,12.6422,13.5135,15.4083,15.7978
spval,8,,  7.21,7.21,8.18,8.18,6.39,6.39,5.92

spfrq,8, 17.6991,21.0084,50.0
spval,8,,  5.92,2.25,1.55

/com,
/com, Spectrum 9 (Group 3 - Z - Direction Excitation)
/com,**************************************************

spunit,9,accg, gval

spfrq,9, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,9,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,9, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,9,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,9, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,9,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,9, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
spval,9,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,9, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
spval,9,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,9, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,9,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,9, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,9,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,9, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,9,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,9, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,9,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,9, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,9,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,9, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,9,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,9, 1000.0
spval,9,, 0.771

/com,------------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 10 (Group 4 - X - Direction Excitation)
/com,**************************************************

spunit,10,accg, gval

spfrq,10, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,10,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,10, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,10,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,10, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,10,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,10, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
```

```
spval,10,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,10, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
spval,10,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,10, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,10,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,10, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,10,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,10, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,10,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,10, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,10,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,10, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,10,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,10, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,10,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,10, 1000.0
spval,10,, 0.771


/com,
/com, Spectrum 11 (Group 4 - Y - Direction Excitation)
/com,**************************************************

spunit,11,accg, gval

spfrq,11, 0.5,1.3004,2.0,3.003,4.0486,4.9505,6.993
spval,11,,  0.5,1.4,2.75,2.75,3.5,3.5,4.5

spfrq,11, 8.1301,10.4167,11.4943,14.845,17.5439,22.2222,50.0
spval,11,,  12.1,12.1,10.7,10.7,2.7,1.8,1.5


/com,
/com, Spectrum 12 (Group 4 - Z - Direction Excitation)
/com,**************************************************

spunit,12,accg, gval

spfrq,12, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,12,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,12, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,12,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,12, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,12,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,12, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
spval,12,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,12, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
spval,12,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,12, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,12,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,12, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,12,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,12, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,12,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,12, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,12,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855
```

```
spfrq,12, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,12,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,12, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,12,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,12, 1000.0
spval,12,, 0.771

/com,-----------------------------------------------------------------------------------
/com,

/com,
/com, Nodal Components for Excitation Points (non rotated)
/com,*****************************************************

allsel,all

nsel,s,node,,68
nsel,a,node,,71
nsel,a,node,,73
nsel,a,node,,591,593
nplo
cm,group_1,node

allsel,all,all

nsel,s,node,,70
nsel,a,node,,75
nsel,a,node,,65
nplo
cm,group_2,node

allsel,all,all
nsel,s,node,,69
nsel,a,node,,72
nsel,a,node,,74
nplo
cm,group_3,node

allsel,all,all
nsel,s,node,,101,103
nplo
cm,group_4,node

allsel,all,


/com,-----------------------------------------------------------------------------------
/com,

/com,
/com, -- Support Group 1 - spectrum 1 (Along X - Direction)(68,61,71,63,73,310,591,592,593)
/com,***************************************************************************************

d,591,ux,1.0
d,61,ux,4.5974e-2
d,63,ux,0.58075
d,310,ux,-0.81378

pfact,1

d,591,ux,0.0
d,61,ux,0
d,63,ux,0
d,310,ux,0

/com,
/com, -- Support Group 1 - spectrum 2 (Along Y - Direction)
/com,******************************************************
```

```
d,68,uy,1
d,71,uy,1
d,73,uy,1
d,592,uy,1
d,61,ux,-0.5842e-16
d,63,ux,0.2567e-16
d,310,ux,-0.2074e-15

pfact,2

d,68,uy,0
d,71,uy,0
d,73,uy,0
d,592,uy,0
d,61,ux,0
d,63,ux,0
d,310,ux,0

/com,
/com, -- Support Group 1 - spectrum 3 (Along Z - Direction)
/com,*******************************************************

d,593,uz,1.0
d,61,ux,0.9989
d,63,ux,0.8141
d,310,ux,0.5812

pfact,3

d,593,uz,0.0
d,61,ux,0
d,63,ux,0
d,310,ux,0

/com,--------------------------------------------------------------------------------
/com,

/com,
/com, -- Support Group 2 - spectrum 4 (Along X - Direction)(120,70,62,65,75,67)
/com,*************************************************************************


d,120,ux,-0.998923
d,62,ux,0.1021963
d,67,ux,-0.8135

pfact,4

d,120,ux,0
d,62,ux,0
d,67,ux,0

/com,
/com, -- Support Group 2 - spectrum 5 (Along Y - Direction)
/com,*******************************************************

d,70,uy,1
d,65,uy,1
d,75,uy,1
d,120,ux,0.1299e-13
d,62,ux,0.5497e-16
d,67,ux,0.1110e-15

pfact,5

d,70,uy,0
d,65,uy,0
d,75,uy,0
d,120,ux,0
d,62,ux,0
d,67,ux,0
```

```
/com,
/com, -- Support Group 2 - spectrum 6 (Along Z - Direction)
/com,******************************************************

d,120,ux,0.4638e-01
d,62,ux,-0.9948
d,67,ux,-0.5816

pfact,6

d,120,ux,0
d,62,ux,0
d,67,ux,0

/com,-----------------------------------------------------------------------------------
/com,

/com,
/com, -- Support Group 3 - spectrum 7 (Along X - Direction)(69,72,74)
/com,****************************************************************

pfact,7

/com,
/com, -- Support Group 3 - spectrum 8 (Along Y - Direction)
/com,******************************************************

d,69,uy,1
d,72,uy,1
d,74,uy,1

pfact,8

d,69,uy,0
d,72,uy,0
d,74,uy,0

/com,
/com, -- Support Group 3 - spectrum 9 (Along Z - Direction)
/com,******************************************************

pfact,9

/com,-----------------------------------------------------------------------------------
/com,

/com,
/com, -- Support Group 4 - spectrum 10 (Along X - Direction)(101,102,103,55)
/com,***********************************************************************

d,101,ux,1.0
d,66,ux,0.1397268

pfact,10

d,101,ux,0
d,66,ux,0

/com,
/com, -- Support Group 4 - spectrum 11 (Along Y - Direction)
/com,*******************************************************

d,102,uy,1
d,66,ux,-0.5268e-16

pfact,11

d,102,uy,0
d,66,ux,0

/com,
/com, -- Support Group 4 - spectrum 12 (Along Z - Direction)
```

```
/com,*******************************************************

d,103,uz,1
d,66,ux,-0.9902

pfact,12

d,103,uz,0
d,66,ux,0

srss,0.0      ! take all modes (Mode combination method)
solve

/com,-----------------------------------------------------------------------------------
/com,
finish

/com,-----------------------------------------------------------------------------------
/com,

/post1
/input,,mcom

/com,---------------------------------

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1
*dim,label5,char,22,1

/com,------------------------

label2(1,1) = 'ux_36'
label2(1,2) = 'uy_51'
label2(1,3) = 'uz_36'
label2(1,4) ='rotx_22'
label2(1,5) ='roty_22'
label2(1,6) ='rotz_35'

/com,----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,------------------------

label5(1,1)='65'
label5(2,1)='66'
label5(3,1)='67'
label5(4,1)='75'
label5(5,1)='68'
label5(6,1)='69'
label5(7,1)='70'
label5(8,1)='71'
label5(9,1)='72'
label5(10,1)='73'
label5(11,1)='74'
label5(12,1)='101'
```

```
label5(13,1)='102'
label5(14,1)='103'
label5(15,1)='591'
label5(16,1)='592'
label5(17,1)='593'
label5(18,1)='120'
label5(19,1)='61'
label5(20,1)='62'
label5(21,1)='63'
label5(22,1)='310'


/com,-------------------------------------------------------------------------------------

/com,
/com,=======================================================
/com, Maximum nodal displacements and rotations comparsion
/com,=======================================================
/com,

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,36,U,X
*GET,AdisY,NODE,51,U,Y
*GET,AdisZ,NODE,36,U,Z
*GET,ArotX,NODE,22,ROT,X
*GET,ArotY,NODE,22,ROT,Y
*GET,ArotZ,NODE,35,ROT,Z

/com,
/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,5.67443e-01
*SET,EdisY,3.88826e-01
*SET,EdisZ,5.21947e-01
*SET,ErotX,2.78523e-03
*SET,ErotY,8.14600e-05
*SET,ErotZ,7.05298e-03

/com,
/com, Error computation
/com,********************

ERdisX=ABS(AdisX/EdisX)
ERdisY=ABS(AdisY/EdisY)
ERdisZ=ABS(AdisZ/EdisZ)
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
```

```
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,-------------------------------------------------------------------------------------

/com,=========================================================
/com, Element Forces and Moments Comparison
/com,=========================================================

/com, Solution obtained from Mechanical APDL
/com,******************************

*dim,elem_res_I,,3,6
*dim,elem_res_J,,3,6

*dim,pxi,,3
*dim,vyi,,3
*dim,vzi,,3
*dim,txi,,3
*dim,myi,,3
*dim,mzi,,3

*dim,pxj,,3
*dim,vyj,,3
*dim,vzj,,3
*dim,txj,,3
*dim,myj,,3
*dim,mzj,,3

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #17
/com,*************

*get,pxi(2,1),elem,17,smisc,1
*get,vyi(2,1),elem,17,smisc,2
*get,vzi(2,1),elem,17,smisc,3
*get,txi(2,1),elem,17,smisc,4
*get,myi(2,1),elem,17,smisc,5
*get,mzi(2,1),elem,17,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
```

```
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com, Element #50
/com,*************

*get,pxi(3,1),elem,50,smisc,1
*get,vyi(3,1),elem,50,smisc,2
*get,vzi(3,1),elem,50,smisc,3
*get,txi(3,1),elem,50,smisc,4
*get,myi(3,1),elem,50,smisc,5
*get,mzi(3,1),elem,50,smisc,6

*vfill,elem_res_I(3,1),data,pxi(3,1)
*vfill,elem_res_I(3,2),data,vyi(3,1)
*vfill,elem_res_I(3,3),data,vzi(3,1)
*vfill,elem_res_I(3,4),data,txi(3,1)
*vfill,elem_res_I(3,5),data,myi(3,1)
*vfill,elem_res_I(3,6),data,mzi(3,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #17
/com,*************

*get,pxj(2,1),elem,17,smisc,7
*get,vyj(2,1),elem,17,smisc,8
*get,vzj(2,1),elem,17,smisc,9
*get,txj(2,1),elem,17,smisc,10
*get,myj(2,1),elem,17,smisc,11
*get,mzj(2,1),elem,17,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com, Element #50
/com,*************

*get,pxj(3,1),elem,50,smisc,7
*get,vyj(3,1),elem,50,smisc,8
*get,vzj(3,1),elem,50,smisc,9
*get,txj(3,1),elem,50,smisc,10
*get,myj(3,1),elem,50,smisc,11
*get,mzj(3,1),elem,50,smisc,12

*vfill,elem_res_J(3,1),data,pxj(3,1)
*vfill,elem_res_J(3,2),data,vyj(3,1)
*vfill,elem_res_J(3,3),data,vzj(3,1)
```

```
*vfill,elem_res_J(3,4),data,txj(3,1)
*vfill,elem_res_J(3,5),data,myj(3,1)
*vfill,elem_res_J(3,6),data,mzj(3,1)

/com,---------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,3,6
*dim,exp_J,,3,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,3.807e+03
*vfill,exp_I(1,2),data,1.091e+02
*vfill,exp_I(1,3),data,1.139e+03
*vfill,exp_I(1,4),data,1.722e+04
*vfill,exp_I(1,5),data,7.741e+04
*vfill,exp_I(1,6),data,5.027e+03

*vfill,exp_J(1,1),data,3.807e+03
*vfill,exp_J(1,2),data,1.091e+02
*vfill,exp_J(1,3),data,1.139e+03
*vfill,exp_J(1,4),data,1.722e+04
*vfill,exp_J(1,5),data,3.093e+04
*vfill,exp_J(1,6),data,7.753e+02

/com, Element #17
/com,*************

*vfill,exp_I(2,1),data,3.539e+03
*vfill,exp_I(2,2),data,9.333e+02
*vfill,exp_I(2,3),data,5.331e+02
*vfill,exp_I(2,4),data,2.639e+04
*vfill,exp_I(2,5),data,9.809e+03
*vfill,exp_I(2,6),data,4.163e+04

*vfill,exp_J(2,1),data,3.539e+03
*vfill,exp_J(2,2),data,9.333e+02
*vfill,exp_J(2,3),data,5.331e+02
*vfill,exp_J(2,4),data,2.639e+04
*vfill,exp_J(2,5),data,2.900e+04
*vfill,exp_j(2,6),data,4.198e+04

/com, Element #48
/com,*************

*vfill,exp_I(3,1),data,3.150e+03
*vfill,exp_I(3,2),data,6.496e+02
*vfill,exp_I(3,3),data,1.386e+03
*vfill,exp_I(3,4),data,1.748e+04
*vfill,exp_I(3,5),data,2.813e+04
*vfill,exp_I(3,6),data,1.915e+04

*vfill,exp_J(3,1),data,3.413e+03
*vfill,exp_J(3,2),data,6.496e+02
*vfill,exp_J(3,3),data,4.442e+02
*vfill,exp_J(3,4),data,2.351e+04
*vfill,exp_J(3,5),data,3.899e+04
*vfill,exp_J(3,6),data,2.353e+04

/com,--------------------------------------------------------------------------

/com, Error computation
/com, ********************

*dim,elem_error_I,,3,6
*dim,elem_error_J,,3,6
*dim,elem_tab,,36,3
```

```
/com,============
/com,   Node I
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,------------------------------------------------------------------------

*do,i,1,3
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+18
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3

/com,----------------------------------------------------------------------------------

/com,*****************************
/com, Reaction forces comparision
/com,******************************

*dim,rf_tab,,22,3

/com, Solution obtained from Mechanical APDL
/com,******************************

*GET,RFA65,NODE,65,RF,FY
*GET,RFA66,NODE,66,RF,FX
*GET,RFA67,NODE,67,RF,FX
*GET,RFA75,NODE,75,RF,FY
*GET,RFA68,NODE,68,RF,FY

*GET,RFA69,NODE,69,RF,FY
*GET,RFA70,NODE,70,RF,FY
*GET,RFA71,NODE,71,RF,FY
*GET,RFA72,NODE,72,RF,FY
*GET,RFA73,NODE,73,RF,FY

*GET,RFA74,NODE,74,RF,FY
*GET,RFA101,NODE,101,RF,FX
*GET,RFA102,NODE,102,RF,FY
*GET,RFA103,NODE,103,RF,FZ
*GET,RFA591,NODE,591,RF,FX

*GET,RFA592,NODE,592,RF,FY
*GET,RFA593,NODE,593,RF,FZ
```

```
*GET,RFA120,NODE,120,RF,FX
*GET,RFA61,NODE,61,RF,FX
*GET,RFA62,NODE,62,RF,FX
*GET,RFA63,NODE,63,RF,FX
*GET,RFA310,NODE,310,RF,FX

/com, Expected results from NRC manual
/com,*********************************

*SET,RFE65,4
*SET,RFE66,6845
*SET,RFE67,3100
*SET,RFE75,2923
*SET,RFE68,524

*SET,RFE69,1144
*SET,RFE70,1068
*SET,RFE71,1416
*SET,RFE72,1666
*SET,RFE73,2776

*SET,RFE74,1738
*SET,RFE101,3160
*SET,RFE102,109
*SET,RFE103,2408
*SET,RFE591,2834

*SET,RFE592,4923
*SET,RFE593,803

*SET,RFE120,4953
*SET,RFE61,831
*SET,RFE62,312
*SET,RFE63,4411
*SET,RFE310,5898

/com, Error computation
/com,*******************

ER65 = ABS(RFA65/RFE65)
ER66 = ABS(RFA66/RFE66)
ER67 = ABS(RFA67/RFE67)
ER75 = ABS(RFA75/RFE75)
ER68 = ABS(RFA68/RFE68)

ER69 = ABS(RFA69/RFE69)
ER70 = ABS(RFA70/RFE70)
ER71 = ABS(RFA71/RFE71)
ER72 = ABS(RFA72/RFE72)
ER73 = ABS(RFA73/RFE73)

ER74  = ABS(RFA74/RFE74)
ER101 = ABS(RFA101/RFE101)
ER102 = ABS(RFA102/RFE102)
ER103 = ABS(RFA103/RFE103)
ER591 = ABS(RFA591/RFE591)

ER592 = ABS(RFA592/RFE592)
ER593 = ABS(RFA593/RFE593)

ER120 = ABS(RFA120/RFE120)
ER61 = ABS(RFA61/RFE61)
ER62 = ABS(RFA62/RFE62)
ER63 = ABS(RFA63/RFE63)
ER310 = ABS(RFA310/RFE310)

*vfill,rf_tab(1,1),data,RFE65
*vfill,rf_tab(1,2),data,RFA65
*vfill,rf_tab(1,3),data,ER65

*vfill,rf_tab(2,1),data,RFE66
```

```
*vfill,rf_tab(2,2),data,RFA66
*vfill,rf_tab(2,3),data,ER66

*vfill,rf_tab(3,1),data,RFE67
*vfill,rf_tab(3,2),data,RFA67
*vfill,rf_tab(3,3),data,ER67

*vfill,rf_tab(4,1),data,RFE75
*vfill,rf_tab(4,2),data,RFA75
*vfill,rf_tab(4,3),data,ER75

*vfill,rf_tab(5,1),data,RFE68
*vfill,rf_tab(5,2),data,RFA68
*vfill,rf_tab(5,3),data,ER68

*vfill,rf_tab(6,1),data,RFE69
*vfill,rf_tab(6,2),data,RFA69
*vfill,rf_tab(6,3),data,ER69

*vfill,rf_tab(7,1),data,RFE70
*vfill,rf_tab(7,2),data,RFA70
*vfill,rf_tab(7,3),data,ER70

*vfill,rf_tab(8,1),data,RFE71
*vfill,rf_tab(8,2),data,RFA71
*vfill,rf_tab(8,3),data,ER71

*vfill,rf_tab(9,1),data,RFE72
*vfill,rf_tab(9,2),data,RFA72
*vfill,rf_tab(9,3),data,ER72

*vfill,rf_tab(10,1),data,RFE73
*vfill,rf_tab(10,2),data,RFA73
*vfill,rf_tab(10,3),data,ER73

*vfill,rf_tab(11,1),data,RFE74
*vfill,rf_tab(11,2),data,RFA74
*vfill,rf_tab(11,3),data,ER74

*vfill,rf_tab(12,1),data,RFE101
*vfill,rf_tab(12,2),data,RFA101
*vfill,rf_tab(12,3),data,ER101

*vfill,rf_tab(13,1),data,RFE102
*vfill,rf_tab(13,2),data,RFA102
*vfill,rf_tab(13,3),data,ER102

*vfill,rf_tab(14,1),data,RFE103
*vfill,rf_tab(14,2),data,RFA103
*vfill,rf_tab(14,3),data,ER103

*vfill,rf_tab(15,1),data,RFE591
*vfill,rf_tab(15,2),data,RFA591
*vfill,rf_tab(15,3),data,ER591

*vfill,rf_tab(16,1),data,RFE592
*vfill,rf_tab(16,2),data,RFA592
*vfill,rf_tab(16,3),data,ER592

*vfill,rf_tab(17,1),data,RFE593
*vfill,rf_tab(17,2),data,RFA593
*vfill,rf_tab(17,3),data,ER593

*vfill,rf_tab(18,1),data,RFE120
*vfill,rf_tab(18,2),data,RFA120
*vfill,rf_tab(18,3),data,ER120

*vfill,rf_tab(19,1),data,RFE61
*vfill,rf_tab(19,2),data,RFA61
*vfill,rf_tab(19,3),data,ER61

*vfill,rf_tab(20,1),data,RFE62
```

```
*vfill,rf_tab(20,2),data,RFA62
*vfill,rf_tab(20,3),data,ER62

*vfill,rf_tab(21,1),data,RFE63
*vfill,rf_tab(21,2),data,RFA63
*vfill,rf_tab(21,3),data,ER63

*vfill,rf_tab(22,1),data,RFE310
*vfill,rf_tab(22,2),data,RFA310
*vfill,rf_tab(22,3),data,ER310

save,table_4

/com,------------------------------------------------------------------------------------------
/com,

/out,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-2-3b-a,vrt

/com,
/com, ---------------------vm-nr1677-2-3b-a Results Verification ------------------------------
/com,

/com,
/com, ===========================================
/com,  COMPARISON OF MODAL FREQUENCY
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*VWRITE,moden(1),Emode(1),Amode(1),ERmode(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,' ')

/com,

/com,------------------------------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr

/com,
/com,=====================================================
/com,  COMPARISON OF NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,=====================================================
/com,

/com,  Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
```

```
/com,

/com,----------------------------------------------------------------------
/com,

/nopr
resume,table_4
/gopr

/com,
/com, ==========================================
/com,  COMPARISON OF REACTION FORCES
/com,      WITH EXPECTED RESULTS
/com, ==========================================
/com,

/com,  Node | Expected |  Mechanical APDL  |  Ratio
/com,

*vwrite,label5(1,1),rf_tab(1,1),rf_tab(1,2),rf_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-----------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,===============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,===============================================
/com,

/com,------------------------------------------------
/com, Note: Element Forces and Moments for some elements
/com,       along Y & Z directions are flipped between Mechanical APDL
/com,  and NRC results
/com,
/com,       Element numbers from Mechanical APDL and NRC are
/com,       different.
/com,       Element 1 (Mechanical APDL) = Element 1 (NRC)
/com,       Element 17 (Mechanical APDL) = Element 17 (NRC)
/com,       Element 50 (Mechanical APDL) = Element 48 (NRC)
/com,------------------------------------------------


/com,  Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)

/com,
/com,

/com,===============
```

```
/com,   Element 17
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(25,1),elem_tab(25,2),elem_tab(25,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 50
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(31,1),elem_tab(31,2),elem_tab(31,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,
/com,
/com,*******************************************************************
/com,*******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-2-3b-a,vrt
finish
```

vm-nr1677-2-3c-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-2-3c-a
/title,vm-nr1677-2-3c-a,NRC piping benchmarks problems,Volume II,Problem 3c

/com, ******************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com, Element used: Pipe16, Pipe18, Combin14,
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, ******************************************************************************

/out,scratch

/prep7

YoungModulus1 = 0.277e+08   ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
```

```
ShearModulus1 = YoungModulus1/(2*(1+Nu)) ! Shear Modulus
WMass = 1.546e-03     ! Density
WTick=0.3750     ! Wall Thickness
OD=12.750      ! Outer Diameter
RADCUR1 = 60     ! Radius of Curvature
RADCUR2 = 18
Temperature = 400
Pressue = 615
maxm=15      ! No. of Modes to Extract


/com,-----------------------------------------------------------------------------------

et, 1,pipe16     ! Element 1 - PIPE16
et, 2,pipe18     ! Element 2 - PIPE18
keyopt,2,3,1     ! Use ANSYS Flexibility term with pressure item
et, 3,pipe18     ! Element 3 - PIPE18
keyopt,3,3,1     ! Use ANSYS Flexibility term with pressure item
et, 4,combin14     ! Element 4 - COMBIN14
keyopt,4,2,2     ! Y Degree of Freedom
et, 5,combin14     ! Element 5 - COMBIN14
keyopt,5,2,1     ! X Degree of Freedom
et, 6,combin14     ! Element 6 - COMBIN14
keyopt,6,2,2     ! Y Degree of Freedom
et, 7,combin14     ! Element 7 - COMBIN14
keyopt,7,2,3     ! Z Degree of Freedom
et, 8,combin14     ! Element 8 - COMBIN14
keyopt,8,2,4     ! ROT-X Degree of Freedom
et, 9,combin14     ! Element 9 - COMBIN14
keyopt,9,2,5     ! ROT-Y Degree of Freedom
et,10,combin14     ! Element 10 - COMBIN14
keyopt,10,2,6     ! ROT-Z Degree of Freedom

/com,-----------------------------------------------------------------------------------

/com, Real Constants
/com,****************

r, 1, OD,WTick
r, 2, OD,WTick,RADCUR1
r, 3, OD,WTick,RADCUR2
r, 4, 0.1e+2
r, 5, 0.1e+13
r, 6, 0.1e+13
r, 7, 0.1e+13
r, 8, 0.1e+13
r, 9, 0.1e+13
r,10, 0.1e+13

/com, ---------------------------------------------------------------------------------

/com, Material Properties
/com,********************

mp,ex,  1, YoungModulus1
mp,nuxy,1, Nu
mp,gxy ,1, ShearModulus1
mp,dens,1, WMass

mp,ex,  2, YoungModulus1
mp,nuxy,2, Nu
mp,gxy ,2, ShearModulus1
mp,dens,2, WMass

mp,ex,  3, YoungModulus1
mp,nuxy,3, Nu
mp,gxy ,3, ShearModulus1
mp,dens,3, WMass

/com,-----------------------------------------------------------------------------------

/com, Nodes
```

```
/com,*******

n,1,0,1226.875,0
n,2,30.021,1226.875,30.550
n,3,60.042,1226.875,61.100
n,4,90.064,1226.875,91.651
n,5,105.154,1226.875,102.817
n,6,139.302,1226.875,120.593
n,7,181.878,1226.875,142.757
n,8,224.435,1226.875,164.922
n,9,243.383,1226.875,174.774
n,10,262.311,1226.875,184.628

n,11,292.798,1226.875,191.342

n,12,334.171,1226.875,189.421
n,120,334.171,1226.875,189.421

n,13,375.543,1226.875,187.500

n,14,405.511,1226.875,186.110
n,140,431.483,1226.875,184.904

n,15,501.172,1226.875,181.669
n,16,570.860,1226.875,178.433
n,17,579.777,1226.875,178.683
n,18,615.118,1226.875,182.316
n,20,633.028,1226.875,184.156

n,21,678.227,1226.875,188.802
n,22,723.426,1226.875,193.448
n,23,768.625,1226.875,198.095
n,24,809.602,1226.875,187.256
n,25,814.057,1226.875,184.079
n,26,852.626,1226.875,156.568
n,27,891.195,1226.875,129.058
n,28,929.764,1226.875,101.547

n,29,968.332,1226.875,74.036
n,290,978.101,1226.875,67.067

n,31,1012.600,1226.875,42.430
n,310,1012.600,1226.875,42.430

n,32,1047.098,1226.875,17.793
n,34,1061.752,1244.875,7.340
n,35,1061.752,1272.375,7.340
n,36,1072.214,1290.375,-7.307
n,37,1081.623,1290.375,-20.48
n,38,1108.85,1290.375,-58.399
n,39,1136.077,1290.375,-96.317
n,40,1163.304,1290.375,-134.236
n,41,1190.531,1290.375,-172.154

/com,
/com, Elastic Support Nodes
/com,***********************

n,410,1190.531,1290.375,-172.154

n,43,1197.006,1290.375,-182.019
n,44,1207.729,1290.375,-209.536
n,45,1211.63,1290.375,-241.111
n,46,1215.531,1290.375,-272.687
n,47,1219.432,1290.375,-304.262
n,48,1223.333,1290.375,-335.873
n,49,1227.234,1290.375,-367.413

n,51,1232.114,1290.375,-407.115
n,52,1233.704,1295.647,-419.787
n,53,1234.945,1305.772,-429.836
```

```
n,55,1254.329,1318.500,-439.952
n,56,1279.579,1318.500,-436.387
n,57,1304.829,1318.500,-432.823
n,58,1330.078,1318.500,-429.258
n,59,1355.328,1318.500,-425.693

n,61,431.943,1226.875,194.899
n,62,616.14,1226.875,172.368
n,63,974.139,1226.875,82.176
n,65,1227.234,1300.375,-367.413
n,66,1255.726,1318.500,-449.852

n,67,1182.401,1290.375,-177.966
n,68,105.154,1236.875,102.817
n,69,224.435,1236.875,164.922
n,70,405.511,1236.875,186.110
n,71,633.028,1236.875,184.156
n,72,814.057,1236.875,184.079
n,73,978.101,1236.875,67.067
n,74,1081.623,1300.375,-20.48
n,75,1190.531,1300.375,-172.154

n,101,10,1226.875,0
n,102,0,1236.875,0
n,103,0,1226.875,10

n,591,1345.328,1318.5,-425.693
n,592,1355.328,1328.5,-425.693
n,593,1355.328,1318.5,-415.693

n,601,93.495,1226.9,94.879
n,602,97.170,1226.9,97.828
n,603,101.06,1226.9,100.48

/com,----------------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,*********************************

mat,1       ! Material ID 1
type,1      ! Element Type 1
real,1      ! Real Constant Set 1

e,1,2
e,2,3
e,3,4

e,5,6
e,6,7
e,7,8

e,8,9
e,9,10

e,11,12
e,12,13
e,13,14
e,14,140
e,140,15
e,15,16

e,17,18

e,18,20
e,20,21
e,21,22
e,22,23

e,24,25
e,25,26
e,26,27
```

```
e,27,28
e,28,29
e,29,290
e,290,31
e,31,32

e,34,35

e,36,37
e,37,38
e,38,39
e,39,40
e,40,41
e,41,43

e,44,45
e,45,46
e,46,47
e,47,48
e,48,49
e,49,51

e,52,53

e,55,56
e,56,57
e,57,58
e,58,59

/com,
/com, Pipe Bend Elements
/com,*******************

type,2
real,2
e,4,601,3
e,601,602,603
e,602,603,5
e,603,5,6
e,10,11,9
e,16,17,15
e,23,24,25
e,43,44,45

type,3
real,3
e,32,34,35
e,35,36,37
e,51,52,53
e,53,55,56

/com,
/com, Spring Elements
/com,****************

type,4
real,4
e,49,65

type,6
real,6
e,5,68
e,8,69
e,14,70
e,20,71
e,25,72
e,290,73
e,37,74
e,410,75

type,5
real,5
```

```
n1 = 55
n2 = 66
n3 = 56

ics = 11
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 41
n2 = 67
n3 = 40

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

/com,
/com, Snubber Elements
/com,******************

n1 = 13
n2 = 120
n3 = 59

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 140
n2 = 61
n3 = 15

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 18
n2 = 62
n3 = 17

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 29
n2 = 63
n3 = 28

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
```

```
nrotat,n2
csys,0
e,n1,n2

n1 = 32
n2 = 310
n3 = 34
!n3 = 59

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

/com,
/com, 3D Support at both ends
/com,*************************

type,5
real,5
e,1,101
e,59,591

type,6
real,6
e,1,102
e,59,592

type,7
real,7
e,1,103
e,59,593

type,8
real,8
e,1,101
e,59,591

type,9
real,9
e,1,102
e,59,592

type,10
real,10
e,1,103
e,59,593

/com,-------------------------------------------------------------------------------------

/com,
/com, Model Rigid Region
/com,********************

cerig,41,410,uy

/com,-------------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,s,node,,61,63
nsel,a,node,,65,75
nsel,a,node,,101,103
nsel,a,node,,120
nsel,a,node,,310
nsel,a,node,,591,593
d,all,all,0
```

```
nsel,all

/com,-------------------------------------------------------------------------------------

/com,
/com, Loads
/com,*******

/com, Temperature Input
/com,******************

bf,all,temp,Temperature

eplo
esel,r,type,,1
esel,a,type,,2
esel,a,type,,3

/com, Pressure Input
/com,***************

sfe,all,1,pres,,Pressue,,,

allsel,all,all
save
finish

/com,-------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,maxm
lump,on
mxpand,maxm,,,yes
solve


/com,
/com,===========================
/com, Compare Modal Frequencies
/com,===========================
/com,

*dim,Amode,ARRAY,maxm
*dim,Emode,ARRAY,maxm
*dim,ERmode,ARRAY,maxm
*dim,moden,ARRAY,maxm

*do,i,1,maxm
 *GET, Amode(i), MODE, i, FREQ
*enddo

*VFILL,Emode,DATA,7.238,10.145,14.579,15.991,17.198,17.987,22.282,23.632,27.864,29.211
*VFILL,Emode(11),DATA,29.514,31.554,34.018,34.778,35.122

*do,i,1,maxm
  ERmode(i) = ABS(Amode(i)/Emode(i))
  moden(i) = i
*enddo

save,table_1
finish

/com,-------------------------------------------------------------------------------------
```

```
/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
sfedele,all,1,pres,,,
bfdele,all,temp,,,

antype,spectrum
spopt,mprs,maxm     ! Multi-point response spectrum analysis

srss,,,
gval = 386.4

/com,-----------------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 1 (Group 1 - X - Direction Excitation)
/com,*************************************************

id = 1
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771


/com,
/com, Spectrum 2 (Group 1 - Y - Direction Excitation)
/com,*************************************************

id = 2
spunit, id,accg, gval

spfrq,id, 0.5,1.4993,1.6207,1.9011,2.0704,3.8023,4.2553
spval,id,,  0.35,1.45,1.8,1.8,2.61,2.61,2.78
```

```
spfrq,id, 5.1813,5.4054,7.8125,8.1301,9.901,11.5207,14.1044
spval,id,,  2.78,2.58,2.58,3.25,3.25,3.62,3.62

spfrq,id, 14.4928,17.6991,23.9981,59.988
spval,id,,  3.05,3.05,1.20,0.75

/com,
/com, Spectrum 3 (Group 1 - Z - Direction Excitation)
/com,*************************************************

id = 3
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771

/com,------------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 4 (Group 2 - X - Direction Excitation)
/com,*************************************************

id = 4
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189
```

```
spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771

/com,
/com, Spectrum 5 (Group 2 - Y - Direction Excitation)
/com,*************************************************

id = 5
spunit, id,accg, gval

spfrq,id, 0.50,1.4556,1.9011,2.0704,2.907,4.065,4.9603
spval,id,,  1.45,1.8,1.8,2.68,2.68,3.17,3.17

spfrq,id, 5.0,7.5988,8.5034,10.9051,11.5207,14.0845,16.0
spval,id,,  3.03,3.03,4.82,4.82,5.95,5.95,4.49

spfrq,id, 19.1205,21.0084,50.0
spval,id,,  4.49,1.85,1.05

/com,
/com, Spectrum 6 (Group 2 - Z - Direction Excitation)
/com,*************************************************

id = 6
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
```

```
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771

/com,-------------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 7 (Group 3 - X - Direction Excitation)
/com,*************************************************

id = 7
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771

/com,
/com, Spectrum 8 (Group 3 - Y - Direction Excitation)
/com,*************************************************

id = 8
spunit, id,accg, gval

spfrq,id, 0.5,1.9011,2.0704,3.003,4.0486,4.9505,7.1942
spval,id,,  0.4,1.88,2.72,2.72,3.42,3.42,3.82

spfrq,id, 8.1301,9.5238,10.352,12.6422,13.5135,15.4083,15.7978
spval,id,, 7.21,7.21,8.18,8.18,6.39,6.39,5.92

spfrq,id, 17.6991,21.0084,50.0
spval,id,,  5.92,2.25,1.55
```

```
/com,
/com, Spectrum 9 (Group 3 - Z - Direction Excitation)
/com,*************************************************

id = 9
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771

/com,-------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 10 (Group 4 - X - Direction Excitation)
/com,*************************************************

id = 10
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667
```

```
spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771

/com,
/com, Spectrum 11 (Group 4 - Y - Direction Excitation)
/com,**************************************************

id = 11
spunit, id,accg, gval

spfrq,id, 0.5,1.3004,2.0,3.003,4.0486,4.9505,6.993
spval,id,,  0.5,1.4,2.75,2.75,3.5,3.5,4.5

spfrq,id, 8.1301,10.4167,11.4943,14.845,17.5439,22.2222,50.0
spval,id,,  12.1,12.1,10.7,10.7,2.7,1.8,1.5

/com,
/com, Spectrum 12 (Group 4 - Z - Direction Excitation)
/com,**************************************************

id = 12
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
```

```
spval,id,, 0.771

/com,-------------------------------------------------------------------------------
/com,
/com,
/com, Nodal Components for Excitation Points (non rotated)
/com,*****************************************************

allsel,all

nsel,s,node,,68
nsel,a,node,,61
nsel,a,node,,71
nsel,a,node,,63
nsel,a,node,,73
nsel,a,node,,310
nsel,a,node,,591,593
nplo
cm,group_1,node

allsel,all,all

nsel,s,node,,70
nsel,a,node,,120
nsel,a,node,,62
nsel,a,node,,67
nsel,a,node,,75
nsel,a,node,,65
nplo
cm,group_2,node

allsel,all,all
nsel,s,node,,69
nsel,a,node,,72
nsel,a,node,,74
nplo
cm,group_3,node

allsel,all,all
nsel,s,node,,101,103
nsel,a,node,,66
nplo
cm,group_4,node

allsel,all,all
eplo


/com, *****************************************************
! -- Support Group 1 - spectrum 1 (Along X - Direction)

sed,1,,,group_1
pfact,1
sed,0,,,group_1

! -- Support Group 1 - spectrum 2 (Along Y - Direction)

sed,,1,,group_1
pfact,2
sed,,0,,group_1

! -- Support Group 1 - spectrum 3 (Along Z - Direction)

sed,,,1,group_1
pfact,3
sed,,,0,group_1

! -- Support Group 2 - spectrum 4 (Along X - Direction)

sed,1,,,group_2
pfact,4
sed,0,,,group_2
```

```
! -- Support Group 2 - spectrum 5 (Along Y - Direction)

sed,,1,,group_2
pfact,5
sed,,0,,group_2

! -- Support Group 2 - spectrum 6 (Along Z - Direction)

sed,,,1,group_2
pfact,6
sed,,,0,group_2


! -- Support Group 3 - spectrum 8 (Along Y - Direction)

sed,,1,,group_3
pfact,8
sed,,0,,group_3


! -- Support Group 4 - spectrum 10 (Along X - Direction)

sed,1,,,group_4
pfact,10
sed,0,,,group_4

! -- Support Group 4 - spectrum 11 (Along Y - Direction)

sed,,1,,group_4
pfact,11
sed,,0,,group_4

! -- Support Group 4 - spectrum 12 (Along Z - Direction)

sed,,,1,group_4
pfact,12
sed,,,0,group_4
/com, *****************************************************

srss,0,,YES   ! activate Absolute Sum for MPRS
solve

fini
/com, *****************************************************
/post1

/input,,mcom

/com,----------------------------------

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1
*dim,label5,char,22,1

/com,------------------------

label2(1,1) = 'ux_36'
label2(1,2) = 'uy_51'
label2(1,3) = 'uz_36'
label2(1,4) ='rotx_12'
label2(1,5) ='roty_12'
label2(1,6) ='rotz_35'

/com,----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
```

```
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,--------------------------------

/com,-------------------------------------------------------------------------------------

/com,
/com,=========================================================
/com, Maximum nodal displacements and rotations comparsion
/com,=========================================================
/com,

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,36,U,X
*GET,AdisY,NODE,51,U,Y
*GET,AdisZ,NODE,36,U,Z
*GET,ArotX,NODE,12,ROT,X
*GET,ArotY,NODE,12,ROT,Y
*GET,ArotZ,NODE,35,ROT,Z

/com,
/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,8.27192e-01
*SET,EdisY,5.47549e-01
*SET,EdisZ,7.61900e-01
*SET,ErotX,1.87354e-03
*SET,ErotY,2.46820e-04
*SET,ErotZ,1.02513e-02

/com,
/com, Error computation
/com,*******************

ERdisX=ABS(AdisX/EdisX)
ERdisY=ABS(AdisY/EdisY)
ERdisZ=ABS(AdisZ/EdisZ)
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX
```

```
*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,-------------------------------------------------------------------------------------

/com,========================================================
/com, Element Forces and Moments Comparison
/com,========================================================

/com, Solution obtained from Mechanical APDL
/com,******************************

*dim,elem_res_I,,3,6
*dim,elem_res_J,,3,6

*dim,pxi,,3
*dim,vyi,,3
*dim,vzi,,3
*dim,txi,,3
*dim,myi,,3
*dim,mzi,,3

*dim,pxj,,3
*dim,vyj,,3
*dim,vzj,,3
*dim,txj,,3
*dim,myj,,3
*dim,mzj,,3

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com, Element #17
/com,*************

*get,pxi(2,1),elem,17,smisc,1
*get,vyi(2,1),elem,17,smisc,2
*get,vzi(2,1),elem,17,smisc,3
*get,txi(2,1),elem,17,smisc,4
*get,myi(2,1),elem,17,smisc,5
*get,mzi(2,1),elem,17,smisc,6

*vfill,elem_res_I(2,1),data,pxi(2,1)
*vfill,elem_res_I(2,2),data,vyi(2,1)
```

```
*vfill,elem_res_I(2,3),data,vzi(2,1)
*vfill,elem_res_I(2,4),data,txi(2,1)
*vfill,elem_res_I(2,5),data,myi(2,1)
*vfill,elem_res_I(2,6),data,mzi(2,1)

/com, Element #50
/com,*************

*get,pxi(3,1),elem,50,smisc,1
*get,vyi(3,1),elem,50,smisc,2
*get,vzi(3,1),elem,50,smisc,3
*get,txi(3,1),elem,50,smisc,4
*get,myi(3,1),elem,50,smisc,5
*get,mzi(3,1),elem,50,smisc,6

*vfill,elem_res_I(3,1),data,pxi(3,1)
*vfill,elem_res_I(3,2),data,vyi(3,1)
*vfill,elem_res_I(3,3),data,vzi(3,1)
*vfill,elem_res_I(3,4),data,txi(3,1)
*vfill,elem_res_I(3,5),data,myi(3,1)
*vfill,elem_res_I(3,6),data,mzi(3,1)


/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com, Element #17
/com,*************

*get,pxj(2,1),elem,17,smisc,7
*get,vyj(2,1),elem,17,smisc,8
*get,vzj(2,1),elem,17,smisc,9
*get,txj(2,1),elem,17,smisc,10
*get,myj(2,1),elem,17,smisc,11
*get,mzj(2,1),elem,17,smisc,12

*vfill,elem_res_J(2,1),data,pxj(2,1)
*vfill,elem_res_J(2,2),data,vyj(2,1)
*vfill,elem_res_J(2,3),data,vzj(2,1)
*vfill,elem_res_J(2,4),data,txj(2,1)
*vfill,elem_res_J(2,5),data,myj(2,1)
*vfill,elem_res_J(2,6),data,mzj(2,1)

/com, Element #50
/com,*************

*get,pxj(3,1),elem,50,smisc,7
*get,vyj(3,1),elem,50,smisc,8
*get,vzj(3,1),elem,50,smisc,9
*get,txj(3,1),elem,50,smisc,10
*get,myj(3,1),elem,50,smisc,11
*get,mzj(3,1),elem,50,smisc,12

*vfill,elem_res_J(3,1),data,pxj(3,1)
```

```
*vfill,elem_res_J(3,2),data,vyj(3,1)
*vfill,elem_res_J(3,3),data,vzj(3,1)
*vfill,elem_res_J(3,4),data,txj(3,1)
*vfill,elem_res_J(3,5),data,myj(3,1)
*vfill,elem_res_J(3,6),data,mzj(3,1)

/com,---------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,3,6
*dim,exp_J,,3,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,5.223e+03
*vfill,exp_I(1,2),data,1.679e+02
*vfill,exp_I(1,3),data,1.753e+03
*vfill,exp_I(1,4),data,2.559e+04
*vfill,exp_I(1,5),data,1.221e+05
*vfill,exp_I(1,6),data,7.826e+03

*vfill,exp_J(1,1),data,5.223e+03
*vfill,exp_J(1,2),data,1.679e+02
*vfill,exp_J(1,3),data,1.753e+03
*vfill,exp_J(1,4),data,2.559e+04
*vfill,exp_J(1,5),data,4.988e+04
*vfill,exp_J(1,6),data,1.213e+03

/com, Element #17
/com,*************

*vfill,exp_I(2,1),data,4.944e+03
*vfill,exp_I(2,2),data,1.380e+03
*vfill,exp_I(2,3),data,7.416e+02
*vfill,exp_I(2,4),data,3.846e+04
*vfill,exp_I(2,5),data,1.520e+04
*vfill,exp_I(2,6),data,6.374e+04

*vfill,exp_J(2,1),data,4.944e+03
*vfill,exp_J(2,2),data,1.380e+03
*vfill,exp_J(2,3),data,7.416e+02
*vfill,exp_J(2,4),data,3.846e+04
*vfill,exp_J(2,5),data,4.084e+04
*vfill,exp_j(2,6),data,6.762e+04

/com, Element #50
/com,*************

*vfill,exp_I(3,1),data,4.365e+03
*vfill,exp_I(3,2),data,1.042e+03
*vfill,exp_I(3,3),data,1.942e+03
*vfill,exp_I(3,4),data,2.574e+04
*vfill,exp_I(3,5),data,4.522e+04
*vfill,exp_I(3,6),data,2.797e+04

*vfill,exp_J(3,1),data,4.738e+03
*vfill,exp_J(3,2),data,1.042e+03
*vfill,exp_J(3,3),data,6.159e+02
*vfill,exp_J(3,4),data,3.421e+04
*vfill,exp_J(3,5),data,6.163e+04
*vfill,exp_J(3,6),data,3.715e+04

/com,--------------------------------------------------------------------------

/com, Error computation
/com, ********************

*dim,elem_error_I,,3,6
*dim,elem_error_J,,3,6
```

```
*dim,elem_tab,,36,3

/com,============
/com,   Node I
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo
*enddo

/com,============
/com,   Node J
/com,============

*do,i,1,3
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
*enddo

/com,-----------------------------------------------------------------------

*do,i,1,3
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+18
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo
*enddo

save,table_3

/com,---------------------------------------------------------------------------------

/com,*****************************
/com, Reaction forces comparision
/com,******************************

*dim,Areac,,22
*dim,Ereac,,22
*dim,ERreac,,22
*dim,Nreac,STRING,8,22

Nreac(1,1) = 'FY49'
Nreac(1,2) = 'FX55'
Nreac(1,3) = 'FX41'
Nreac(1,4) = 'FY41'
Nreac(1,5) = 'FY5'

Nreac(1,6) = 'FY8'
Nreac(1,7) = 'FY14'
Nreac(1,8) = 'FY20'
Nreac(1,9) = 'FY25'
Nreac(1,10) = 'FY290'

Nreac(1,11) = 'FY37'
Nreac(1,12) = 'FX1'
Nreac(1,13) = 'FY1'
Nreac(1,14) = 'FZ1'
Nreac(1,15) = 'FX59'
```

```
Nreac(1,16) = 'FY59'
Nreac(1,17) = 'FZ59'

Nreac(1,18) = 'FX13'
Nreac(1,19) = 'FX140'
Nreac(1,20) = 'FX18'
Nreac(1,21) = 'FX29'
Nreac(1,22) = 'FX32'

*GET,Areac(1),NODE,65,RF,FY
*GET,Areac(2),NODE,66,RF,FX
*GET,Areac(3),NODE,67,RF,FX
*GET,Areac(4),NODE,75,RF,FY
*GET,Areac(5),NODE,68,RF,FY

*GET,Areac(6),NODE,69,RF,FY
*GET,Areac(7),NODE,70,RF,FY
*GET,Areac(8),NODE,71,RF,FY
*GET,Areac(9),NODE,72,RF,FY
*GET,Areac(10),NODE,73,RF,FY

*GET,Areac(11),NODE,74,RF,FY
*GET,Areac(12),NODE,101,RF,FX
*GET,Areac(13),NODE,102,RF,FY
*GET,Areac(14),NODE,103,RF,FZ
*GET,Areac(15),NODE,591,RF,FX

*GET,Areac(16),NODE,592,RF,FY
*GET,Areac(17),NODE,593,RF,FZ

*GET,Areac(18),NODE,120,RF,FX
*GET,Areac(19),NODE,61,RF,FX
*GET,Areac(20),NODE,62,RF,FX
*GET,Areac(21),NODE,63,RF,FX
*GET,Areac(22),NODE,310,RF,FX


*VFILL,Ereac,DATA,5,9479,4250,4011,832,1828,1689,2149,2467,4062
*VFILL,Ereac(11),DATA,2537,4353,168,3376,3937,6819,1069,6866,1276,492.544
*VFILL,Ereac(21),DATA,6332.01,8415.285

*do,i,1,22
   ERreac(i) = abs(Areac(i)/Ereac(i))
*enddo

save,table_4

/com,------------------------------------------------------------------------------------
/com,

/out,

/com,
/com, ----------------------vm-nr1677-2-3c-a Results Verification------------------------------
/com,


/nopr
resume,table_1
/gopr

/out,vm-nr1677-2-3c-a,vrt


/com,
/com, ===========================================
/com,  COMPARISON OF MODAL FREQUENCY
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
```

```
/com,

*VWRITE,moden(1),Emode(1),Amode(1),ERmode(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,' ')

/com,

/com,------------------------------------------------------------------------------------

/nopr
resume,table_2
/gopr

/com,
/com,==================================================
/com,  COMPARISON OF NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,==================================================
/com,

/com,  Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-----------------------------------------------------------------------
/com,

/nopr
resume,table_4
/gopr

/com,
/com, ==========================================
/com,  COMPARISON OF REACTION FORCES
/com,      WITH EXPECTED RESULTS
/com, ==========================================
/com,

/com,   Node | Expected |  Mechanical APDL  |  Ratio
/com,

*VWRITE,Nreac(1),Ereac(1),Areac(1),ERreac(1)
(5X,a,2X,F12.4,3X,F12.4,3X,F8.2,' ')

/com,

/com,------------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,==============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,      WITH EXPECTED RESULTS
/com,==============================================
```

```
/com,

/com,------------------------------------------------------------
/com, Note: Element Forces and Moments for some elements
/com,       along Y & Z directions are flipped between Mechanical APDL
/com,  and NRC results
/com,
/com,       Element numbers from Mechanical APDL and NRC are
/com,       different.
/com,       Element 1 (Mechanical APDL) = Element 1 (NRC)
/com,       Element 17 (Mechanical APDL) = Element 17 (NRC)
/com,       Element 50 (Mechanical APDL) = Element 48 (NRC)
/com,----------------------------------------------------------

/com,  Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(19,1),elem_tab(19,2),elem_tab(19,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 17
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(25,1),elem_tab(25,2),elem_tab(25,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,
/com,

/com,===============
/com,   Element 50
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(13,1),elem_tab(13,2),elem_tab(13,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(31,1),elem_tab(31,2),elem_tab(31,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,
/com,
/com,*******************************************************************
/com,*******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-2-3c-a,vrt
```

```
finish
```

vm-nr1677-2-4a-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-2-4a-a
/title,vm-nr1677-2-4a-a,NRC piping benchmarks problems,Volume II,Problem 4a

/com, ***************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com, Element used: Pipe16, Pipe18, Combin14 and Mass21
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, *******************************************************************************

/out,scratch

/prep7

YoungModulus = 0.283e+8    ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus = YoungModulus/(2*(1+Nu)) ! Shear Modulus
K = 0.911e-5     ! Thermal Expansion
maxm = 50      ! No. of Modes Extracted

/com,
/com, Section Property
/com,*****************

/com,
/com, Wall Thickness
/com,----------------

WTick_1 = 2.25
WTick_2 = 3.44
WTick_3 = 1.0
WTick_4 = 2.64
WTick_5 = 74.775

WTick_6 = 1.0
WTick_7 = 2.64
WTick_8 = 0.7180
WTick_9 = 1.62
WTick_10 = 46.035

WTick_11 = 0.7180
WTick_12 = 0.906
WTick_13 = 0.365

/com,
/com, Outer Diameter
/com,----------------

OD_1 = 32.25
OD_2 = 15.625
OD_3 = 10.75
OD_4 = 16.03
OD_5 = 160.3
```

```
OD_6 = 10.75
OD_7 = 16.03
OD_8 = 6.625
OD_9 = 9.87
OD_10 = 98.7

OD_11 = 6.625
OD_12 = 8.625
OD_13 = 10.75

/com,
/com, Bend Radius
/com,--------------

RADCUR_1 = 15.0
RADCUR_2 = 14.9
RADCUR_3 = 9.0
RADCUR_4 = 12.0
RADCUR_5 = 40.0
RADCUR_6 = 8.0

/com,------------------------------------------------------------------------------------

/com,
/com, Element Types
/com,***************

et,1,pipe16
et,2,pipe16
et,3,pipe16
et,4,pipe16
et,5,pipe16
et,6,pipe16
et,7,pipe16
et,8,pipe16
et,9,pipe16
et,10,pipe16
et,11,pipe16
et,12,pipe16
et,13,pipe16

et,14,pipe18
et,15,pipe18
et,16,pipe18
et,17,pipe18
et,18,pipe18
et,19,pipe18
et,20,pipe18
et,21,pipe18
et,22,pipe18

et,23,mass21      ! 3D Mass without rotatary inertia
keyopt,23,3,2
et,24,mass21
keyopt,24,3,2
et,25,mass21
keyopt,25,3,2
et,26,mass21
keyopt,26,3,2
et,27,mass21
keyopt,27,3,2
et,28,mass21
keyopt,28,3,2
et,29,mass21
keyopt,29,3,2
et,30,mass21
keyopt,30,3,2
et,31,mass21
keyopt,31,3,2
et,32,mass21
keyopt,32,3,2
```

```
et,33,mass21
keyopt,33,3,2
et,34,mass21
keyopt,34,3,2
et,35,mass21
keyopt,35,3,2
et,36,mass21
keyopt,36,3,2
et,37,mass21
keyopt,37,3,2
et,38,mass21
keyopt,38,3,2
et,39,mass21
keyopt,39,3,2
et,40,mass21
keyopt,40,3,2
et,41,mass21
keyopt,41,3,2
et,42,mass21
keyopt,42,3,2
et,43,mass21
keyopt,43,3,2
et,44,mass21
keyopt,44,3,2
et,45,mass21
keyopt,45,3,2
et,46,mass21
keyopt,46,3,2
et,47,mass21
keyopt,47,3,2

et,48,combin14,,1       ! Spring Elements Types and Real constants
keyopt,48,2,1      ! X Degree of Freedom
et,49,combin14,,2
keyopt,49,2,2      ! Y Degree of Freedom
et,50,combin14,,3
keyopt,50,2,3      ! Z Degree of Freedom
et,51,combin14,,2
keyopt,51,2,2      ! Y Degree of Freedom
et,52,combin14,,2
keyopt,52,2,2      ! Y Degree of Freedom
et,53,combin14,,3
keyopt,53,2,3      ! Z Degree of Freedom
et,54,combin14,,1
keyopt,54,2,1      ! X Degree of Freedom
et,55,combin14,,2
keyopt,55,2,2      ! Y Degree of Freedom
et,56,combin14,,1
keyopt,56,2,1      ! X Degree of Freedom
et,57,combin14,,1
keyopt,57,2,1      ! X Degree of Freedom
et,58,combin14,,2
keyopt,58,2,2      ! Y Degree of Freedom
et,59,combin14,,1
keyopt,59,2,1      ! X Degree of Freedom
et,60,combin14,,2
keyopt,60,2,2      ! Y Degree of Freedom
et,61,combin14,,1
keyopt,61,2,1      ! X Degree of Freedom
et,62,combin14,,2
keyopt,62,2,2      ! Y Degree of Freedom
et,63,combin14,,2
keyopt,63,2,2      ! Y Degree of Freedom
et,64,combin14,,1
keyopt,64,2,1      ! X Degree of Freedom
et,65,combin14,,2
keyopt,65,2,2      ! Y Degree of Freedom
et,66,combin14,,3
keyopt,66,2,3      ! Z Degree of Freedom
et,67,combin14,,2
keyopt,67,2,2      ! Y Degree of Freedom
et,68,combin14,,1
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keyopt,68,2,1      ! X Degree of Freedom
et,69,combin14,,1
keyopt,69,2,1      ! X Degree of Freedom
et,70,combin14,,2
keyopt,70,2,2      ! Y Degree of Freedom
et,71,combin14,,1
keyopt,71,2,1      ! X Degree of Freedom
et,72,combin14,,2
keyopt,72,2,2      ! Y Degree of Freedom
et,73,combin14,,1
keyopt,73,2,1      ! X Degree of Freedom
et,74,combin14,,1
keyopt,74,2,1      ! X Degree of Freedom
et,75,combin14,,3
keyopt,75,2,3      ! Z Degree of Freedom
et,76,combin14,,2
keyopt,76,2,2      ! Y Degree of Freedom
et,77,combin14,,2
keyopt,77,2,2      ! Y Degree of Freedom
et,78,combin14,,1
keyopt,78,2,1      ! X Degree of Freedom
et,79,combin14,,2
keyopt,79,2,2      ! Y Degree of Freedom
et,80,combin14,,2
keyopt,80,2,2      ! Y Degree of Freedom
et,81,combin14,,1
keyopt,81,2,1      ! X Degree of Freedom
et,82,combin14,,2
keyopt,82,2,2      ! Y Degree of Freedom
et,83,combin14,,3
keyopt,83,2,3      ! Z Degree of Freedom

/com,---------------------------------------------------------------------------------
/com

/com, Real Constants
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r, 1,OD_1,WTick_1
r, 2,OD_2,WTick_2
r, 3,OD_3,WTick_3
r, 4,OD_4,WTick_4
r, 5, OD_5,WTick_5
r, 6, OD_6,WTick_6
r, 7, OD_7,WTick_7
r, 8, OD_8,WTick_8
r, 9, OD_9,WTick_9
r, 10, OD_10,WTick_10
r, 11, OD_11,WTick_11
r, 12, OD_12,WTick_12
r, 13, OD_13,WTick_13

r, 14, OD_3, WTick_3,RADCUR_1
r, 15, OD_6, WTick_6,RADCUR_1
r, 16, OD_6, WTick_6,RADCUR_2
r, 17, OD_13, WTick_13,RADCUR_1
r, 18, OD_13, WTick_13,RADCUR_2
r, 19, OD_8, WTick_8,RADCUR_3
r, 20, OD_12, WTick_12,RADCUR_4
r, 21, OD_12, WTick_12,RADCUR_5
r, 22, OD_12, WTick_12,RADCUR_6

r,23,1.69306
r,24,5.07505
r,25,4.96894
r,26,1.20212
r,27,1.42495
r,28,1.88768
r,29,2.18323
r,30,2.4397
r,31,2.98188
r,32,1.41874
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r,33,1.04943e+1
r,34,9.30124e-1
r,35,1.6118
r,36,6.74431e-1
r,37,6.43116e-1
r,38,1.06962
r,39,1.20549
r,40,1.05642
r,41,1.25388
r,42,1.3543
r,43,6.66149e-1
r,44,2.27769
r,45,1.15217
r,46,1.23214
r,47,1.52976

r,48, 0.1e+9
r,49, 0.1e+9
r,50, 0.1e+9
r,51, 0.1080e+4
r,52, 0.6001e+5
r,53, 0.6001e+5
r,54, 0.6001e+5
r,55, 0.7541e+6
r,56, 0.7541e+6
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r,58, 0.6000e+3
r,59, 0.6001e+5
r,60, 0.7601e+5
r,61, 0.6001e+5
r,62, 0.8000e+3
r,63, 0.6001e+5
r,64, 0.1000e+9
r,65, 0.1000e+9
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r,67, 0.2600e+3
r,68, 0.5901e+5
r,69, 0.2400e+5
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r,72, 0.2460e+6
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r,74, 0.6001e+5
r,75, 0.7501e+5
r,76, 0.4660e+6
r,77, 0.3400e+3
r,78, 0.6001e+5
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r,82, 0.1000e+9
r,83, 0.1000e+9

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/com, Material Properties
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MP,GXY ,1, ShearModulus
MP,ALPX,1, K

MP,EX,  2, YoungModulus
MP,NUXY,2, Nu
MP,GXY ,2, ShearModulus
MP,ALPX,2, K

MP,EX,  3, YoungModulus
MP,NUXY,3, Nu
MP,GXY ,3, ShearModulus
MP,ALPX,3, K
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MP,EX,  4, YoungModulus
MP,NUXY,4, Nu
MP,GXY ,4, ShearModulus
MP,ALPX,4, K

MP,EX,  5, YoungModulus
MP,NUXY,5, Nu
MP,GXY ,5, ShearModulus
MP,ALPX,5, K

MP,EX,  6, YoungModulus
MP,NUXY,6, Nu
MP,GXY ,6, ShearModulus
MP,ALPX,6, K

MP,EX,  7, YoungModulus
MP,NUXY,7, Nu
MP,GXY ,7, ShearModulus
MP,ALPX,7, K

MP,EX,  8, YoungModulus
MP,NUXY,8, Nu
MP,GXY ,8, ShearModulus
MP,ALPX,8, K

MP,EX,  9, YoungModulus
MP,NUXY,9, Nu
MP,GXY ,9, ShearModulus
MP,ALPX,9, K

MP,EX,  10, YoungModulus
MP,NUXY,10, Nu
MP,GXY ,10, ShearModulus
MP,ALPX,10, K

MP,EX,  11, YoungModulus
MP,NUXY,11, Nu
MP,GXY ,11, ShearModulus
MP,ALPX,11, K

MP,EX,  12, YoungModulus
MP,NUXY,12, Nu
MP,GXY ,12, ShearModulus
MP,ALPX,12, K

MP,EX,  13, YoungModulus
MP,NUXY,13, Nu
MP,GXY ,13, ShearModulus
MP,ALPX,13, K

MP,EX,  14, YoungModulus
MP,NUXY,14, Nu
MP,GXY ,14, ShearModulus
MP,ALPX,14, K

MP,EX,  15, YoungModulus
MP,NUXY,15, Nu
MP,GXY ,15, ShearModulus
MP,ALPX,15, K

MP,EX,  16, YoungModulus
MP,NUXY,16, Nu
MP,GXY ,16, ShearModulus
MP,ALPX,16, K

MP,EX,  17, YoungModulus
MP,NUXY,17, Nu
MP,GXY ,17, ShearModulus
MP,ALPX,17, K

MP,EX,  18, YoungModulus
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MP,NUXY,18, Nu
MP,GXY ,18, ShearModulus
MP,ALPX,18, K

MP,EX,  19, YoungModulus
MP,NUXY,19, Nu
MP,GXY ,19, ShearModulus
MP,ALPX,19, K

MP,EX,  20, YoungModulus
MP,NUXY,20, Nu
MP,GXY ,20, ShearModulus
MP,ALPX,20, K

MP,EX,  21, YoungModulus
MP,NUXY,21, Nu
MP,GXY ,21, ShearModulus
MP,ALPX,21, K

MP,EX,  22, YoungModulus
MP,NUXY,22, Nu
MP,GXY ,22, ShearModulus
MP,ALPX,22, K

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n,5,-203.268,4719.852,154.860
n,6,-202.308,4726.800,182.748
n,7,-202.008,4728.948,191.340
n,8,-201.876,4729.392,194.916
n,9,-201.888,4729.392,194.988
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n,12,-212.160,4729.392,212.436
n,13,-213.324,4729.392,213.684
n,14,-220.968,4729.392,221.868
n,15,-220.968,4734.492,221.868
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n,37,-314.988,4613.952,198.720
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/com,
/com, Straight Pipe (Tangent) Elements
/com,**********************************

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type,2
real,2
e,5,6

type,3
real,3
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e,10,11

type,4
real,4
e,11,12
e,12,13
e,13,14
e,14,16
e,31,32
e,32,34

type,5
real,5
e,14,15
e,32,33
e,77,78

type,6
real,6
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type,7
real,7
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type,13
real,13
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real,8
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e,163,164

type,9
real,9
e,159,160
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e,161,163

type,10
real,10
e,161,162

type,12
real,12
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/com,
/com, Pipe Bend Elements
/com,********************

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real,14
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type,15
real,15
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e,54,55,53
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e,64,65,66

type,16
real,16
e,70,272,69
e,272,71,72

type,17
real,17
e,81,82,83
e,91,273,89
e,273,92,93

type,18
real,18
e,85,274,83
e,274,86,87

type,19
real,19
e,100,275,99
e,275,101,102
e,103,104,105
e,105,106,107
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e,139,140,138
e,147,276,145
e,276,148,149
e,152,277,151
e,277,153,154
e,155,156,157

type,20
real,20
e,171,172,173
e,174,175,176
e,181,278,180
e,278,182,183
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e,279,184,185

type,21
real,21
e,186,187,188

type,22
real,22
e,179,180,181

/com, Point Mass without considering rotatary inertia
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e,21
e,25

type,24
real,24
e,15

type,25
real,25
e,33
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type,26
real,26
e,34

type,27
real,27
e,39
e,42

type,28
real,28
e,45
e,46

type,29
real,29
e,53

type,30
real,30
e,58
e,59

type,31
real,31
e,66

type,32
real,32
e,69

type,33
real,33
e,78

type,34
real,34
e,79
e,83
e,84

type,35
real,35
e,93

type,36
real,36
e,102
e,104
e,107

type,37
real,37
e,110
e,111

type,38
real,38
e,114

type,39
real,39
e,123
e,124

type,40
real,40
e,129
e,130

type,41
```

```
real,41
e,137
e,138

type,42
real,42
e,143
e,144

type,43
real,43
e,151
e,154
e,160

type,44
real,44
e,162

type,45
real,45
e,167
e,168

type,46
real,46
e,173
e,176
e,178
e,185

type,47
real,47
e,189
e,190
e,191

/com,
/com, Elastic supports and anchors
/com,******************************

type,48
real,48
e,1,2

type,49
real,49
e,1,3

type,50
real,50
e,1,4

id = 51
type,51
real,51
e,17,18

type,52
real,52
e,29,30

type,53
real,53
e,37,38

type,55
real,55
e,49,50

type,58
real,58
```

```
e,62,63

type,60
real,60
e,72,73

type,62
real,62
e,87,88

type,63
real,63
e,89,90

type,64
real,64
e,94,95

type,65
real,65
e,94,96

type,66
real,66
e,94,97

type,67
real,67
e,108,109

type,68
real,68
e,112,113

type,70
real,70
e,119,120

type,72
real,72
e,133,134

type,75
real,75
e,145,146

type,76
real,76
e,149,150

type,77
real,77
e,157,158

id = 79
type,79
real,79
e,169,170

type,80
real,80
e,188,177

type,81
real,81
e,192,193

type,82
real,82
e,192,194

type,83
```

```
real,83
e,192,195

/com,
/com, rotate nodes with less than 3 supports
/com,****************************************

wplane,,nx(43),ny(43),nz(43),nx(44),ny(44),nz(44),nx(45),ny(45),nz(45)
cswplane,11,0
nrotat,43
nrotat,44
csys,0

real,54
type,54
e,43,44

wplane,,nx(51),ny(51),nz(51),nx(52),ny(52),nz(52),nx(49),ny(49),nz(49)
cswplane,12,0
nrotat,51
nrotat,52
csys,0

real,56
type,56
e,51,52

wplane,,nx(56),ny(56),nz(56),nx(57),ny(57),nz(57),nx(55),ny(55),nz(55)
cswplane,13,0
nrotat,56
nrotat,57
csys,0

real,57
type,57
e,56,57

wplane,,nx(67),ny(67),nz(67),nx(68),ny(68),nz(68),nx(66),ny(66),nz(66)
cswplane,14,0
nrotat,67
nrotat,68
csys,0

real,59
type,59
e,67,68

wplane,,nx(74),ny(74),nz(74),nx(75),ny(75),nz(75),nx(72),ny(72),nz(72)
cswplane,15,0
nrotat,74
nrotat,75
csys,0

real,61
type,61
e,74,75

wplane,,nx(117),ny(117),nz(117),nx(118),ny(118),nz(118),nx(116),ny(116),nz(116)
cswplane,16,0
nrotat,117
nrotat,118
csys,0

real,69
type,69
e,117,118

wplane,,nx(127),ny(127),nz(127),nx(128),ny(128),nz(128),nx(126),ny(126),nz(126)
cswplane,17,0
nrotat,127
nrotat,128
csys,0
```

```
real,71
type,71
e,127,128

wplane,,nx(135),ny(135),nz(135),nx(136),ny(136),nz(136),nx(133),ny(133),nz(133)
cswplane,18,0
nrotat,135
nrotat,136
csys,0

real,73
type,73
e,135,136

wplane,,nx(141),ny(141),nz(141),nx(142),ny(142),nz(142),nx(140),ny(140),nz(140)
cswplane,19,0
nrotat,141
nrotat,142
csys,0

real,74
type,74
e,141,142

wplane,,nx(165),ny(165),nz(165),nx(166),ny(166),nz(166),nx(164),ny(164),nz(164)
cswplane,20,0
nrotat,165
nrotat,166
csys,0

real,78
type,78
e,165,166

/com,------------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,s,node,,2,4
nsel,a,node,,18
nsel,a,node,,30
nsel,a,node,,38
nsel,a,node,,44
nsel,a,node,,50
nsel,a,node,,52
nsel,a,node,,57
nsel,a,node,,63
nsel,a,node,,68
nsel,a,node,,73
nsel,a,node,,75
nsel,a,node,,88
nsel,a,node,,90
nsel,a,node,,95,97
nsel,a,node,,109
nsel,a,node,,113
nsel,a,node,,118
nsel,a,node,,120
nsel,a,node,,128
nsel,a,node,,134
nsel,a,node,,136
nsel,a,node,,142
nsel,a,node,,146
nsel,a,node,,150
nsel,a,node,,158
nsel,a,node,,166
nsel,a,node,,170
nsel,a,node,,177
nsel,a,node,,193,195
d,all,all
```

```
allsel,all,all

d,1,rotx,,,,,roty,rotz
d,94,rotx,,,,,roty,rotz
d,192,rotx,,,,,roty,rotz

finish

/com,------------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal     ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on      ! Use Lumped Mass Matrix Approximation
mxpand,maxm,,,yes     ! Expand solutions with Element Calculations turned ON
solve
save

/com,
/com,===========================
/com, Compare Modal Frequencies
/com,===========================
/com,

*dim,Amode,ARRAY,maxm
*dim,Emode,ARRAY,maxm
*dim,ERmode,ARRAY,maxm
*dim,moden,ARRAY,maxm

*do,i,1,maxm
 *GET, Amode(i), MODE, i, FREQ
*enddo
*VFILL,Emode,DATA,2.612,2.914,4.337,4.66,5.734,5.833,7.359,7.769,9.952,10.329
*VFILL,Emode(11),DATA,10.679,10.943,12.03,12.286,13.251,13.407,14.429,14.72,15.253,15.553
*VFILL,Emode(21),DATA,16.172,16.797,17.23,17.275,17.453,18.71,18.898,19.993,21.46,21.523
*VFILL,Emode(31),DATA,22.736,23.281,24.067,24.593,25.117,26.516,26.935,27.509,28.662,29.542
*VFILL,Emode(41),DATA,30.596,31.274,32.283,35.484,36.022,36.394,36.769,38.0,38.42,40.185

*do,i,1,maxm
  ERmode(i) = ABS(Amode(i)/Emode(i))
  moden(i) = i
*enddo

save,table_1
finish

/com,------------------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr      ! Perform Spectrum Analysis
spopt,sprs,maxm      ! Single Point Response Spectrum
SRSS,0.0       ! Combine modes using SRSS mode combination

/com,------------------------------------------------------------------------------------------
/com,

/com,
/com, spectrum 1 (X - Direction)
/com,****************************
```

```
svtyp, 2, 386.20

freq,0.2,0.5,0.5263,0.578,0.7752,1.7241,2.0,2.1978,2.2472,
SV,,0.16,0.16,0.16,0.23,0.339,0.55,0.555,0.555,0.65,

freq,2.9851,3.125,4.1667,5.0,5.7143,7.6923,9.0909,9.5238,10.4167
sv,,0.65,1.5,1.5,1.36,0.45,0.935,0.935,0.995,1.31,

freq,14.0845,17.8571,19.6078,27.027,33.3333,50.0,100.0
sv,,1.31,1.0,1.222,1.222,0.5,0.252,0.252,

sed,1,0,0
solve

/com,
/com, spectrum 2 (Y - Direction)
/com,****************************

svtyp, 2, 386.20
freq,,

FREQ,0.2,0.6061,0.667,1.9231,2.439,3.7037,4.0,5.3476,5.5866,
SV,,0.085,0.115,0.125,0.36,0.40,0.525,0.54,0.54,0.506,

FREQ,8.333,10.989,12.5,14.7059,20.0,21.2766,22.2222,27.7778,28.5714,
SV,,2.6,2.6,0.9,0.875,0.875,0.76,0.85,0.85,0.522,

FREQ,30.303,33.3333,50.0,100.0
SV,,0.255,0.295,0.194,0.194

sed,0,1,0
solve

/com,
/com, spectrum 3 (Z - Direction)
/com,***************************

svtyp, 2, 386.20
freq,,,

FREQ,0.2,0.5,0.5814,1.7544,2.1739,2.8571,3.0303,4.1667,5.0,
SV,,0.16,0.16,0.23,0.56,0.56,0.80,1.5,1.5,1.15,

FREQ,5.2632,5.7143,5.8824,6.2893,6.5789,7.4074,9.6154,10.4167,14.0845,
SV,,0.64,0.64,0.7,0.7,0.875,1.05,1.05,1.31,1.31,

FREQ,15.873,17.2414,25.0,27.027,32.2581,50.0,100.0
SV,,0.85,1.15,1.15,1.1,0.5,0.225,0.225,

sed,0,0,1
solve

finish

/com,------------------------------------------------------------------------------------
/com,

/post1
/input,,mcom

/com,----------------------------------

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1
*dim,label5,char,22,1

/com,-------------------------

label2(1,1) = 'ux_81'
label2(1,2) = 'uy_155'
```

```
label2(1,3) = 'uz_61'
label2(1,4) ='rotx_143'
label2(1,5) ='roty_149'
label2(1,6) ='rotz_84'

/com,----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,----------------------------------

/com,----------------------------------------------------------------------------------

/com,
/com,=====================================================
/com, Maximum nodal displacements and rotations comparsion
/com,=====================================================
/com,

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,81,U,X
*GET,AdisY,NODE,155,U,Y
*GET,AdisZ,NODE,61,U,Z
*GET,ArotX,NODE,143,ROT,X
*GET,ArotY,NODE,149,ROT,Y
*GET,ArotZ,NODE,84,ROT,Z

/com,
/com, Expected results from NRC manual
/com, *********************************

*SET,EdisX,9.29050e-01
*SET,EdisY,3.19026e-01
*SET,EdisZ,6.18342e-01
*SET,ErotX,5.98220e-03
*SET,ErotY,1.00078e-02
*SET,ErotZ,9.17224e-03

/com,
/com, Error computation
/com,********************

ERdisX=ABS(AdisX/EdisX)
ERdisY=ABS(AdisY/EdisY)
ERdisZ=ABS(AdisZ/EdisZ)
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
```

```
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,------------------------------------------------------------------------------------

/com,=============================================================
/com, Element Forces and Moments Comparison
/com,=============================================================

/com, Solution obtained from Mechanical APDL
/com,******************************

*dim,elem_res_I,,1,6
*dim,elem_res_J,,1,6

*dim,pxi,,1
*dim,vyi,,1
*dim,vzi,,1
*dim,txi,,1
*dim,myi,,1
*dim,mzi,,1

*dim,pxj,,1
*dim,vyj,,1
*dim,vzj,,1
*dim,txj,,1
*dim,myj,,1
*dim,mzj,,1

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,***********

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com,==========
```

```
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com,-------------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,1,6
*dim,exp_J,,1,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,2.273e+03
*vfill,exp_I(1,2),data,3.719e+03
*vfill,exp_I(1,3),data,2.287e+03
*vfill,exp_I(1,4),data,1.050e+05
*vfill,exp_I(1,5),data,2.299e+05
*vfill,exp_I(1,6),data,3.516e+05

*vfill,exp_J(1,1),data,2.273e+03
*vfill,exp_J(1,2),data,3.719e+03
*vfill,exp_J(1,3),data,2.287e+03
*vfill,exp_J(1,4),data,1.050e+05
*vfill,exp_J(1,5),data,1.987e+05
*vfill,exp_J(1,6),data,2.920e+05

/com,------------------------------------------------------------------------------

/com, Error computation
/com, ********************

*dim,elem_error_I,,1,6
*dim,elem_error_J,,1,6
*dim,elem_tab,,12,3

/com,============
/com,   Node I
/com,============

i = 1
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
 *enddo

/com,============
/com,   Node J
/com,============

i = 1
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo
```

```
/com,--------------------------------------------------------------------------

i = 1
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+6
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo

save,table_3

/com,------------------------------------------------------------------------------------

/com,*****************************
/com, Reaction forces comparision
/com,******************************

*dim,Areac,,36
*dim,Ereac,,36
*dim,ERreac,,36
*dim,Nreac,STRING,8,36

/com, Labels
/com,********

Nreac(1,1) = 'FX1'
Nreac(1,2) = 'FY1'
Nreac(1,3) = 'FZ1'
Nreac(1,4) = 'FY17'
Nreac(1,5) = 'FY29'

Nreac(1,6) = 'FZ37'
Nreac(1,7) = 'FX43'
Nreac(1,8) = 'FY49'
Nreac(1,9) = 'FZ51'
Nreac(1,10) = 'FX56'

Nreac(1,11) = 'FY62'
Nreac(1,12) = 'FZ67'
Nreac(1,13) = 'FY72'
Nreac(1,14) = 'FZ74'
Nreac(1,15) = 'FY87'

Nreac(1,16) = 'FY89'
Nreac(1,17) = 'FX94'
Nreac(1,18) = 'FY94'
Nreac(1,19) = 'FZ94'
Nreac(1,20) = 'FY108'

Nreac(1,21) = 'FX112'
Nreac(1,22) = 'FZ117'
Nreac(1,23) = 'FY119'
Nreac(1,24) = 'FZ127'
Nreac(1,25) = 'FY133'

Nreac(1,26) = 'FZ135'
Nreac(1,27) = 'FX141'
Nreac(1,28) = 'FZ145'
Nreac(1,29) = 'FY149'
Nreac(1,30) = 'FY157'

Nreac(1,31) = 'FX165'
Nreac(1,32) = 'FY169'
```

```
Nreac(1,33) = 'FY188'
Nreac(1,34) = 'FX192'
Nreac(1,35) = 'FY192'
Nreac(1,36) = 'FZ192'

/com, Solution obtained from Mechanical APDL
/com,******************************

*GET,Areac(1),NODE,2,RF,FX
*GET,Areac(2),NODE,3,RF,FY
*GET,Areac(3),NODE,4,RF,FZ
*GET,Areac(4),NODE,18,RF,FY
*GET,Areac(5),NODE,30,RF,FY

*GET,Areac(6),NODE,38,RF,FZ
*GET,Areac(7),NODE,44,RF,FX
*GET,Areac(8),NODE,50,RF,FY
*GET,Areac(9),NODE,52,RF,FX
*GET,Areac(10),NODE,57,RF,FX

*GET,Areac(11),NODE,63,RF,FY
*GET,Areac(12),NODE,68,RF,FX
*GET,Areac(13),NODE,73,RF,FY
*GET,Areac(14),NODE,75,RF,FX
*GET,Areac(15),NODE,88,RF,FY

*GET,Areac(16),NODE,90,RF,FY
*GET,Areac(17),NODE,95,RF,FX
*GET,Areac(18),NODE,96,RF,FY
*GET,Areac(19),NODE,97,RF,FZ
*GET,Areac(20),NODE,109,RF,FY

*GET,Areac(21),NODE,113,RF,FX
*GET,Areac(22),NODE,118,RF,FX
*GET,Areac(23),NODE,120,RF,FY
*GET,Areac(24),NODE,128,RF,FX
*GET,Areac(25),NODE,134,RF,FY

*GET,Areac(26),NODE,136,RF,FX
*GET,Areac(27),NODE,142,RF,FX
*GET,Areac(28),NODE,146,RF,FZ
*GET,Areac(29),NODE,150,RF,FY
*GET,Areac(30),NODE,158,RF,FY

*GET,Areac(31),NODE,166,RF,FX
*GET,Areac(32),NODE,170,RF,FY
*GET,Areac(33),NODE,177,RF,FY
*GET,Areac(34),NODE,193,RF,FX
*GET,Areac(35),NODE,194,RF,FY
*GET,Areac(36),NODE,195,RF,FZ

/com, Expected results from NRC manual
/com,**********************************

*VFILL,Ereac,DATA,3724,2390,2156,42,2466,4850,4765,3835,3482,2101
*VFILL,Ereac(11),DATA,61,6860,2669,6554,109,5015,3334,4739,861,64
*VFILL,Ereac(21),DATA,2312,2079,1153,1829,886,889,1858,2571,1349,106
*VFILL,Ereac(31),DATA,4370,1340,1170,970,749,2952

/com, Error computation
/com,******************

*do,i,1,36
   ERreac(i) = abs(Areac(i)/Ereac(i))
*enddo

save,table_4

/com,-------------------------------------------------------------------------------------
/com,

/out,
```

```
/com,
/com, ------------------------vm-nr1677-2-4a-a Results Verification-------------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-2-4a-a,vrt

/com,
/com, ===========================================
/com,  COMPARISON OF MODAL FREQUENCY
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*VWRITE,moden(1),Emode(1),Amode(1),ERmode(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,' ')

/com,
/com, -------------------------------------------------------------------------

/nopr
resume,table_2
/gopr

/com,
/com,====================================================
/com,  COMPARISON OF NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,====================================================
/com,

/com,  Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,------------------------------------------------------------------------
/com,

/nopr
resume,table_4
/gopr

/com,
/com, ===========================================
/com,  COMPARISON OF REACTION FORCES
/com,      WITH EXPECTED RESULTS
/com, ===========================================
/com,

/com,  Node | Expected |  Mechanical APDL  |  Ratio
/com,
```

```
*VWRITE,Nreac(1),Ereac(1),Areac(1),ERreac(1)
(5X,a,2X,F12.4,3X,F12.4,3X,F8.4,' ')

/com,

/com,--------------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,===============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,===============================================
/com,

/com,--------------------------------------------------------
/com, Note: Element Forces and Moments for some elements
/com,       along Y & Z directions are flipped between Mechanical APDL
/com,  and NRC results
/com,--------------------------------------------------------


/com,  Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,

*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,
/com,
/com,*******************************************************************
/com,*******************************************************************
/com,
/com,

/out,
*list,vm-nr1677-2-4a-a,vrt
finish
```

vm-nr1677-2-4c-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-2-4c-a
/title,vm-nr1677-2-4c-a,NRC piping benchmarks problems,Volume II,Problem 4c

/com, ********************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com,
/com, Element used: Pipe16, Pipe18, Combin14 and Mass21
```

```
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com,
/com, ********************************************************************************

/out,scratch

/prep7

YoungModulus = 0.283e+8    ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus = YoungModulus/(2*(1+Nu)) ! Shear Modulus
K = 0.911e-5     ! Thermal Expansion
maxm = 50      ! No. of Modes Extracted

/com,
/com, Section Property
/com,*****************

/com,
/com, Wall Thickness
/com,----------------

WTick_1 = 2.25
WTick_2 = 3.44
WTick_3 = 1.0
WTick_4 = 2.64
WTick_5 = 74.775

WTick_6 = 1.0
WTick_7 = 2.64
WTick_8 = 0.7180
WTick_9 = 1.62
WTick_10 = 46.035

WTick_11 = 0.7180
WTick_12 = 0.906
WTick_13 = 0.365

/com,
/com, Outer Diameter
/com,----------------

OD_1 = 32.25
OD_2 = 15.625
OD_3 = 10.75
OD_4 = 16.03
OD_5 = 160.3

OD_6 = 10.75
OD_7 = 16.03
OD_8 = 6.625
OD_9 = 9.87
OD_10 = 98.7

OD_11 = 6.625
OD_12 = 8.625
OD_13 = 10.75

/com,
/com, Bend Radius
/com,--------------

RADCUR_1 = 15.0
RADCUR_2 = 14.9
RADCUR_3 = 9.0
```

```
RADCUR_4 = 12.0
RADCUR_5 = 40.0
RADCUR_6 = 8.0

/com,-----------------------------------------------------------------------------------

/com,
/com, Element Types
/com,***************

et,1,pipe16
et,2,pipe16
et,3,pipe16
et,4,pipe16
et,5,pipe16
et,6,pipe16
et,7,pipe16
et,8,pipe16
et,9,pipe16
et,10,pipe16
et,11,pipe16
et,12,pipe16
et,13,pipe16

et,14,pipe18
et,15,pipe18
et,16,pipe18
et,17,pipe18
et,18,pipe18
et,19,pipe18
et,20,pipe18
et,21,pipe18
et,22,pipe18

et,23,mass21      ! 3D Mass without rotatary inertia
keyopt,23,3,2
et,24,mass21
keyopt,24,3,2
et,25,mass21
keyopt,25,3,2
et,26,mass21
keyopt,26,3,2
et,27,mass21
keyopt,27,3,2
et,28,mass21
keyopt,28,3,2
et,29,mass21
keyopt,29,3,2
et,30,mass21
keyopt,30,3,2
et,31,mass21
keyopt,31,3,2
et,32,mass21
keyopt,32,3,2
et,33,mass21
keyopt,33,3,2
et,34,mass21
keyopt,34,3,2
et,35,mass21
keyopt,35,3,2
et,36,mass21
keyopt,36,3,2
et,37,mass21
keyopt,37,3,2
et,38,mass21
keyopt,38,3,2
et,39,mass21
keyopt,39,3,2
et,40,mass21
keyopt,40,3,2
et,41,mass21
keyopt,41,3,2
```

```
et,42,mass21
keyopt,42,3,2
et,43,mass21
keyopt,43,3,2
et,44,mass21
keyopt,44,3,2
et,45,mass21
keyopt,45,3,2
et,46,mass21
keyopt,46,3,2
et,47,mass21
keyopt,47,3,2

et,48,combin14,,1      ! Spring Elements Types and Real constants
keyopt,48,2,1      ! X Degree of Freedom
et,49,combin14,,2
keyopt,49,2,2      ! Y Degree of Freedom
et,50,combin14,,3
keyopt,50,2,3      ! Z Degree of Freedom
et,51,combin14,,2
keyopt,51,2,2      ! Y Degree of Freedom
et,52,combin14,,2
keyopt,52,2,2      ! Y Degree of Freedom
et,53,combin14,,3
keyopt,53,2,3      ! Z Degree of Freedom
et,54,combin14,,1
keyopt,54,2,1      ! X Degree of Freedom
et,55,combin14,,2
keyopt,55,2,2      ! Y Degree of Freedom
et,56,combin14,,1
keyopt,56,2,1      ! X Degree of Freedom
et,57,combin14,,1
keyopt,57,2,1      ! X Degree of Freedom
et,58,combin14,,2
keyopt,58,2,2      ! Y Degree of Freedom
et,59,combin14,,1
keyopt,59,2,1      ! X Degree of Freedom
et,60,combin14,,2
keyopt,60,2,2      ! Y Degree of Freedom
et,61,combin14,,1
keyopt,61,2,1      ! X Degree of Freedom
et,62,combin14,,2
keyopt,62,2,2      ! Y Degree of Freedom
et,63,combin14,,2
keyopt,63,2,2      ! Y Degree of Freedom
et,64,combin14,,1
keyopt,64,2,1      ! X Degree of Freedom
et,65,combin14,,2
keyopt,65,2,2      ! Y Degree of Freedom
et,66,combin14,,3
keyopt,66,2,3      ! Z Degree of Freedom
et,67,combin14,,2
keyopt,67,2,2      ! Y Degree of Freedom
et,68,combin14,,1
keyopt,68,2,1      ! X Degree of Freedom
et,69,combin14,,1
keyopt,69,2,1      ! X Degree of Freedom
et,70,combin14,,2
keyopt,70,2,2      ! Y Degree of Freedom
et,71,combin14,,1
keyopt,71,2,1      ! X Degree of Freedom
et,72,combin14,,2
keyopt,72,2,2      ! Y Degree of Freedom
et,73,combin14,,1
keyopt,73,2,1      ! X Degree of Freedom
et,74,combin14,,1
keyopt,74,2,1      ! X Degree of Freedom
et,75,combin14,,3
keyopt,75,2,3      ! Z Degree of Freedom
et,76,combin14,,2
keyopt,76,2,2      ! Y Degree of Freedom
et,77,combin14,,2
```

```
keyopt,77,2,2      ! Y Degree of Freedom
et,78,combin14,,1
keyopt,78,2,1      ! X Degree of Freedom
et,79,combin14,,2
keyopt,79,2,2      ! Y Degree of Freedom
et,80,combin14,,2
keyopt,80,2,2      ! Y Degree of Freedom
et,81,combin14,,1
keyopt,81,2,1      ! X Degree of Freedom
et,82,combin14,,2
keyopt,82,2,2      ! Y Degree of Freedom
et,83,combin14,,3
keyopt,83,2,3      ! Z Degree of Freedom

/com,--------------------------------------------------------------------------------

/com

/com, Real Constants
/com,****************

r, 1,OD_1,WTick_1
r, 2,OD_2,WTick_2
r, 3,OD_3,WTick_3
r, 4,OD_4,WTick_4
r, 5, OD_5,WTick_5
r, 6, OD_6,WTick_6
r, 7, OD_7,WTick_7
r, 8, OD_8,WTick_8
r, 9, OD_9,WTick_9
r, 10, OD_10,WTick_10
r, 11, OD_11,WTick_11
r, 12, OD_12,WTick_12
r, 13, OD_13,WTick_13

r, 14, OD_3, WTick_3,RADCUR_1
r, 15, OD_6, WTick_6,RADCUR_1
r, 16, OD_6, WTick_6,RADCUR_2
r, 17, OD_13, WTick_13,RADCUR_1
r, 18, OD_13, WTick_13,RADCUR_2
r, 19, OD_8, WTick_8,RADCUR_3
r, 20, OD_12, WTick_12,RADCUR_4
r, 21, OD_12, WTick_12,RADCUR_5
r, 22, OD_12, WTick_12,RADCUR_6

r,23,1.69306
r,24,5.07505
r,25,4.96894
r,26,1.20212
r,27,1.42495
r,28,1.88768
r,29,2.18323
r,30,2.4397
r,31,2.98188
r,32,1.41874
r,33,1.04943e+1
r,34,9.30124e-1
r,35,1.6118
r,36,6.74431e-1
r,37,6.43116e-1
r,38,1.06962
r,39,1.20549
r,40,1.05642
r,41,1.25388
r,42,1.3543
r,43,6.66149e-1
r,44,2.27769
r,45,1.15217
r,46,1.23214
r,47,1.52976

r,48, 0.1e+9
```

```
r,49, 0.1e+9
r,50, 0.1e+9
r,51, 0.1080e+4
r,52, 0.6001e+5
r,53, 0.6001e+5
r,54, 0.6001e+5
r,55, 0.7541e+6
r,56, 0.7541e+6
r,57, 0.6001e+5
r,58, 0.6000e+3
r,59, 0.6001e+5
r,60, 0.7601e+5
r,61, 0.6001e+5
r,62, 0.8000e+3
r,63, 0.6001e+5
r,64, 0.1000e+9
r,65, 0.1000e+9
r,66, 0.1000e+9
r,67, 0.2600e+3
r,68, 0.5901e+5
r,69, 0.2400e+5
r,70, 0.7601e+5
r,71, 0.2801e+5
r,72, 0.2460e+6
r,73, 0.6001e+5
r,74, 0.6001e+5
r,75, 0.7501e+5
r,76, 0.4660e+6
r,77, 0.3400e+3
r,78, 0.6001e+5
r,79, 0.5000e+6
r,80, 0.5000e+6
r,81, 0.1000e+9
r,82, 0.1000e+9
r,83, 0.1000e+9

/com,-----------------------------------------------------------------------------------

/com, Material Properties
/com,*********************

MP,EX,  1, YoungModulus
MP,NUXY,1, Nu
MP,GXY ,1, ShearModulus
MP,ALPX,1, K

MP,EX,  2, YoungModulus
MP,NUXY,2, Nu
MP,GXY ,2, ShearModulus
MP,ALPX,2, K

MP,EX,  3, YoungModulus
MP,NUXY,3, Nu
MP,GXY ,3, ShearModulus
MP,ALPX,3, K

MP,EX,  4, YoungModulus
MP,NUXY,4, Nu
MP,GXY ,4, ShearModulus
MP,ALPX,4, K

MP,EX,  5, YoungModulus
MP,NUXY,5, Nu
MP,GXY ,5, ShearModulus
MP,ALPX,5, K

MP,EX,  6, YoungModulus
MP,NUXY,6, Nu
MP,GXY ,6, ShearModulus
MP,ALPX,6, K

MP,EX,  7, YoungModulus
```

```
MP,NUXY,7, Nu
MP,GXY ,7, ShearModulus
MP,ALPX,7, K

MP,EX,  8, YoungModulus
MP,NUXY,8, Nu
MP,GXY ,8, ShearModulus
MP,ALPX,8, K

MP,EX,  9, YoungModulus
MP,NUXY,9, Nu
MP,GXY ,9, ShearModulus
MP,ALPX,9, K

MP,EX,  10, YoungModulus
MP,NUXY,10, Nu
MP,GXY ,10, ShearModulus
MP,ALPX,10, K

MP,EX,  11, YoungModulus
MP,NUXY,11, Nu
MP,GXY ,11, ShearModulus
MP,ALPX,11, K

MP,EX,  12, YoungModulus
MP,NUXY,12, Nu
MP,GXY ,12, ShearModulus
MP,ALPX,12, K

MP,EX,  13, YoungModulus
MP,NUXY,13, Nu
MP,GXY ,13, ShearModulus
MP,ALPX,13, K

MP,EX,  14, YoungModulus
MP,NUXY,14, Nu
MP,GXY ,14, ShearModulus
MP,ALPX,14, K

MP,EX,  15, YoungModulus
MP,NUXY,15, Nu
MP,GXY ,15, ShearModulus
MP,ALPX,15, K

MP,EX,  16, YoungModulus
MP,NUXY,16, Nu
MP,GXY ,16, ShearModulus
MP,ALPX,16, K

MP,EX,  17, YoungModulus
MP,NUXY,17, Nu
MP,GXY ,17, ShearModulus
MP,ALPX,17, K

MP,EX,  18, YoungModulus
MP,NUXY,18, Nu
MP,GXY ,18, ShearModulus
MP,ALPX,18, K

MP,EX,  19, YoungModulus
MP,NUXY,19, Nu
MP,GXY ,19, ShearModulus
MP,ALPX,19, K

MP,EX,  20, YoungModulus
MP,NUXY,20, Nu
MP,GXY ,20, ShearModulus
MP,ALPX,20, K

MP,EX,  21, YoungModulus
MP,NUXY,21, Nu
MP,GXY ,21, ShearModulus
```

```
MP,ALPX,21, K

MP,EX,  22, YoungModulus
MP,NUXY,22, Nu
MP,GXY ,22, ShearModulus
MP,ALPX,22, K

/com,--------------------------------------------------------------------------------

/com, Nodes
/com,*******

n,1,-203.808,4715.952,139.224
n,2,-215.808,4715.952,139.224
n,3,-203.808,4703.952,139.224
n,4,-203.808,4715.952,127.224
n,5,-203.268,4719.852,154.860
n,6,-202.308,4726.800,182.748
n,7,-202.008,4728.948,191.340
n,8,-201.876,4729.392,194.916
n,9,-201.888,4729.392,194.988
n,10,-205.908,4729.392,205.740
n,11,-210.036,4729.392,210.168
n,12,-212.160,4729.392,212.436
n,13,-213.324,4729.392,213.684
n,14,-220.968,4729.392,221.868
n,15,-220.968,4734.492,221.868
n,16,-231.888,4729.392,233.568
n,17,-233.952,4729.392,235.776
n,18,-233.952,4741.392,235.776
n,19,-235.980,4729.392,237.936
n,20,-246.204,4714.392,248.904

n,21,-246.204,4705.860,248.904
n,22,-246.204,4686.792,248.904
n,23,-246.204,4676.952,248.904
n,24,-246.204,4665.900,248.904
n,25,-246.204,4638.876,248.904
n,26,-246.204,4631.628,248.904
n,27,-246.204,4628.952,248.904
n,28,-256.812,4613.952,238.296
n,29,-263.004,4613.952,232.104
n,30,-263.004,4625.952,232.104
n,31,-264.048,4613.952,231.060
n,32,-275.352,4613.952,219.744
n,33,-275.352,4619.052,219.744
n,34,-286.668,4613.952,208.440
n,35,-291.996,4613.952,203.112
n,36,-302.604,4613.952,198.720
n,37,-314.988,4613.952,198.720
n,38,-314.988,4613.952,186.720
n,39,-340.380,4613.952,198.720
n,40,-366.000,4613.952,198.720

n,41,-381.000,4628.952,198.720
n,42,-381.000,4630.560,198.720
n,43,-381.000,4655.952,198.720
n,44,-369.035,4655.952,197.800
n,45,-381.000,4689.588,198.720
n,46,-381.000,4756.872,198.720
n,47,-381.000,4760.952,198.720
n,48,-396.000,4775.952,198.720
n,49,-399.000,4775.952,198.720
n,50,-399.000,4787.952,198.720
n,51,-402.600,4775.952,198.720
n,52,-402.600,4775.872,210.685
n,53,-440.904,4775.952,198.720
n,54,-450.612,4775.952,198.720
n,55,-465.612,4790.952,198.720
n,56,-465.612,4796.592,198.720
n,57,-453.643,4796.592,197.860
n,58,-465.612,4840.068,198.720
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n,59,-465.612,4927.032,198.720
n,60,-465.612,4943.952,198.720

n,61,-459.864,4958.952,212.568
n,62,-458.712,4958.952,215.340
n,63,-458.712,4970.952,215.340
n,64,-455.748,4958.952,222.480
n,65,-463.860,4958.952,242.076
n,66,-484.044,4958.952,250.452
n,67,-533.124,4958.952,270.828
n,68,-537.724,4958.952,259.745
n,69,-552.516,4958.952,278.880
n,70,-552.600,4958.952,278.916
n,71,-560.652,4958.952,298.392
n,72,-559.464,4958.952,301.248
n,73,-559.464,4970.952,301.248
n,74,-558.312,4958.952,304.020
n,75,-553.866,4961.957,293.286
n,76,-554.868,4958.952,312.324
n,77,-548.736,4958.952,327.108
n,78,-548.736,4981.752,327.108
n,79,-546.708,4958.952,331.992
n,80,-542.604,4958.952,341.880

n,81,-538.152,4958.952,352.620
n,82,-532.404,4973.952,366.468
n,83,-532.404,4988.628,366.468
n,84,-532.404,5039.952,366.468
n,85,-532.404,5040.048,366.468
n,86,-546.168,5054.952,372.180
n,87,-551.904,5054.952,374.568
n,88,-551.904,5066.952,374.568
n,89,-560.988,5054.952,378.336
n,90,-560.988,5066.952,378.336
n,91,-565.128,5054.952,380.052
n,92,-578.988,5069.952,385.812
n,93,-578.988,5091.924,385.812
n,94,-578.988,5141.940,385.812
n,95,-590.988,5141.940,385.812
n,96,-578.988,5129.940,385.812
n,97,-578.988,5141.940,373.812
n,98,-242.400,4676.952,252.708
n,99,-242.382,4676.952,252.720
n,100,-238.434,4676.952,256.680

n,101,-232.056,4667.952,263.052
n,102,-232.056,4665.936,263.052
n,103,-232.056,4622.952,263.052
n,104,-225.696,4613.952,256.692
n,105,-218.688,4613.952,249.684
n,106,-216.048,4613.952,243.312
n,107,-216.048,4613.952,208.800
n,108,-216.048,4613.952,181.644
n,109,-216.048,4625.952,181.644
n,110,-216.048,4613.952,155.748
n,111,-216.048,4613.952,103.944
n,112,-216.048,4613.952,78.048
n,113,-204.048,4613.952,78.048
n,114,-216.048,4613.952,34.980
n,115,-216.048,4613.952,27.048
n,116,-225.048,4613.952,18.048
n,117,-231.048,4613.952,18.048
n,118,-231.048,4616.447,29.785
n,119,-246.048,4613.952,18.048
n,120,-246.048,4625.952,18.048

n,121,-267.048,4613.952,18.048
n,122,-276.048,4613.952,27.048
n,123,-276.048,4613.952,40.452
n,124,-276.048,4613.952,137.544
n,125,-276.048,4613.952,168.948
n,126,-276.048,4622.952,177.948
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n,127,-276.048,4625.952,177.948
n,128,-274.814,4625.952,189.884
n,129,-276.048,4668.492,177.948
n,130,-276.048,4753.560,177.948
n,131,-276.048,4766.952,177.948
n,132,-285.048,4775.952,177.948
n,133,-288.048,4775.952,177.948
n,134,-288.048,4787.952,177.948
n,135,-300.048,4775.952,177.948
n,136,-300.048,4781.441,188.620
n,137,-350.532,4775.952,177.948
n,138,-451.512,4775.952,177.948
n,139,-472.020,4775.952,177.948
n,140,-481.020,4784.952,177.948

n,141,-481.020,4800.792,177.948
n,142,-469.580,4800.792,181.571
n,143,-481.020,4855.320,177.948
n,144,-481.020,4964.388,177.948
n,145,-481.020,4979.592,177.948
n,146,-481.020,4979.592,189.948
n,147,-481.020,5000.592,177.948
n,148,-489.336,5009.952,181.392
n,149,-492.876,5009.952,182.868
n,150,-492.876,5021.952,182.868
n,151,-520.044,5009.952,194.148
n,152,-558.600,5009.952,210.156
n,153,-566.916,5018.952,213.600
n,154,-566.916,5021.892,213.600
n,155,-566.916,5048.952,213.600
n,156,-563.472,5057.952,221.912
n,157,-562.320,5057.952,224.688
n,158,-562.320,5069.952,224.688
n,159,-558.864,5057.952,233.004
n,160,-556.716,5057.952,238.188

n,161,-553.884,5057.952,245.004
n,162,-553.884,5062.044,245.004
n,163,-548.904,5057.952,257.016
n,164,-546.600,5057.952,262.560
n,165,-545.436,5057.952,265.368
n,166,-556.148,5060.878,260.821
n,167,-534.588,5057.952,291.528
n,168,-512.880,5057.952,343.824
n,169,-502.020,5057.952,369.984
n,170,-502.020,5069.952,369.984
n,171,-500.988,5057.952,372.468
n,172,-496.392,5045.952,383.544
n,173,-496.392,5037.192,383.544
n,174,-496.392,5033.952,383.544
n,175,-506.700,5021.952,389.676
n,176,-539.784,5021.952,409.358
n,177,-596.976,5059.452,495.504
n,178,-588.540,5021.952,438.372
n,179,-588.624,5021.952,438.420
n,180,-595.416,5029.848,442.464

n,181,-595.416,5035.452,442.464
n,182,-605.748,5047.452,448.596
n,183,-610.896,5047.452,451.668
n,184,-615.072,5047.452,468.120
n,185,-613.716,5047.452,470.388
n,186,-603.960,5047.452,486.792
n,187,-597.504,5047.452,494.988
n,188,-596.976,5047.452,495.504
n,189,-570.048,5047.452,521.736
n,190,-516.180,5047.452,574.200
n,191,-462.312,5047.452,626.676
n,192,-435.384,5047.452,652.920
n,193,-447.384,5047.452,652.920
n,194,-435.384,5035.452,652.920
n,195,-435.384,5047.452,640.920
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n,271,-249.31,4618.4,245.79
n,272,-560.66,4959,286.99
n,273,-574.94,5059.4,384.11
n,274,-536.41,5050.6,368.12
n,275,-233.93,4674.4,261.18
n,276,-483.33,5007.2,178.89
n,277,-564.48,5012.6,212.59
n,278,-598.45,5044.0,444.25
n,279,-616.39,5047.5,459.03

/com,-------------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,*********************************

mat,1
type,1
real,1
e,1,5

type,2
real,2
e,5,6

type,3
real,3
e,6,7
e,8,9
e,10,11

type,4
real,4
e,11,12
e,12,13
e,13,14
e,14,16
e,31,32
e,32,34

type,5
real,5
e,14,15
e,32,33
e,77,78

type,6
real,6
e,16,17
e,17,19
e,20,21
e,21,22
e,22,23
e,23,24
e,24,25
e,25,26
e,26,27
e,28,29
e,29,31
e,34,35
e,36,37
e,37,39
e,39,40
e,41,42
e,42,43
e,43,45
e,45,46
e,46,47
e,48,49
e,49,51
e,51,53
```

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e,53,54
e,55,56
e,56,58
e,58,59
e,59,60
e,61,62
e,62,64
e,65,66
e,66,67
e,67,69
e,69,70
e,71,72
e,72,74
e,74,76

type,7
real,7
e,76,77
e,77,79
e,79,80

type,13
real,13
e,80,81
e,82,83
e,83,84
e,84,85
e,86,87
e,87,89
e,89,91
e,92,93
e,93,94

id = 8
type,8
real,8
e,23,98
e,98,99
e,99,100
e,101,102
e,102,103
e,104,105
e,106,107
e,107,108
e,108,110
e,110,111
e,111,112
e,112,114
e,114,115
e,116,117
e,117,119
e,119,121
e,122,123
e,123,124
e,124,125
e,126,127
e,127,129
e,129,130
e,130,131
e,132,133
e,133,135
e,135,137
e,137,138
e,138,139
e,140,141
e,141,143
e,143,144
e,144,145
e,145,147
e,148,149
e,149,151
e,151,152
```

```
e,153,154
e,154,155
e,156,157
e,157,159
e,163,164

type,9
real,9
e,159,160
e,160,161
e,161,163

type,10
real,10
e,161,162

type,12
real,12
e,164,165
e,165,167
e,167,168
e,168,169
e,169,171
e,172,173
e,173,174
e,175,176
e,176,178
e,178,179
e,180,181
e,182,183
e,184,185
e,185,186
e,187,188
e,188,189
e,189,190
e,190,191
e,191,192

/com,
/com, Pipe Bend Elements
/com,********************

mat,1

type,14
real,14
e,7,8,6
e,9,10,11

type,15
real,15
e,19,20,21
e,27,271,26
e,271,28,29
e,35,36,37
e,40,41,42
e,47,48,49
e,54,55,53
e,60,61,62
e,64,65,66

type,16
real,16
e,70,272,69
e,272,71,72

type,17
real,17
e,81,82,83
e,91,273,89
e,273,92,93
```

```
type,18
real,18
e,85,274,83
e,274,86,87

type,19
real,19
e,100,275,99
e,275,101,102
e,103,104,105
e,105,106,107
e,115,116,114
e,121,122,123
e,125,126,124
e,131,132,133
e,139,140,138
e,147,276,145
e,276,148,149
e,152,277,151
e,277,153,154
e,155,156,157

type,20
real,20
e,171,172,173
e,174,175,176
e,181,278,180
e,278,182,183
e,183,279,182
e,279,184,185

type,21
real,21
e,186,187,188

type,22
real,22
e,179,180,181

/com, Point Mass without considering rotatary inertia
/com,*************************************************

type,23
real,23
e,12
e,21
e,25

type,24
real,24
e,15

type,25
real,25
e,33

type,26
real,26
e,34

type,27
real,27
e,39
e,42

type,28
real,28
e,45
e,46

type,29
real,29
```

```
e,53

type,30
real,30
e,58
e,59

type,31
real,31
e,66

type,32
real,32
e,69

type,33
real,33
e,78

type,34
real,34
e,79
e,83
e,84

type,35
real,35
e,93

type,36
real,36
e,102
e,104
e,107

type,37
real,37
e,110
e,111

type,38
real,38
e,114

type,39
real,39
e,123
e,124

type,40
real,40
e,129
e,130

type,41
real,41
e,137
e,138

type,42
real,42
e,143
e,144

type,43
real,43
e,151
e,154
e,160

type,44
real,44
```

```
e,162

type,45
real,45
e,167
e,168

type,46
real,46
e,173
e,176
e,178
e,185

type,47
real,47
e,189
e,190
e,191

/com,
/com, Elastic supports and anchors
/com,******************************

type,48
real,48
e,1,2

type,49
real,49
e,1,3

type,50
real,50
e,1,4

id = 51
type,51
real,51
e,17,18

type,52
real,52
e,29,30

type,53
real,53
e,37,38

type,55
real,55
e,49,50

type,58
real,58
e,62,63

type,60
real,60
e,72,73

type,62
real,62
e,87,88

type,63
real,63
e,89,90

type,64
real,64
e,94,95
```

```
type,65
real,65
e,94,96

type,66
real,66
e,94,97

type,67
real,67
e,108,109

type,68
real,68
e,112,113

type,70
real,70
e,119,120

type,72
real,72
e,133,134

type,75
real,75
e,145,146

type,76
real,76
e,149,150

type,77
real,77
e,157,158

id = 79
type,79
real,79
e,169,170

type,80
real,80
e,188,177

type,81
real,81
e,192,193

type,82
real,82
e,192,194

type,83
real,83
e,192,195

/com,
/com, rotate nodes with less than 3 supports
/com,****************************************

wplane,,nx(43),ny(43),nz(43),nx(44),ny(44),nz(44),nx(45),ny(45),nz(45)
cswplane,11,0
nrotat,43
nrotat,44
csys,0

real,54
type,54
e,43,44
```

```
wplane,,nx(51),ny(51),nz(51),nx(52),ny(52),nz(52),nx(49),ny(49),nz(49)
cswplane,12,0
nrotat,51
nrotat,52
csys,0

real,56
type,56
e,51,52

wplane,,nx(56),ny(56),nz(56),nx(57),ny(57),nz(57),nx(55),ny(55),nz(55)
cswplane,13,0
nrotat,56
nrotat,57
csys,0

real,57
type,57
e,56,57

wplane,,nx(67),ny(67),nz(67),nx(68),ny(68),nz(68),nx(66),ny(66),nz(66)
cswplane,14,0
nrotat,67
nrotat,68
csys,0

real,59
type,59
e,67,68

wplane,,nx(74),ny(74),nz(74),nx(75),ny(75),nz(75),nx(72),ny(72),nz(72)
cswplane,15,0
nrotat,74
nrotat,75
csys,0

real,61
type,61
e,74,75

wplane,,nx(117),ny(117),nz(117),nx(118),ny(118),nz(118),nx(116),ny(116),nz(116)
cswplane,16,0
nrotat,117
nrotat,118
csys,0

real,69
type,69
e,117,118

wplane,,nx(127),ny(127),nz(127),nx(128),ny(128),nz(128),nx(126),ny(126),nz(126)
cswplane,17,0
nrotat,127
nrotat,128
csys,0

real,71
type,71
e,127,128

wplane,,nx(135),ny(135),nz(135),nx(136),ny(136),nz(136),nx(133),ny(133),nz(133)
cswplane,18,0
nrotat,135
nrotat,136
csys,0

real,73
type,73
e,135,136

wplane,,nx(141),ny(141),nz(141),nx(142),ny(142),nz(142),nx(140),ny(140),nz(140)
cswplane,19,0
```

```
nrotat,141
nrotat,142
csys,0

real,74
type,74
e,141,142

wplane,,nx(165),ny(165),nz(165),nx(166),ny(166),nz(166),nx(164),ny(164),nz(164)
cswplane,20,0
nrotat,165
nrotat,166
csys,0

real,78
type,78
e,165,166

/com,------------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,s,node,,2,4
nsel,a,node,,18
nsel,a,node,,30
nsel,a,node,,38
nsel,a,node,,44
nsel,a,node,,50
nsel,a,node,,52
nsel,a,node,,57
nsel,a,node,,63
nsel,a,node,,68
nsel,a,node,,73
nsel,a,node,,75
nsel,a,node,,88
nsel,a,node,,90
nsel,a,node,,95,97
nsel,a,node,,109
nsel,a,node,,113
nsel,a,node,,118
nsel,a,node,,120
nsel,a,node,,128
nsel,a,node,,134
nsel,a,node,,136
nsel,a,node,,142
nsel,a,node,,146
nsel,a,node,,150
nsel,a,node,,158
nsel,a,node,,166
nsel,a,node,,170
nsel,a,node,,177
nsel,a,node,,193,195
d,all,all
allsel,all,all

d,1,rotx,,,,,roty,rotz
d,94,rotx,,,,,roty,rotz
d,192,rotx,,,,,roty,rotz

finish

/com,------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
```

```
antype,modal     ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on      ! Use Lumped Mass Matrix Approximation
mxpand,maxm,,,yes     ! Expand solutions with Element Calculations turned ON
solve
save

/com,
/com,===========================
/com, Compare Modal Frequencies
/com,===========================
/com,

*dim,Amode,ARRAY,maxm
*dim,Emode,ARRAY,maxm
*dim,ERmode,ARRAY,maxm
*dim,moden,ARRAY,maxm

*do,i,1,maxm
 *GET, Amode(i), MODE, i, FREQ
*enddo
*VFILL,Emode,DATA,2.612,2.914,4.337,4.66,5.734,5.833,7.359,7.769,9.952,10.329
*VFILL,Emode(11),DATA,10.679,10.943,12.03,12.286,13.251,13.407,14.429,14.72,15.253,15.553
*VFILL,Emode(21),DATA,16.172,16.797,17.23,17.275,17.453,18.71,18.898,19.993,21.46,21.523
*VFILL,Emode(31),DATA,22.736,23.281,24.067,24.593,25.117,26.516,26.935,27.509,28.662,29.542
*VFILL,Emode(41),DATA,30.596,31.274,32.283,35.484,36.022,36.394,36.769,38.0,38.42,40.185

*do,i,1,maxm
  ERmode(i) = ABS(Amode(i)/Emode(i))
  moden(i) = i
*enddo

save,table_1
finish

/com,-----------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,mprs,maxm     ! Multi Point Response Spectrum

gval = 386.0

/com,
/com, Support Group 1, Spectrum 1X
/com,******************************

id = 1
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.5263,0.7018,0.7752,1.0582,1.105
spval,id,,  0.16,0.16,0.195,0.235,0.339,0.339,0.305

spfrq,id, 1.25,1.3889,1.5221,1.7241,1.9231,2.0,2.1978
spval,id,,  0.305,0.395,0.395,0.525,0.525,0.555,0.555

spfrq,id, 2.2472,2.9851,3.3333,5.0,5.7143,7.6923,9.0909
spval,id,,  0.65,0.65,1.36,1.36,0.45,0.935,0.935

spfrq,id, 9.5238,12.8205,13.8889,17.8571,19.6078,27.027,33.3333
spval,id,,  0.995,0.995,1.0,1.0,1.222,1.222,0.5

spfrq,id, 50.0,100.0
spval,id,,  0.252,0.252

/com,
```

```
/com, spectrum 1Y (Group 1)
/com,***********************

id = 2
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.6061,0.6086,0.7752,1.5504,1.6667
spval,id,,  8.0e-2,8.0e-2,0.115,0.115,0.141,0.255,0.255

spfrq,id, 1.8349,2.0,2.2727,2.381,2.9762,3.4722,3.9216
spval,id,,  0.265,0.34,0.34,0.36,0.36,0.452,0.452

spfrq,id, 3.9841,5.4054,5.5556,6.3694,7.8125,10.5263,11.236
spval,id,,  0.5,0.5,0.4,0.4,1.4,1.4,1.0

spfrq,id, 11.7647,12.987,14.7059,20.0,22.2222,23.809,26.3158
spval,id,,  1.0,0.625,0.875,0.875,0.6,0.6,0.415

spfrq,id, 28.5714,30.303,33.3333,50.0,100.0
spval,id,,  0.415,0.295,0.295,0.165,0.165

/com,
/com, spectrum 1Z (Group 1)
/com,***********************

id = 3
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.5263,0.9524,1.0417,1.5601,1.5873
spval,id,,  0.15,0.15,0.167,0.24,0.305,0.305,0.28

spfrq,id, 1.7391,1.9048,2.1053,2.5974,3.3333,5.0,5.2632
spval,id,,  0.435,0.435,0.496,0.496,1.15,1.15,0.64

spfrq,id, 5.7143,5.8824,6.2893,6.5789,7.4074,9.6154,11.3636
spval,id,,  0.64,0.7,0.7,0.875,1.05,1.05,0.62

spfrq,id, 12.8205,14.0845,15.873,17.2414,25.0,27.027,32.2581
spval,id,,  0.62,0.755,0.65,1.15,1.15,1.1,0.5

spfrq,id, 50.0,100.0
spval,id,,  0.225,0.225

/com,----------------------------------------------------------------------------------

/com,
/com, Support Group 2, Spectrum 2X
/com,******************************

id = 4
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.5714,0.9091,0.9524,1.25,1.7544
spval,id,,  0.15,0.15,0.22,0.25,0.31,0.31,0.47

spfrq,id, 2.3256,3.2258,4.5455,5.1282,5.5556,7.6923,10.0
spval,id,,  0.47,0.39,0.35,0.29,0.35,0.35,0.23

spfrq,id, 12.5,16.6667,19.2308,33.3333,100.0
spval,id,,  0.3,0.3,0.25,0.09,0.09

/com,
/com, spectrum 2Y (Group 2)
/com,***********************

id = 5
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.6667,3.7037,4.3478,4.5455,5.5556
spval,id,,  0.085,0.085,0.125,0.525,0.525,0.47,0.47

spfrq,id, 8.3333,10.989,13.3333,16.667,17.2414,21.2766,22.2222
```

```
spval,id,,  2.6,2.6,0.5,0.5,0.76,0.76,0.85

spfrq,id, 27.7778,29.4118,100.0
spval,id,,  0.85,0.194,0.194

/com,
/com, spectrum 2Z (Group 2)
/com,**********************

id = 6
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.5714,0.9091,0.9524,1.25,1.7544
spval,id,,  0.15,0.15,0.22,0.25,0.31,0.31,0.47

spfrq,id, 2.3256,3.2258,4.5455,5.1282,5.5556,7.6923,10.0
spval,id,,  0.47,0.39,0.35,0.29,0.35,0.35,0.23

spfrq,id, 12.5,16.6667,19.2308,33.3333,100.0
spval,id,,  0.3,0.3,0.25,0.09,0.09

/com,-------------------------------------------------------------------------------------

/com,
/com, Support Group 3, Spectrum 3X
/com,*****************************

id = 7
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.578,1.7241,2.9412,3.0303,4.1667
spval,id,,  0.16,0.16,0.23,0.52,0.50,0.73,0.73

spfrq,id, 4.7619,5.4054,8.3333,10.5263,14.2857,17.8571,23.8095
spval,id,,  0.28,0.34,0.32,0.8,0.8,0.3,0.3

spfrq,id, 25.0,31.25,38.4615,100.0
spval,id,,  0.27,0.27,0.12,0.11

/com,
/com, spectrum 3Y (Group 3)
/com,**********************

id = 8
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.5814,1.25,1.4286,1.9231,2.3256
spval,id,,  0.08,0.08,0.11,0.19,0.20,0.35,0.35

spfrq,id, 2.439,3.3898,4.0,5.4054,5.8824,6.25,8.3333
spval,id,,  0.40,0.42,0.52,0.52,0.40,0.43,0.43

spfrq,id, 12.5,16.6667,23.2558,100.0
spval,id,,  0.47,0.14,0.14,0.12

/com,
/com, spectrum 3Z (Group 3)
/com,**********************

id = 9
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.578,1.7241,2.9412,3.0303,4.1667
spval,id,,  0.16,0.16,0.23,0.52,0.50,0.73,0.73

spfrq,id, 4.7619,5.4054,8.3333,10.5263,14.2857,17.8571,23.8095
spval,id,,  0.28,0.34,0.32,0.8,0.8,0.3,0.3

spfrq,id, 25.0,31.25,38.4615,100.0
spval,id,,  0.27,0.27,0.12,0.11

/com,-------------------------------------------------------------------------------------
```

```
/com,
/com, Support Group 4, Spectrum 4X
/com,******************************

id = 10
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.578,1.25,1.7241,2.2222,2.9412
spval,id,,  0.16,0.16,0.23,0.32,0.55,0.55,0.81

spfrq,id, 3.125,4.1667,5.1282,7.6923,10.4167,14.0845,16.9492
spval,id,,  1.50,1.50,0.29,0.3,1.31,1.31,0.46

spfrq,id, 23.8095,26.3158,32.2581,38.4615,100.0
spval,id,,  0.46,0.30,0.30,0.17,0.16

/com,
/com, spectrum 4Y (Group 4)
/com,***********************

id = 11
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.5848,1.5625,1.9231,2.3256,2.439
spval,id,,  0.08,0.08,0.11,0.20,0.36,0.36,0.40

spfrq,id, 3.0303,3.4483,4.0,5.3476,5.7143,6.25,8.0
spval,id,,  0.43,0.43,0.54,0.54,0.45,0.52,0.52

spfrq,id, 9.0909,12.5,18.1818,100.0
spval,id,,  0.9,0.9,0.18,0.14

/com,
/com, spectrum 4Z (Group 4)
/com,***********************

id = 12
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.578,1.25,1.7241,2.2222,2.9412
spval,id,,  0.16,0.16,0.23,0.32,0.55,0.55,0.81

spfrq,id, 3.125,4.1667,5.1282,7.6923,10.4167,14.0845,14.4928
spval,id,,  1.5,1.5,0.29,0.3,1.31,1.31,0.46

spfrq,id, 23.8095,26.3158,32.2581,38.4615,100.0
spval,id,,  0.46,0.3,0.3,0.17,0.16

/com,--------------------------------------------------------------------------------

/com,
/com, Nodal Components for Excitation Points
/com,****************************************

allsel,all,all

nsel,,node,,2,4
nsel,a,node,,18
cm,group1,node

allsel

nsel,,node,,30
nsel,a,node,,38
nsel,a,node,,109
nsel,a,node,,113
nsel,a,node,,118
nsel,a,node,,120
nsel,a,node,,128
nsel,a,node,,134
cm,group2,node
```

```
allsel

nsel,,node,,44
nsel,a,node,,50
nsel,a,node,,52
nsel,a,node,,57
nsel,a,node,,136
nsel,a,node,,142
nsel,a,node,,146
cm,group3,node

allsel

nsel,,node,,63
nsel,a,node,,68
nsel,a,node,,73
nsel,a,node,,75
nsel,a,node,,88
nsel,a,node,,90
nsel,a,node,,95,97
nsel,a,node,,150
nsel,a,node,,158
nsel,a,node,,166
nsel,a,node,,170
nsel,a,node,,177
nsel,a,node,,193,195
cm,group4,node

allsel,all,all
/com,-------------------------------------------------------------------------------

! -- Support Group 1 - spectrum 1 (Along X - Direction)
sed,1,,,group1
pfact,1
sed,0,,,group1

! -- Support Group 1 - spectrum 2 (Along Y - Direction)
sed,,1,,group1
pfact,2
sed,,0,,group1

! -- Support Group 1 - spectrum 3 (Along Z - Direction)
sed,,,1,group1
pfact,3
sed,,,0,group1

! -- Support Group 2 - spectrum 4 (Along X - Direction)
sed,1,,,group2
pfact,4
sed,0,,,group2

! -- Support Group 2 - spectrum 5 (Along Y - Direction)
sed,,1,,group2
pfact,5
sed,,0,,group2

! -- Support Group 2 - spectrum 6 (Along Z - Direction)
sed,,,1,group2
pfact,6
sed,,,0,group2

! -- Support Group 3 - spectrum 7 (Along X - Direction)
sed,1,,,group3
pfact,7
sed,0,,,group3

! -- Support Group 3 - spectrum 8 (Along Y - Direction)
sed,,1,,group3
pfact,8
sed,,0,,group3
```

```
! -- Support Group 3 - spectrum 9 (Along Z - Direction)
sed,,,1,group3
pfact,9
sed,,,0,group3

! -- Support Group 4 - spectrum 10 (Along X - Direction)
sed,1,,,group4
pfact,10
sed,0,,,group4

! -- Support Group 4 - spectrum 11 (Along Y - Direction)
sed,,1,,group4
pfact,11
sed,,0,,group4

! -- Support Group 4 - spectrum 12 (Along Z - Direction)
sed,,,1,group4
pfact,12
sed,,,0,group4

! *****************************************************
srss,0.00010,,yes   ! activate Absolute Sum

solve

finish

/com,-------------------------------------------------------------------------------

/post1

/input,,mcom

/com,-----------------------------------

/com, *Labels*
*dim,label2,char,1,6
*dim,label3,char,6,1
*dim,label4,char,6,1
*dim,label5,char,22,1

/com,-------------------------

label2(1,1) = 'ux_182'
label2(1,2) = 'uy_155'
label2(1,3) = 'uz_143'
label2(1,4) ='rotx_143'
label2(1,5) ='roty_149'
label2(1,6) ='rotz_155'

/com,-----------------------

label3(1,1)='PX(I)'
label3(2,1)='VY(I)'
label3(3,1)='VZ(I)'
label3(4,1)='TX(I)'
label3(5,1)='MY(I)'
label3(6,1)='MZ(I)'

/com,-----------------------

label4(1,1)='PX(J)'
label4(2,1)='VY(J)'
label4(3,1)='VZ(J)'
label4(4,1)='TX(J)'
label4(5,1)='MY(J)'
label4(6,1)='MZ(J)'

/com,-----------------------------------

/com,--------------------------------------------------------------------------------
```

```
/com,
/com,=======================================================
/com, Maximum nodal displacements and rotations comparsion
/com,=======================================================
/com,

/com, Solution obtained from Mechanical APDL
/com, ***************************

*GET,AdisX,NODE,182,U,X
*GET,AdisY,NODE,155,U,Y
*GET,AdisZ,NODE,143,U,Z
*GET,ArotX,NODE,143,ROT,X
*GET,ArotY,NODE,149,ROT,Y
*GET,ArotZ,NODE,155,ROT,Z

/com,
/com, Expected results from NRC manual
/com, ********************************

*SET,EdisX,6.88420e-01
*SET,EdisY,2.59046e-01
*SET,EdisZ,6.24744e-01
*SET,ErotX,5.30052e-03
*SET,ErotY,7.86745e-03
*SET,ErotZ,2.81817e-03

/com,
/com, Error computation
/com,*******************

ERdisX=ABS(AdisX/EdisX)
ERdisY=ABS(AdisY/EdisY)
ERdisZ=ABS(AdisZ/EdisZ)
ERrotX=ABS((ArotX)/(ErotX))
ERrotY=ABS((ArotY)/(ErotY))
ERrotZ=ABS((ArotZ)/(ErotZ))

*dim,value,,6,3

*vfill,value(1,1),data,EdisX
*vfill,value(1,2),data,AdisX
*vfill,value(1,3),data,ERdisX

*vfill,value(2,1),data,EdisY
*vfill,value(2,2),data,AdisY
*vfill,value(2,3),data,ERdisY

*vfill,value(3,1),data,EdisZ
*vfill,value(3,2),data,AdisZ
*vfill,value(3,3),data,ERdisZ

*vfill,value(4,1),data,ErotX
*vfill,value(4,2),data,ArotX
*vfill,value(4,3),data,ERrotX

*vfill,value(5,1),data,ErotY
*vfill,value(5,2),data,ArotY
*vfill,value(5,3),data,ERrotY

*vfill,value(6,1),data,ErotZ
*vfill,value(6,2),data,ArotZ
*vfill,value(6,3),data,ERrotZ

save,table_2

/com,--------------------------------------------------------------------------------

/com,
/com,==============================
/com, Reaction forces comparision
/com,==============================
```

```
/com,

*dim,Areac,,36
*dim,Ereac,,36
*dim,ERreac,,36
*dim,Nreac,STRING,8,36

Nreac(1,1) = 'FX1'
Nreac(1,2) = 'FY1'
Nreac(1,3) = 'FZ1'
Nreac(1,4) = 'FY17'
Nreac(1,5) = 'FY29'

Nreac(1,6) = 'FZ37'
Nreac(1,7) = 'FX43'
Nreac(1,8) = 'FY49'
Nreac(1,9) = 'FZ51'
Nreac(1,10) = 'FX56'

Nreac(1,11) = 'FY62'
Nreac(1,12) = 'FZ67'
Nreac(1,13) = 'FY72'
Nreac(1,14) = 'FZ74'
Nreac(1,15) = 'FY87'

Nreac(1,16) = 'FY89'
Nreac(1,17) = 'FX94'
Nreac(1,18) = 'FY94'
Nreac(1,19) = 'FZ94'
Nreac(1,20) = 'FY108'

Nreac(1,21) = 'FX112'
Nreac(1,22) = 'FZ117'
Nreac(1,23) = 'FY119'
Nreac(1,24) = 'FZ127'
Nreac(1,25) = 'FY133'

Nreac(1,26) = 'FZ135'
Nreac(1,27) = 'FX141'
Nreac(1,28) = 'FZ145'
Nreac(1,29) = 'FY149'
Nreac(1,30) = 'FY157'

Nreac(1,31) = 'FX165'
Nreac(1,32) = 'FY169'
Nreac(1,33) = 'FY188'
Nreac(1,34) = 'FX192'
Nreac(1,35) = 'FY192'
Nreac(1,36) = 'FZ192'

*GET,Areac(1),NODE,2,RF,FX
*GET,Areac(2),NODE,3,RF,FY
*GET,Areac(3),NODE,4,RF,FZ
*GET,Areac(4),NODE,18,RF,FY
*GET,Areac(5),NODE,30,RF,FY

*GET,Areac(6),NODE,38,RF,FZ
*GET,Areac(7),NODE,44,RF,FX
*GET,Areac(8),NODE,50,RF,FY
*GET,Areac(9),NODE,52,RF,FX
*GET,Areac(10),NODE,57,RF,FX

*GET,Areac(11),NODE,63,RF,FY
*GET,Areac(12),NODE,68,RF,FX
*GET,Areac(13),NODE,73,RF,FY
*GET,Areac(14),NODE,75,RF,FX
*GET,Areac(15),NODE,88,RF,FY

*GET,Areac(16),NODE,90,RF,FY
*GET,Areac(17),NODE,95,RF,FX
*GET,Areac(18),NODE,96,RF,FY
*GET,Areac(19),NODE,97,RF,FZ
```

```
*GET,Areac(20),NODE,109,RF,FY

*GET,Areac(21),NODE,113,RF,FX
*GET,Areac(22),NODE,118,RF,FX
*GET,Areac(23),NODE,120,RF,FY
*GET,Areac(24),NODE,128,RF,FX
*GET,Areac(25),NODE,134,RF,FY

*GET,Areac(26),NODE,136,RF,FX
*GET,Areac(27),NODE,142,RF,FX
*GET,Areac(28),NODE,146,RF,FZ
*GET,Areac(29),NODE,150,RF,FY
*GET,Areac(30),NODE,158,RF,FY

*GET,Areac(31),NODE,166,RF,FX
*GET,Areac(32),NODE,170,RF,FY
*GET,Areac(33),NODE,177,RF,FY
*GET,Areac(34),NODE,193,RF,FX
*GET,Areac(35),NODE,194,RF,FY
*GET,Areac(36),NODE,195,RF,FZ

*VFILL,Ereac,DATA,3033,2119,1917,34,2018,3482,4132.177,2970,2882.485,1739.497
*VFILL,Ereac(11),DATA,47,6205.159,2469,6490.198,97,4444,2944,4206,823,51
*VFILL,Ereac(21),DATA,1887,1752.225,914,1258.628,703,626.592,1363.724,2031,1182,86
*VFILL,Ereac(31),DATA,3972.166,1058,665,834,431,2296

*do,i,1,36
   ERreac(i) = abs(Areac(i)/Ereac(i))
*enddo

save,table_4

/com,-----------------------------------------------------------------------------------

/com,========================================================
/com, Element Forces and Moments Comparison
/com,========================================================

/com, Solution obtained from Mechanical APDL
/com,******************************

*dim,elem_res_I,,1,6
*dim,elem_res_J,,1,6

*dim,pxi,,1
*dim,vyi,,1
*dim,vzi,,1
*dim,txi,,1
*dim,myi,,1
*dim,mzi,,1

*dim,pxj,,1
*dim,vyj,,1
*dim,vzj,,1
*dim,txj,,1
*dim,myj,,1
*dim,mzj,,1

esel,s,ename,,16
esel,a,ename,,18

/com,==========
/com,  Node I
/com,==========

/com, Element #1
/com,************

*get,pxi(1,1),elem,1,smisc,1
*get,vyi(1,1),elem,1,smisc,2
*get,vzi(1,1),elem,1,smisc,3
*get,txi(1,1),elem,1,smisc,4
```

```
*get,myi(1,1),elem,1,smisc,5
*get,mzi(1,1),elem,1,smisc,6

*vfill,elem_res_I(1,1),data,pxi(1,1)
*vfill,elem_res_I(1,2),data,vyi(1,1)
*vfill,elem_res_I(1,3),data,vzi(1,1)
*vfill,elem_res_I(1,4),data,txi(1,1)
*vfill,elem_res_I(1,5),data,myi(1,1)
*vfill,elem_res_I(1,6),data,mzi(1,1)

/com,==========
/com,  Node J
/com,==========

/com, Element #1
/com,************

*get,pxj(1,1),elem,1,smisc,7
*get,vyj(1,1),elem,1,smisc,8
*get,vzj(1,1),elem,1,smisc,9
*get,txj(1,1),elem,1,smisc,10
*get,myj(1,1),elem,1,smisc,11
*get,mzj(1,1),elem,1,smisc,12

*vfill,elem_res_J(1,1),data,pxj(1,1)
*vfill,elem_res_J(1,2),data,vyj(1,1)
*vfill,elem_res_J(1,3),data,vzj(1,1)
*vfill,elem_res_J(1,4),data,txj(1,1)
*vfill,elem_res_J(1,5),data,myj(1,1)
*vfill,elem_res_J(1,6),data,mzj(1,1)

/com,-----------------------------------------------------------------------------

/com, Results from NRC benchmarks
/com, ***************************

*dim,exp_I,,1,6
*dim,exp_J,,1,6

/com, Element #1
/com,************

*vfill,exp_I(1,1),data,2.021e+03
*vfill,exp_I(1,2),data,3.016e+03
*vfill,exp_I(1,3),data,2.045e+03
*vfill,exp_I(1,4),data,8.226e+04
*vfill,exp_I(1,5),data,2.007e+05
*vfill,exp_I(1,6),data,2.902e+05

*vfill,exp_J(1,1),data,2.021e+03
*vfill,exp_J(1,2),data,3.016e+03
*vfill,exp_J(1,3),data,2.045e+03
*vfill,exp_J(1,4),data,8.226e+04
*vfill,exp_J(1,5),data,1.721e+05
*vfill,exp_J(1,6),data,2.418e+05

/com,----------------------------------------------------------------------------

/com, Error computation
/com, *********************

*dim,elem_error_I,,1,6
*dim,elem_error_J,,1,6
*dim,elem_tab,,12,3

/com,============
/com,   Node I
/com,============

i = 1
 *do,j,1,6
  *vfill,elem_error_I(i,j),data,abs(elem_res_I(i,j)/exp_I(i,j))
```

```
 *enddo

/com,============
/com,   Node J
/com,============

i = 1
 *do,j,1,6
  *vfill,elem_error_J(i,j),data,abs(elem_res_J(i,j)/exp_J(i,j))
 *enddo

/com,-----------------------------------------------------------------------

i = 1
 cs=(i-1)*6
 *do,j,1,6
  n=cs+j
  *vfill,elem_tab(n,1),data,exp_I(i,j)
  *vfill,elem_tab(n,2),data,elem_res_I(i,j)
  *vfill,elem_tab(n,3),data,elem_error_I(i,j)
 *enddo

 *do,j,1,6
  m=cs+j+6
  *vfill,elem_tab(m,1),data,exp_J(i,j)
  *vfill,elem_tab(m,2),data,elem_res_J(i,j)
  *vfill,elem_tab(m,3),data,elem_error_J(i,j)
 *enddo

save,table_3

/com,---------------------------------------------------------------------------------

/com,---------------------------------------------------------------------------------
/com,

/out,

/com,
/com, ---------------------vm-nr1677-2-4c-a Results Verification----------------------------
/com,

/nopr
resume,table_1
/gopr

/out,vm-nr1677-2-4c-a,vrt

/com,
/com, ==========================================
/com,  COMPARISON OF MODAL FREQUENCY
/com,      WITH EXPECTED RESULTS
/com, ==========================================
/com,

/com, Mode | Expected | Mechanical APDL |  Ratio
/com,

*VWRITE,moden(1),Emode(1),Amode(1),ERmode(1)
(1X,F3.0,2X,F8.4,3X,F8.4,3X,F4.2,' ')

/com,

/com,---------------------------------------------------------------------------------
/com,

/nopr
resume,table_2
/gopr

/com,
/com,===================================================
```

```
/com,  COMPARISON OF NODAL DISPLACEMENTS AND ROTATIONS
/com,         WITH EXPECTED RESULTS
/com,==================================================
/com,

/com,  Result_Node | Expected | Mechanical APDL |  Ratio
/com,

*vwrite,label2(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label2(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'  ',f10.4,'  ',f10.4,'   ',f5.3)

/com,

/com,-----------------------------------------------------------------------
/com,

/nopr
resume,table_4
/gopr

/com,
/com, ================================
/com,  COMPARISON OF REACTIONS FORCES
/com, ================================
/com,

/com,        Node  | Expected  | Mechanical APDL  |  Ratio
/com,

*VWRITE,Nreac(1),Ereac(1),Areac(1),ERreac(1)
(5X,a,1X,F12.4,1X,F12.4,1X,F12.4,' ')

/com,

/com,------------------------------------------------------------------------
/com,

/nopr
resume,table_3
/gopr

/com,
/com,===============================================
/com,  COMPARISON OF ELEMENT FORCES AND MOMENTS
/com,       WITH EXPECTED RESULTS
/com,===============================================
/com,

/com,-----------------------------------------------------
/com, Note: Element Forces and Moments for some elements
/com,       along Y & Z directions are flipped between Mechanical APDL
/com,  and NRC results
/com,-----------------------------------------------------

/com,  Result | Expected | Mechanical APDL |  Ratio
/com,

/com,===============
/com,   Element 1
/com,===============
/com,
```

```
*vwrite,label3(1,1),elem_tab(1,1),elem_tab(1,2),elem_tab(1,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,

*vwrite,label4(1,1),elem_tab(7,1),elem_tab(7,2),elem_tab(7,3)
(1x,a8,'   ',f12.4,'  ',f12.4,'   ',f5.3)

/com,

/com,-------------------------------------------------------------------------------------
/com,

/out,
*list,vm-nr1677-2-4c-a,vrt
finish
```

vm-nr6645-1-1a-a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr6645-1-1a-a
/title,vm-nr6645-1-1a-a,NRC Piping Benchmark Problems,Volume 1,Method 1

/com,****************************************************************************
/com,
/com, Reference: Reevaluation of Regulatory Guidance
/com,            on modal response combination methods
/com,            for seismic response spectrum analysis
/com,           NUREG/CR-6645
/com,    R.Morante, Y.Wang
/com,    December 1999.
/com,
/com, Description:
/com, Response spectrum analysis on BM3 piping model using 14 modes + missing mass
/com,
/com, Elements used: Pipe16, Pipe18,Combin14
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Reaction forces obtained from spectrum solution. SRSS, 1% damping
/com,
/com, Note:
/com, The reaction moments are not compared since the rotational degrees of
/com, freedom for curved pipe elements are not included in the lumped mass
/com, matrix formulation.
/com,
/com,****************************************************************************

/out,scratch
/prep7

youngmodulus = 2.9e+7     ! Young's modulus
nu = 0.3      ! Poisson ratio
shearmodulus = youngmodulus/(2*(1+nu))   ! Shear modulus

et,1,pipe16      ! Pipe 16
r,1,3.500,0.2160     ! Outer dia, wall thickness

mp,ex,1,youngmodulus     ! Material properties
mp,nuxy,1,nu
mp,gxy,1,shearmodulus
mp,dens,1,1.043e-3

et,2,pipe16      ! Pipe 16
r,2,4.500,0.2370     ! Outer dia, wall thickness

mp,ex,2,youngmodulus     ! Material properties
```

```
mp,nuxy,2,nu
mp,gxy,2,shearmodulus
mp,dens,2,1.107e-03

et,3,pipe16      ! Pipe 16
r,3,8.625,0.3220     ! Outer dia, wall thickness

mp,ex,3,youngmodulus     ! Material properties
mp,nuxy,3,nu
mp,gxy,3,shearmodulus
mp,dens,3,1.253e-3

et,4,pipe18      ! Pipe 18
r,4,3.500,0.2160,4.500     ! Outer dia, wall thickness, radius of curvature

mp,ex,4,youngmodulus     ! Material properties
mp,nuxy,4,nu
mp,gxy,4,shearmodulus
mp,dens,4,1.043e-3

et,5,pipe18      ! Pipe 18
r,5,4.500,0.2370,6.000     ! Outer dia, wall thickness, radius of curvature

mp,ex,5,youngmodulus     ! Material properties
mp,nuxy,5,nu
mp,gxy,5,shearmodulus
mp,dens,5,1.107e-3

et,6,pipe18      ! Pipe 18
r,6,8.625,0.3220,12.000     ! Outer dia, wall thickness, radius of curvature

mp,ex,6,youngmodulus     ! Material properties
mp,nuxy,6,nu
mp,gxy,6,shearmodulus
mp,dens,6,1.253e-3

et,7,combin14      ! COMBIN14 spring-damper element
keyopt,7,2,1      ! Longitudinal spring damper element (UX DOF)
r,7,1.0e+5      ! Spring constant

et,8,combin14      ! COMBIN14 spring-damper element
keyopt,8,2,2      ! Longitudinal spring damper element (UY DOF)
r,8,1.0e+8      ! Spring constant

et,9,combin14      ! COMBIN14 spring-damper element
keyopt,9,2,3      ! Longitudinal spring damper element (Uz DOF)
r,9,1.0e+11      ! Spring constant

et,10,combin14      ! COMBIN14 spring-damper element
keyopt,10,2,4      ! Torsional spring damper element (ROTX DOF)
r,10,1.0e+20      ! Spring constant

et,11,combin14      ! COMBIN14 spring-damper element
keyopt,11,2,5      ! Torsional spring damper element (ROTY DOF)
r,11,1.0e+20      ! Spring constant

et,12,combin14      ! COMBIN14 spring-damper element
keyopt,12,2,6      ! Torsional spring damper element (ROTZ DOF)
r,12,1.0e+20      ! Spring constant


/com, ********************
/com,  Nodes
/com, ********************


n,  1,
n,  2,  15.000,
n,  3,  19.500,   -4.500
n,  4,  19.500, -180.000
n,  5,  19.500, -199.500
n,  6,  19.500, -204.000,   4.500
```

```
n,  7,  19.500, -204.000, 139.500
n,  8,  24.000, -204.000, 144.000
n,  9,  96.000, -204.000, 144.000
n, 10, 254.000, -204.000, 144.000
n, 11, 333.000, -204.000, 144.000
n, 12, 411.000, -204.000, 144.000
n, 13, 483.000, -204.000, 144.000
n, 14, 487.500, -204.000, 148.500
n, 15, 487.500, -204.000, 192.000
n, 16, 487.500, -204.000, 235.500
n, 17, 492.000, -204.000, 240.000
n, 18, 575.000, -204.000, 240.000
n, 19, 723.000, -204.000, 240.000
n, 20, 727.500, -208.500, 240.000
n, 21, 727.500, -264.000, 240.000
n, 22, 727.500, -264.000, 205.000
n, 23, 727.500, -264.000, 190.000
n, 24, 733.500, -264.000, 184.000
n, 25, 753.500, -264.000, 184.000
n, 26, 845.500, -264.000, 184.000
n, 27, 851.500, -264.000, 178.000
n, 28, 851.500, -264.000, 160.000
n, 29, 851.500, -264.000, 142.000
n, 30, 851.500, -270.000, 136.000
n, 31, 851.500, -360.000, 136.000
n, 32, 727.500, -264.000, 255.000
n, 33, 727.500, -264.000, 270.000
n, 34, 727.500, -264.000, 306.000
n, 35, 727.500, -264.000, 414.000
n, 36, 739.500, -264.000, 426.000
n, 37, 847.500, -264.000, 426.000
n, 38, 955.500, -264.000, 426.000

/com, ********************
/com, Nodes for curvature
/com, ********************

n, 203,  15.000,   -4.500
n, 506,  19.500, -199.500,   4.500
n, 708,  24.000, -204.000, 139.500
n,1314, 483.000, -204.000, 148.500
n,1617, 492.000, -204.000, 235.500
n,1920, 723.000, -208.500, 240.000
n,2324, 733.500, -264.000, 190.000
n,2627, 845.500, -264.000, 178.000
n,2930, 851.500, -270.000, 142.000
n,3536, 739.500, -264.000, 414.000

/com, ***************************
/com, Nodes for elastic support
/com, ****************************

dist = 50.0       ! Visualization

n,10001,        -dist
n,20001,            ,          dist
n,30001,            ,              , -dist
n,10004,  19.500+dist, -180.000
n,30004,  19.500     , -180.000     , -dist
n,20007,  19.500     , -204.000+dist, 139.500
n,20011, 333.000     , -204.000+dist, 144.000
n,30011, 333.000     , -204.000     , 144.000-dist
n,10015, 487.500-dist, -204.000     , 192.000
n,20017, 492.000     , -204.000-dist, 240.000
n,30017, 492.000     , -204.000     , 240.000-dist
n,10023, 727.500-dist, -264.000     , 190.000
n,20023, 727.500     , -264.000+dist, 190.000
n,10031, 851.500+dist, -360.000     , 136.000
n,20031, 851.500     , -360.000-dist, 136.000
n,30031, 851.500     , -360.000     , 136.000-dist
n,20036, 739.500     , -264.000-dist, 426.000
n,30036, 739.500     , -264.000     , 426.000-dist
```

```
n,10038, 955.500+dist, -264.000     , 426.000
n,20038, 955.500     , -264.000-dist, 426.000
n,30038, 955.500     , -264.000     , 426.000-dist


/com, *************************
/com,  Straight pipe elements
/com, *************************

type,1
real,1
mat,1

e, 1, 2
e, 3, 4
e, 4, 5
e, 6, 7
e, 8, 9
e, 9,10
e,10,11
e,11,12
e,12,13
e,14,15
e,15,16
e,17,18
e,18,19
e,20,21

type,2
real,2
mat,2

e,21,22
e,22,23
e,24,25
e,25,26
e,27,28
e,28,29
e,30,31

type,3
real,3
mat,3

e,21,32
e,32,33
e,33,34
e,34,35
e,36,37
e,37,38

/com, ********************
/com, Curved pipe elements
/com, *********************

type,4
real,4
mat,4

e,2,3,203
e,5,6,506
e,7,8,708
e,13,14,1314
e,16,17,1617
e,19,20,1920

type,5
real,5
mat,5

e,23,24,2324
e,26,27,2627
```

```
e,29,30,2930

type,6
real,6
mat,6

e,35,36,3536

/com, ****************************
/com, Elastic supports and anchors
/com, ****************************

type,7
real,8
e, 4,10004

real,7
e,15,10015
e,23,10023

real,9
e, 1,10001
e,31,10031
e,38,10038

type,8
real,8
e, 7,20007
e,11,20011
e,17,20017
e,23,20023
e,36,20036

real,9
e, 1,20001
e,31,20031
e,38,20038

type,9
real,8
e, 4,30004

real,7
e,11,30011
e,17,30017
e,36,30036

real,9
e, 1,30001
e,31,30031
e,38,30038

type,10
real,10
e, 1,10001
e,31,10031
e,38,10038

type,11
real,10

e, 1,20001
e,31,20031
e,38,20038

type,12
real,10

e, 1,30001
e,31,30031
e,38,30038
```

```
/com, ***************
/com, Constraints
/com, ***************

nsel,s,node,,10000,40000
d,all,all,0
allsel,all
fini

/com, ****************
/com, Modal analysis
/com, ****************

/solu
antype,modal
modopt,lanb,14
lumpm,on
mxpand,14,,,yes
solve
save

*dim,label,,14
*dim,freq_ans,,14      ! Frequencies obtained from Mechanical APDL
*dim,freq_exp,,14          ! Frequencies obtained from reference
*dim,freq_err,,14

*do,i,1,14
label(i) = i
*enddo

*do,i,1,14
*get,freq_ans(i),mode,i,freq
*enddo

*vfill,freq_exp,data,2.91,4.39,5.52,5.70,6.98,7.34,7.88,10.30,11.06,11.23
*vfill,freq_exp(11),data,11.50,12.43,13.88,16.12

*stat,freq_ans
*stat,freq_exp

*do,i,1,14
freq_err(i) = abs(freq_ans(i))/(freq_exp(i))
*enddo

save,table_1
fini

/com, **********************
/com,  Spectrum analysis
/com, **********************

/solu
antype,spectrum
spopt,sprs,,     ! Single point response spectrum solve
svtype,2,386.4     ! Seismic acceleration response
srss,0.001,disp     ! SRSS mode combination, displacement solution

sed,1,0,0     ! Excitation in X direction

freq    , 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.00
sv, 0.01, 0.06, 0.13, 0.13, 0.20, 0.35, 0.39, 0.37, 0.41, 0.76

freq    , 1.10, 1.20, 1.30, 1.40, 1.50, 1.60, 1.70, 1.80, 1.90
sv, 0.01, 0.64, 0.59, 0.91, 1.03, 1.46, 0.95, 0.91, 1.61, 1.92

freq    , 2.00, 2.10, 2.20, 2.30, 2.40, 2.50, 2.60, 2.70, 2.80
sv, 0.01, 1.57, 1.18, 2.65, 2.85, 3.26, 4.47, 4.75, 5.29, 7.44

freq    , 2.90, 3.00, 3.15, 3.30, 3.45, 3.60, 3.80, 4.00, 4.20
sv, 0.01, 4.27, 4.61, 4.13, 3.96, 4.05, 2.44, 2.09, 2.29, 1.52
```

```
freq    , 4.40, 4.60, 4.80, 5.00, 5.25, 5.50, 5.75, 6.00, 6.25
sv, 0.01, 1.34, 1.37, 1.36, 1.31, 1.69, 1.27, 1.04, 0.76, 0.76

freq    , 6.50, 6.75, 7.00, 7.25, 7.50, 7.75, 8.00, 8.50, 9.00
sv, 0.01, 0.69, 0.70, 0.74, 0.70, 0.67, 0.66, 0.61, 0.75, 0.60

freq    , 9.50,10.00,10.50,11.00,11.50,12.00,12.50,13.00,13.50
sv, 0.01, 0.69, 0.61, 0.70, 0.59, 0.61, 0.56, 0.59, 0.59, 0.59

freq    ,14.00,14.50,15.00,16.00,17.00,18.00,20.00,22.00,25.00
sv, 0.01, 0.58, 0.59, 0.58, 0.55, 0.56, 0.55, 0.55, 0.55, 0.54

freq    ,28.00,31.00,34.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
sv, 0.01, 0.54, 0.54, 0.54, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00


mmass,on,0.54     ! Missing mass with ZPA = 0.54
solve
save
fini


/post1
/input,,mcom

/com, *************************************
/com,  Reaction forces obtained from Mechanical APDL
/com, *************************************

*get,rf1_x,node,10001,rf,fx
*get,rf1_y,node,20001,rf,fy
*get,rf1_z,node,30001,rf,fz
*get,rf4_x,node,10004,rf,fx
*get,rf4_z,node,30004,rf,fz
*get,rf7_y,node,20007,rf,fy
*get,rf11_y,node,20011,rf,fy
*get,rf11_z,node,30011,rf,fz
*get,rf15_x,node,10015,rf,fx
*get,rf17_y,node,20017,rf,fy
*get,rf17_z,node,30017,rf,fz
*get,rf36_y,node,20036,rf,fy
*get,rf36_z,node,30036,rf,fz
*get,rf38_x,node,10038,rf,fx
*get,rf38_y,node,20038,rf,fy
*get,rf38_z,node,30038,rf,fz
*get,rf23_x,node,10023,rf,fx
*get,rf23_y,node,20023,rf,fy
*get,rf31_x,node,10031,rf,fx
*get,rf31_y,node,20031,rf,fy
*get,rf31_z,node,30031,rf,fz


*dim,label,char,1,21

*dim,value,,21,3

label(1,1) = 'fx1'
label(1,2) = 'fy1'
label(1,3) = 'fz1'
label(1,4) = 'fx4'
label(1,5) = 'fz4'
label(1,6) = 'fy7'
label(1,7) = 'fy11'
label(1,8) = 'fz11'
label(1,9) = 'fx15'
label(1,10) = 'fy17'
label(1,11) = 'fz17'
label(1,12) = 'fy36'
label(1,13) = 'fz36'
label(1,14) = 'fx38'
label(1,15) = 'fy38'
label(1,16) = 'fz38'
```

```
label(1,17) = 'fx23'
label(1,18) = 'fy23'
label(1,19) = 'fx31'
label(1,20) = 'fy31'
label(1,21) = 'fz31'



/com, ******************************************
/com,  Reaction forces obtained from NRC
/com, ******************************************


*vfill,value(1,1),data,43.71*1.10
*vfill,value(2,1),data,4.36*1.26
*vfill,value(3,1),data,1.60*4.74
*vfill,value(4,1),data,116.79*0.80
*vfill,value(5,1),data,20.01*3.77
*vfill,value(6,1),data,13.27*1.20
*vfill,value(7,1),data,13.31*1.48
*vfill,value(8,1),data,81.34*0.99
*vfill,value(9,1),data,731.47*0.60
*vfill,value(10,1),data,25.60*1.91
*vfill,value(11,1),data,65.36*1.22
*vfill,value(12,1),data,46.69*1.93
*vfill,value(13,1),data,42.12*2.02
*vfill,value(14,1),data,732.18*0.89
*vfill,value(15,1),data,43.44*1.21
*vfill,value(16,1),data,29.95*1.40
*vfill,value(17,1),data,259.59*1.02
*vfill,value(18,1),data,26.08*4.04
*vfill,value(19,1),data,55.05*0.92
*vfill,value(20,1),data,14.17*1.75
*vfill,value(21,1),data,16.08*1.97


*vfill,value(1,2),data,rf1_x
*vfill,value(2,2),data,rf1_y
*vfill,value(3,2),data,rf1_z
*vfill,value(4,2),data,rf4_x
*vfill,value(5,2),data,rf4_z
*vfill,value(6,2),data,rf7_y
*vfill,value(7,2),data,rf11_y
*vfill,value(8,2),data,rf11_z
*vfill,value(9,2),data,rf15_x
*vfill,value(10,2),data,rf17_y
*vfill,value(11,2),data,rf17_z
*vfill,value(12,2),data,rf36_y
*vfill,value(13,2),data,rf36_z
*vfill,value(14,2),data,rf38_x
*vfill,value(15,2),data,rf38_y
*vfill,value(16,2),data,rf38_z
*vfill,value(17,2),data,rf23_x
*vfill,value(18,2),data,rf23_y
*vfill,value(19,2),data,rf31_x
*vfill,value(20,2),data,rf31_y
*vfill,value(21,2),data,rf31_z



*vfill,value(1,3),data,abs(rf1_x/(43.71*1.10))
*vfill,value(2,3),data,abs(rf1_y/(4.36*1.26))
*vfill,value(3,3),data,abs(rf1_z/(1.60*4.74))
*vfill,value(4,3),data,abs(rf4_x/(116.79*0.80))
*vfill,value(5,3),data,abs(rf4_z/(20.01*3.77))
*vfill,value(6,3),data,abs(rf7_y/(13.27*1.20))
*vfill,value(7,3),data,abs(rf11_y/(13.31*1.48))
*vfill,value(8,3),data,abs(rf11_z/(81.34*0.99))
*vfill,value(9,3),data,abs(rf15_x/(731.47*0.60))
*vfill,value(10,3),data,abs(rf17_y/(25.60*1.91))
*vfill,value(11,3),data,abs(rf17_z/(65.36*1.22))
*vfill,value(12,3),data,abs(rf36_y/(46.69*1.93))
```

```
*vfill,value(13,3),data,abs(rf36_z/(42.12*2.02))
*vfill,value(14,3),data,abs(rf38_x/(732.18*0.89))
*vfill,value(15,3),data,abs(rf38_y/(43.44*1.21))
*vfill,value(16,3),data,abs(rf38_z/(29.95*1.40))
*vfill,value(17,3),data,abs(rf23_x/(259.59*1.02))
*vfill,value(18,3),data,abs(rf23_y/(26.08*4.04))
*vfill,value(19,3),data,abs(rf31_x/(55.05*0.92))
*vfill,value(20,3),data,abs(rf31_y/(14.17*1.75))
*vfill,value(21,3),data,abs(rf31_z/(16.08*1.97))

save,table_2

finish

resume,table_1
/com,
/out,vm-nr6645-1-1a-a,vrt
/com,
/com,
/com, ----------------------vm-nr6645-1-1a-a Results comparsion-------------------------
/com,
/com,
/com,
/com,           |  TARGET  |   Mechanical APDL  |  RATIO
/com,
/com,
/com, ==================================
/com,   Frequencies from Modal analysis
/com, ==================================
*vwrite,label(1),freq_exp(1),freq_ans(1),freq_err(1)
(1x,f3.0,4x,f10.4,4x,f10.4,4x,F5.3)
/com,
/com,
/nopr,
resume,table_2
/gopr
/com,
/com,
/com, ==============================================
/com,  Reaction forces obtained from Spectrum solve
/com, ==============================================
/com,
*vwrite,label(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,7),value(7,1),value(7,2),value(7,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,8),value(8,1),value(8,2),value(8,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,9),value(9,1),value(9,2),value(9,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,10),value(10,1),value(10,2),value(10,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,11),value(11,1),value(11,2),value(11,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,12),value(12,1),value(12,2),value(12,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,13),value(13,1),value(13,2),value(13,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,14),value(14,1),value(14,2),value(14,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,15),value(15,1),value(15,2),value(15,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
```

```
*vwrite,label(1,16),value(16,1),value(16,2),value(16,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,17),value(17,1),value(17,2),value(17,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,18),value(18,1),value(18,2),value(18,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,19),value(19,1),value(19,2),value(19,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,20),value(20,1),value(20,2),value(20,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,21),value(21,1),value(21,2),value(21,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
/nopr,
/com,
/com,
/com, ---------------------------------------------------------------------------
/out,
*list,vm-nr6645-1-1a-a,vrt
finish
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vm-nr6645-1-2a-a Input Listing

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/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr6645-1-2a-a
/title,vm-nr6645-1-2a-a,NRC Piping Benchmark Problems,Volume 1,Method 2

/com,****************************************************************************
/com,
/com, Reference: Reevaluation of Regulatory Guidance
/com,            on modal response combination methods
/com,            for seismic response spectrum analysis
/com,          NUREG/CR-6645
/com,   R.Morante, Y.Wang
/com,   December 1999.
/com,
/com, Description:
/com, Response spectrum analysis on BM3 piping model using 14 modes + missing mass
/com, Lindley yow rigid response calculation
/com,
/com,
/com, Elements used: Pipe16, Pipe18 and Combin14
/com,
/com, Results comparsion:
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Reaction forces obtained from spectrum solution. SRSS, 1% damping
/com,
/com, Note:
/com, The reaction moments are not compared since the rotational degrees of
/com, freedom for curved pipe elements are not included in the lumped mass
/com, matrix formulation.
/com,
/com,****************************************************************************

/out,scratch
/prep7

youngmodulus = 2.9e+7     ! Young's modulus
nu = 0.3       ! Poisson ratio
shearmodulus = youngmodulus/(2*(1+nu))  ! Shear modulus

et,1,pipe16       ! Pipe 16
r,1,3.500,0.2160      ! Outer dia, wall thickness

mp,ex,1,youngmodulus     ! Material properties
mp,nuxy,1,nu
mp,gxy,1,shearmodulus
mp,dens,1,1.043e-3
```

```
et,2,pipe16       ! Pipe 16
r,2,4.500,0.2370      ! Outer dia, wall thickness

mp,ex,2,youngmodulus     ! Material properties
mp,nuxy,2,nu
mp,gxy,2,shearmodulus
mp,dens,2,1.107e-03

et,3,pipe16       ! Pipe 16
r,3,8.625,0.3220      ! Outer dia, wall thickness

mp,ex,3,youngmodulus     ! Material properties
mp,nuxy,3,nu
mp,gxy,3,shearmodulus
mp,dens,3,1.253e-3

et,4,pipe18       ! Pipe 18
r,4,3.500,0.2160,4.500     ! Outer dia, wall thickness, radius of curvature

mp,ex,4,youngmodulus     ! Material properties
mp,nuxy,4,nu
mp,gxy,4,shearmodulus
mp,dens,4,1.043e-3

et,5,pipe18       ! Pipe 18
r,5,4.500,0.2370,6.000     ! Outer dia, wall thickness, radius of curvature

mp,ex,5,youngmodulus     ! Material properties
mp,nuxy,5,nu
mp,gxy,5,shearmodulus
mp,dens,5,1.107e-3

et,6,pipe18       ! Pipe 18
r,6,8.625,0.3220,12.000     ! Outer dia, wall thickness, radius of curvature

mp,ex,6,youngmodulus     ! Material properties
mp,nuxy,6,nu
mp,gxy,6,shearmodulus
mp,dens,6,1.253e-3

et,7,combin14      ! COMBIN14 spring-damper element
keyopt,7,2,1      ! Longitudinal spring damper element (UX DOF)
r,7,1.0e+5       ! Spring constant

et,8,combin14      ! COMBIN14 spring-damper element
keyopt,8,2,2      ! Longitudinal spring damper element (UY DOF)
r,8,1.0e+8       ! Spring constant

et,9,combin14      ! COMBIN14 spring-damper element
keyopt,9,2,3      ! Longitudinal spring damper element (Uz DOF)
r,9,1.0e+11       ! Spring constant

et,10,combin14      ! COMBIN14 spring-damper element
keyopt,10,2,4      ! Torsional spring damper element (ROTX DOF)
r,10,1.0e+20      ! Spring constant

et,11,combin14      ! COMBIN14 spring-damper element
keyopt,11,2,5      ! Torsional spring damper element (ROTY DOF)
r,11,1.0e+20      ! Spring constant

et,12,combin14      ! COMBIN14 spring-damper element
keyopt,12,2,6      ! Torsional spring damper element (ROTZ DOF)
r,12,1.0e+20      ! Spring constant


/com, ********************
/com,  Nodes
/com, ********************


n,  1,
```

```
n,  2,  15.000,
n,  3,  19.500,   -4.500
n,  4,  19.500, -180.000
n,  5,  19.500, -199.500
n,  6,  19.500, -204.000,   4.500
n,  7,  19.500, -204.000, 139.500
n,  8,  24.000, -204.000, 144.000
n,  9,  96.000, -204.000, 144.000
n, 10, 254.000, -204.000, 144.000
n, 11, 333.000, -204.000, 144.000
n, 12, 411.000, -204.000, 144.000
n, 13, 483.000, -204.000, 144.000
n, 14, 487.500, -204.000, 148.500
n, 15, 487.500, -204.000, 192.000
n, 16, 487.500, -204.000, 235.500
n, 17, 492.000, -204.000, 240.000
n, 18, 575.000, -204.000, 240.000
n, 19, 723.000, -204.000, 240.000
n, 20, 727.500, -208.500, 240.000
n, 21, 727.500, -264.000, 240.000
n, 22, 727.500, -264.000, 205.000
n, 23, 727.500, -264.000, 190.000
n, 24, 733.500, -264.000, 184.000
n, 25, 753.500, -264.000, 184.000
n, 26, 845.500, -264.000, 184.000
n, 27, 851.500, -264.000, 178.000
n, 28, 851.500, -264.000, 160.000
n, 29, 851.500, -264.000, 142.000
n, 30, 851.500, -270.000, 136.000
n, 31, 851.500, -360.000, 136.000
n, 32, 727.500, -264.000, 255.000
n, 33, 727.500, -264.000, 270.000
n, 34, 727.500, -264.000, 306.000
n, 35, 727.500, -264.000, 414.000
n, 36, 739.500, -264.000, 426.000
n, 37, 847.500, -264.000, 426.000
n, 38, 955.500, -264.000, 426.000

/com, ********************
/com, Nodes for curvature
/com, ********************

n, 203,  15.000,   -4.500
n, 506,  19.500, -199.500,   4.500
n, 708,  24.000, -204.000, 139.500
n,1314, 483.000, -204.000, 148.500
n,1617, 492.000, -204.000, 235.500
n,1920, 723.000, -208.500, 240.000
n,2324, 733.500, -264.000, 190.000
n,2627, 845.500, -264.000, 178.000
n,2930, 851.500, -270.000, 142.000
n,3536, 739.500, -264.000, 414.000

/com, ***************************
/com, Nodes for elastic support
/com, ****************************

dist = 50.0       ! Visualization

n,10001,        -dist
n,20001,             ,          dist
n,30001,             ,              , -dist
n,10004,  19.500+dist, -180.000
n,30004,  19.500     , -180.000     , -dist
n,20007,  19.500     , -204.000+dist, 139.500
n,20011, 333.000     , -204.000+dist, 144.000
n,30011, 333.000     , -204.000     , 144.000-dist
n,10015, 487.500-dist, -204.000     , 192.000
n,20017, 492.000     , -204.000-dist, 240.000
n,30017, 492.000     , -204.000     , 240.000-dist
n,10023, 727.500-dist, -264.000     , 190.000
n,20023, 727.500     , -264.000+dist, 190.000
```

```
n,10031, 851.500+dist, -360.000     , 136.000
n,20031, 851.500     , -360.000-dist, 136.000
n,30031, 851.500     , -360.000     , 136.000-dist
n,20036, 739.500     , -264.000-dist, 426.000
n,30036, 739.500     , -264.000     , 426.000-dist
n,10038, 955.500+dist, -264.000     , 426.000
n,20038, 955.500     , -264.000-dist, 426.000
n,30038, 955.500     , -264.000     , 426.000-dist


/com, *************************
/com,  Straight pipe elements
/com, *************************

type,1
real,1
mat,1

e, 1, 2
e, 3, 4
e, 4, 5
e, 6, 7
e, 8, 9
e, 9,10
e,10,11
e,11,12
e,12,13
e,14,15
e,15,16
e,17,18
e,18,19
e,20,21

type,2
real,2
mat,2

e,21,22
e,22,23
e,24,25
e,25,26
e,27,28
e,28,29
e,30,31

type,3
real,3
mat,3

e,21,32
e,32,33
e,33,34
e,34,35
e,36,37
e,37,38

/com, ********************
/com, Curved pipe elements
/com, *********************

type,4
real,4
mat,4

e,2,3,203
e,5,6,506
e,7,8,708
e,13,14,1314
e,16,17,1617
e,19,20,1920

type,5
```

```
real,5
mat,5

e,23,24,2324
e,26,27,2627
e,29,30,2930

type,6
real,6
mat,6

e,35,36,3536

/com, ****************************
/com, Elastic supports and anchors
/com, ****************************

type,7
real,8
e, 4,10004

real,7
e,15,10015
e,23,10023

real,9
e, 1,10001
e,31,10031
e,38,10038

type,8
real,8
e, 7,20007
e,11,20011
e,17,20017
e,23,20023
e,36,20036

real,9
e, 1,20001
e,31,20031
e,38,20038

type,9
real,8
e, 4,30004

real,7
e,11,30011
e,17,30017
e,36,30036

real,9
e, 1,30001
e,31,30031
e,38,30038

type,10
real,10
e, 1,10001
e,31,10031
e,38,10038

type,11
real,10

e, 1,20001
e,31,20031
e,38,20038

type,12
real,10
```

```
e, 1,30001
e,31,30031
e,38,30038


/com, ***************
/com, Constraints
/com, ***************

nsel,s,node,,10000,40000
d,all,all,0
allsel,all
fini

/com, ****************
/com, Modal analysis
/com, ****************

/solu
antype,modal
modopt,lanb,14
lumpm,on
mxpand,14,,,yes
solve
save

*dim,label,,14
*dim,freq_ans,,14      ! Frequencies obtained from Mechanical APDL
*dim,freq_exp,,14          ! Frequencies obtained from reference
*dim,freq_err,,14

*do,i,1,14
label(i) = i
*enddo

*do,i,1,14
*get,freq_ans(i),mode,i,freq
*enddo

*vfill,freq_exp,data,2.91,4.39,5.52,5.70,6.98,7.34,7.88,10.30,11.06,11.23
*vfill,freq_exp(11),data,11.50,12.43,13.88,16.12

*stat,freq_ans
*stat,freq_exp

*do,i,1,14
freq_err(i) = abs(freq_ans(i))/(freq_exp(i))
*enddo

save,table_1
fini

/com, **********************
/com,  Spectrum analysis
/com, **********************

/solu
antype,spectrum
spopt,sprs,,     ! Single point response spectrum solve
svtype,2,386.4     ! Seismic acceleration response
srss,0.001,disp     ! SRSS mode combination, displacement solution

sed,1,0,0     ! Excitation in X direction

freq    , 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.00
sv, 0.01, 0.06, 0.13, 0.13, 0.20, 0.35, 0.39, 0.37, 0.41, 0.76

freq    , 1.10, 1.20, 1.30, 1.40, 1.50, 1.60, 1.70, 1.80, 1.90
sv, 0.01, 0.64, 0.59, 0.91, 1.03, 1.46, 0.95, 0.91, 1.61, 1.92

freq    , 2.00, 2.10, 2.20, 2.30, 2.40, 2.50, 2.60, 2.70, 2.80
```

```
sv, 0.01, 1.57, 1.18, 2.65, 2.85, 3.26, 4.47, 4.75, 5.29, 7.44

freq    , 2.90, 3.00, 3.15, 3.30, 3.45, 3.60, 3.80, 4.00, 4.20
sv, 0.01, 4.27, 4.61, 4.13, 3.96, 4.05, 2.44, 2.09, 2.29, 1.52

freq    , 4.40, 4.60, 4.80, 5.00, 5.25, 5.50, 5.75, 6.00, 6.25
sv, 0.01, 1.34, 1.37, 1.36, 1.31, 1.69, 1.27, 1.04, 0.76, 0.76

freq    , 6.50, 6.75, 7.00, 7.25, 7.50, 7.75, 8.00, 8.50, 9.00
sv, 0.01, 0.69, 0.70, 0.74, 0.70, 0.67, 0.66, 0.61, 0.75, 0.60

freq    , 9.50,10.00,10.50,11.00,11.50,12.00,12.50,13.00,13.50
sv, 0.01, 0.69, 0.61, 0.70, 0.59, 0.61, 0.56, 0.59, 0.59, 0.59

freq    ,14.00,14.50,15.00,16.00,17.00,18.00,20.00,22.00,25.00
sv, 0.01, 0.58, 0.59, 0.58, 0.55, 0.56, 0.55, 0.55, 0.55, 0.54

freq    ,28.00,31.00,34.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
sv, 0.01, 0.54, 0.54, 0.54, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00


mmass,on,0.54     ! Missing mass with ZPA = 0.54
rigresp,on,lindley,0.54    ! Rigid response using Lindley approach
solve
save
fini


/post1
/input,,mcom

/com, *************************************
/com,  Reaction forces obtained from Mechanical APDL
/com, *************************************

*get,rf1_x,node,10001,rf,fx
*get,rf1_y,node,20001,rf,fy
*get,rf1_z,node,30001,rf,fz
*get,rf4_x,node,10004,rf,fx
*get,rf4_z,node,30004,rf,fz
*get,rf7_y,node,20007,rf,fy
*get,rf11_y,node,20011,rf,fy
*get,rf11_z,node,30011,rf,fz
*get,rf15_x,node,10015,rf,fx
*get,rf17_y,node,20017,rf,fy
*get,rf17_z,node,30017,rf,fz
*get,rf36_y,node,20036,rf,fy
*get,rf36_z,node,30036,rf,fz
*get,rf38_x,node,10038,rf,fx
*get,rf38_y,node,20038,rf,fy
*get,rf38_z,node,30038,rf,fz
*get,rf23_x,node,10023,rf,fx
*get,rf23_y,node,20023,rf,fy
*get,rf31_x,node,10031,rf,fx
*get,rf31_y,node,20031,rf,fy
*get,rf31_z,node,30031,rf,fz


*dim,label,char,1,21

*dim,value,,21,3

label(1,1) = 'fx1'
label(1,2) = 'fy1'
label(1,3) = 'fz1'
label(1,4) = 'fx4'
label(1,5) = 'fz4'
label(1,6) = 'fy7'
label(1,7) = 'fy11'
label(1,8) = 'fz11'
label(1,9) = 'fx15'
label(1,10) = 'fy17'
```

```
label(1,11) = 'fz17'
label(1,12) = 'fy36'
label(1,13) = 'fz36'
label(1,14) = 'fx38'
label(1,15) = 'fy38'
label(1,16) = 'fz38'
label(1,17) = 'fx23'
label(1,18) = 'fy23'
label(1,19) = 'fx31'
label(1,20) = 'fy31'
label(1,21) = 'fz31'



/com, *****************************************
/com,  Reaction forces obtained from NRC
/com, *****************************************


*vfill,value(1,1),data,43.71*1.06
*vfill,value(2,1),data,4.36*0.85
*vfill,value(3,1),data,1.60*2.21
*vfill,value(4,1),data,116.79*0.80
*vfill,value(5,1),data,20.01*1.81
*vfill,value(6,1),data,13.27*1.05
*vfill,value(7,1),data,13.31*1.14
*vfill,value(8,1),data,81.34*0.87
*vfill,value(9,1),data,731.47*0.81
*vfill,value(10,1),data,25.60*1.42
*vfill,value(11,1),data,65.36*0.97
*vfill,value(12,1),data,46.69*1.35
*vfill,value(13,1),data,42.12*1.28
*vfill,value(14,1),data,732.18*1.05
*vfill,value(15,1),data,43.44*1.10
*vfill,value(16,1),data,29.95*1.27
*vfill,value(17,1),data,259.59*1.32
*vfill,value(18,1),data,26.08*2.14
*vfill,value(19,1),data,55.05*1.02
*vfill,value(20,1),data,14.17*1.26
*vfill,value(21,1),data,16.08*1.43


*vfill,value(1,2),data,rf1_x
*vfill,value(2,2),data,rf1_y
*vfill,value(3,2),data,rf1_z
*vfill,value(4,2),data,rf4_x
*vfill,value(5,2),data,rf4_z
*vfill,value(6,2),data,rf7_y
*vfill,value(7,2),data,rf11_y
*vfill,value(8,2),data,rf11_z
*vfill,value(9,2),data,rf15_x
*vfill,value(10,2),data,rf17_y
*vfill,value(11,2),data,rf17_z
*vfill,value(12,2),data,rf36_y
*vfill,value(13,2),data,rf36_z
*vfill,value(14,2),data,rf38_x
*vfill,value(15,2),data,rf38_y
*vfill,value(16,2),data,rf38_z
*vfill,value(17,2),data,rf23_x
*vfill,value(18,2),data,rf23_y
*vfill,value(19,2),data,rf31_x
*vfill,value(20,2),data,rf31_y
*vfill,value(21,2),data,rf31_z



*vfill,value(1,3),data,abs(rf1_x/(43.71*1.06))
*vfill,value(2,3),data,abs(rf1_y/(4.36*0.85))
*vfill,value(3,3),data,abs(rf1_z/(1.60*2.21))
*vfill,value(4,3),data,abs(rf4_x/(116.79*0.90))
*vfill,value(5,3),data,abs(rf4_z/(20.01*1.81))
*vfill,value(6,3),data,abs(rf7_y/(13.27*1.05))
```

```
*vfill,value(7,3),data,abs(rf11_y/(13.31*1.14))
*vfill,value(8,3),data,abs(rf11_z/(81.34*0.87))
*vfill,value(9,3),data,abs(rf15_x/(731.47*0.81))
*vfill,value(10,3),data,abs(rf17_y/(25.60*1.42))
*vfill,value(11,3),data,abs(rf17_z/(65.36*0.97))
*vfill,value(12,3),data,abs(rf36_y/(46.69*1.35))
*vfill,value(13,3),data,abs(rf36_z/(42.12*1.28))
*vfill,value(14,3),data,abs(rf38_x/(732.18*1.05))
*vfill,value(15,3),data,abs(rf38_y/(43.44*1.10))
*vfill,value(16,3),data,abs(rf38_z/(29.95*1.27))
*vfill,value(17,3),data,abs(rf23_x/(259.59*1.32))
*vfill,value(18,3),data,abs(rf23_y/(26.08*2.14))
*vfill,value(19,3),data,abs(rf31_x/(55.05*1.02))
*vfill,value(20,3),data,abs(rf31_y/(14.17*1.26))
*vfill,value(21,3),data,abs(rf31_z/(16.08*1.43))

save,table_2

finish

resume,table_1
/com,
/out,vm-nr6645-1-2a-a,vrt
/com,
/com,
/com, ----------------------vm-nr6645-1-2a-a Results comparsion-------------------------
/com,
/com,
/com,
/com,           |  TARGET  |   Mechanical APDL  |  RATIO
/com,
/com,
/com, =================================
/com,   Frequencies from Modal analysis
/com, =================================
*vwrite,label(1),freq_exp(1),freq_ans(1),freq_err(1)
(1x,f3.0,4x,f10.4,4x,f10.4,4x,F5.3)
/com,
/com,
/nopr,
resume,table_2
/gopr
/com,
/com,
/com, =============================================
/com,  Reaction forces obtained from Spectrum solve
/com, =============================================
/com,
*vwrite,label(1,1),value(1,1),value(1,2),value(1,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,2),value(2,1),value(2,2),value(2,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,3),value(3,1),value(3,2),value(3,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,4),value(4,1),value(4,2),value(4,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,5),value(5,1),value(5,2),value(5,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,6),value(6,1),value(6,2),value(6,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,7),value(7,1),value(7,2),value(7,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,8),value(8,1),value(8,2),value(8,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,9),value(9,1),value(9,2),value(9,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,10),value(10,1),value(10,2),value(10,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,11),value(11,1),value(11,2),value(11,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,12),value(12,1),value(12,2),value(12,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
```

```
*vwrite,label(1,13),value(13,1),value(13,2),value(13,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,14),value(14,1),value(14,2),value(14,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,15),value(15,1),value(15,2),value(15,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,16),value(16,1),value(16,2),value(16,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,17),value(17,1),value(17,2),value(17,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,18),value(18,1),value(18,2),value(18,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,19),value(19,1),value(19,2),value(19,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,20),value(20,1),value(20,2),value(20,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
*vwrite,label(1,21),value(21,1),value(21,2),value(21,3)
(1x,a8,'   ',f10.4,'  ',f10.4,'   ',f5.3)
/nopr,
/com,
/com,
/com, ---------------------------------------------------------------------------
/out,
*list,vm-nr6645-1-2a-a,vrt
finish
```

vm-nr1677-01-1a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-01-1a
/title,vm-nr1677-01-1a,NRC Piping Benchmark Problems,Volume 1,Problem 1
/com,****************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,        NUREG/CR--1677-Vol.1
/com,                P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com, Elements used: Pipe289, Elbow290, Mass21
/com,
/com, Results:
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces and moments obtained from spectrum solution.
/com,
/com,****************************************************************************

/out,scratch

/prep7
et,1,pipe289                                          ! Element 1 - PIPE289 using cubic shape function
et,2,elbow290,,6                                      ! Element 2 - ELBOW290
et,3,mass21                                           ! Element 3 - MASS21

keyopt,3,3,2                                          ! 3-D Mass without Rotary Inertia

/com, Real Constants
/com,****************
sectype,1,pipe
secdata,7.289,0.241,24

/com, Keypoints
/com,*******

k,1,0.0,0.0,0.0
k,2,0.0,54.45,0.0
k,3,0.0,108.9,0.0
```

```
k,4,10.632,134.568,0.0
k,5,36.3,145.2,0.0
k,6,54.15,145.2,0.0
k,7,72.0,145.2,0.0
k,8,97.668,145.2,10.632
k,9,108.3,145.2,36.3
k,10,108.3,145.2,56.80
k,11,108.3,145.2,77.3

k,12,2.7631,122.79,0
k,13,22.408,142.44,0
k,14,85.9,145,2.76
k,15,106,145,22.4

/com, Straight Pipe (Tangent Elements)
/com,*********************************

type,1
mat,1
secnum,1
l,1,2
l,2,3
l,5,6
l,6,7
l,9,10
l,10,11  !Line number 6

/com, Bend Pipe Elements
/com,*********************************

larch,3,4,12   !Line number 7
larch,4,5,13
larch,7,8,14
larch,8,9,15   !line number 10

mp,ex,1,24e6
mp,nuxy,1,0.3

/com, *********************************
/com, Meshing for Straight pipe
/com, *********************************

type,1
secnum,1
mat,1

lsel,s,line,,1,6
allsel,below,line
lesize,all,,,2
lmesh,all

allsel,all,all

/com, *********************************
/com, Meshing for bend pipe
/com, *********************************

type,2
secnum,1
mat,1

lsel,s,,,7,14
allsel,below,line
lesize,all,,,2
lmesh,all

allsel,all,all

/com, Real constants for mass element
/com, ******************************

r,12,0.03988
```

```
r,13,0.05032
r,14,0.02088
r,15,0.01698
r,16,0.01307
r,17,0.01698
r,18,0.01044
r,19,0.01795
r,20,0.01501


/com, Mass Elements
/com,***************

type,3
real,12
e,2

real,13
e,6

real,14
e,28

real,15
e,10

real,16
e,11

real,17,
e,15

real,18
e,35

real,19
e,19

real,20
e,20

allsel,all,all

/com, ************************************************************
/com,  Using ELBOW, to convert some PIPE289 into ELBOW290
/com, ************************************************************

elbow,on,,,sect

/com,*************
/com, Constraints
/com,*************

dk,1,all,0
dk,11,all,0

allsel,all
save
finish

/com,
/com,=============
/com,   Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,5                                    ! LANB mode extraction method
mxpand,,,,yes
solve
finish
```

```
save

/post1
/out,
/com, *******************************
/com,  Frequencies from Modal solve
/com, *******************************
set,list
finish

/com,------------------------------------------------------------------------

/com,
/com,================
/com,   Spectrum Solve
/com,================
/com,
/out,scratch

/solution
antype,spectr                                ! Perform Spectrum Analysis
spopt,sprs                                           ! Single Point Excitation Response Spectrum
dmprat,0.02                                          ! Constant Damping Ratio
grp,0.001                                            ! Group Modes based on significance level
svtyp,2                                      ! Seismic Acceleration Response Loading

sed,1                                                ! Excitation in X direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve

sed,,1                                       ! Excitation in Y direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,266.7,580.7,580.7,466.7,792,792,293.3,516.7,516.7
sv,0.02,355.5,311.5,295.7,253.3,192.7,159.6,128.4,122.7,96.7
solve

sed,,,1                                      ! Excitation in Z direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve
fini

/com,------------------------------------------------------------------------

/post1
/input,,mcom


/com, ****************************

*GET,AdisX,NODE,10,U,X
*GET,AdisY,NODE,36,U,Y
*GET,AdisZ,NODE,28,U,Z
*GET,ArotX,NODE,9,ROT,X
*GET,ArotY,NODE,18,ROT,Y
*GET,ArotZ,NODE,9,ROT,Z
/out,
/com, *=======================================================
/com, * Maximum nodal displacements and rotations obtained from spectrum solution
/com, *=======================================================
*stat,AdisX
*stat,AdisY
*stat,AdisZ
```

```
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com, *=====================================================
/com, * Element Forces and Moments obtained from spectrum solution
/com, *=======================================================
/out,scratch

/com,==========
/com,  Node I
/com,==========


/com, Element #12 (Pipe289 elements)
/com,***********************


esel,s,elem,,12
etable,pxi_12,smisc,1
etable,vyi_12,smisc,6
etable,vzi_12,smisc,5
etable,txi_12,smisc,4
etable,myi_12,smisc,2
etable,mzi_12,smisc,3
esel,all

/com, Element #14 (Elbow 290 elements)
/com,************************

esel,s,elem,,14

etable,pxi_14,smisc,1
etable,vyi_14,smisc,6
etable,vzi_14,smisc,5
etable,txi_14,smisc,4
etable,myi_14,smisc,2
etable,mzi_14,smisc,3
esel,all


/com,==========
/com,  Node J
/com,==========

/com, Element #12 (Pipe289 elements)
/com,***********************

esel,s,elem,,12

etable,pxj_12,smisc,14
etable,vyj_12,smisc,19
etable,vzj_12,smisc,18
etable,txj_12,smisc,17
etable,myj_12,smisc,15
etable,mzj_12,smisc,16
esel,all


/com, Element #14 (Elbow290 elements)
/com,***********************
esel,s,elem,,14

etable,pxj_14,smisc,36
etable,vyj_14,smisc,41
etable,vzj_14,smisc,40
etable,txj_14,smisc,39
etable,myj_14,smisc,37
etable,mzj_14,smisc,38
esel,all

allsel,all
```

```
/out,

/com, ***********************************************
/com,  Element forces and moments at element 12, node i
/com, ************************************************

pretab,pxi_12,vyi_12,vzi_12,txi_12,myi_12,mzi_12

/com, ***********************************************
/com,  Element forces and moments at element 12, node j
/com, ************************************************

pretab,pxj_12,vyj_12,vzj_12,txj_12,myj_12,mzj_12

/com, ***********************************************
/com,  Element forces and moments at element 14, node i
/com, ************************************************

pretab,pxi_14,vyi_14,vzi_14,txi_14,myi_14,mzi_14

/com, ***********************************************
/com,  Element forces and moments at element 14, node j
/com, ************************************************

pretab,pxj_14,vyj_14,vzj_14,txj_14,myj_14,mzj_14



/com,---------------------------------------------------------------------------

/com, *****************************
/com,  Reaction forces
/com, ******************************

prrsol

finish
```

vm-nr1677-01-2a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-01-2a
/title,vm-nr1677-01-2a,NRC Piping Benchmark Problems,Volume 1,Problem 2

/com,********************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,        NUREC/CR--1677-Vol.1
/com,                P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com, Elements used: Pipe288, Mass21
/com,
/com, Results :
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces and moments obtained from spectrum solution.
/com,
/com,********************************************************************************

/out,scratch

/prep7
et,1,pipe288,,,3                        ! Element 1 - PIPE288 using cubic shape function
et,2,mass21                             ! Element 2 - MASS21
```

```
/com, Real Constants
/com,****************

sectype,1,pipe
secdata,2.37500000,0.15400000,14        ! Outer Diameter, Wall Thickness, Cells around the circumference

r,2,0.447000518e-01,0.447000518e-01,0.447000518e-01,0.0,0.0,0.0
r,3,0.447000518e-01,0.447000518e-01,0.447000518e-01,0.0,0.0,0.0
r,4,0.447000518e-01,0.447000518e-01,0.447000518e-01,0.0,0.0,0.0
r,5,0.447000518e-01,0.447000518e-01,0.447000518e-01,0.0,0.0,0.0
r,6,0.432699275e-01,0.432699275e-01,0.432699275e-01,0.0,0.0,0.0
r,7,0.893995859e-02,0.893995859e-02,0.893995859e-02,0.0,0.0,0.0
r,8,0.432699275e-01,0.432699275e-01,0.432699275e-01,0.0,0.0,0.0
r,9,0.893995859e-02,0.893995859e-02,0.893995859e-02,0.0,0.0,0.0
r,10,0.893995859e-02,0.893995859e-02,0.893995859e-02,0.0,0.0,0.0
r,11,0.432699275e-01,0.432699275e-01,0.432699275e-01,0.0,0.0,0.0
r,12,0.893995859e-02,0.893995859e-02,0.893995859e-02,0.0,0.0,0.0
r,13,0.432699275e-01,0.432699275e-01,0.432699275e-01,0.0,0.0,0.0
r,14,0.893995859e-02,0.893995859e-02,0.893995859e-02,0.0,0.0,0.0
r,15,0.893995859e-02,0.893995859e-02,0.893995859e-02,0.0,0.0,0.0

/com, Nodes
/com,*******

n,1,0.0,-30.00                          ! Node Numbers, Global Co-ordinates
n,2,27.25,-30.00
n,3,27.25,-30.00,17.250
n,4,0.0,-30.00,17.250
n,5,0.0,18.625,17.250
n,6,0.0,18.625,8.625
n,7,0.0,18.625
n,8,8.625,18.625,
n,9,18.625,18.625
n,10,27.25,18.625
n,11,27.25,18.625,8.625
n,12,27.25,18.625,17.250
n,13,18.625,18.625,17.250
n,14,8.625,18.625,17.250
n,15,0.0,-80.00
n,16,27.25,-80.00
n,17,27.25,-80.00,17.250
n,18,0.0,-80.00,17.25

/com, Straight Pipe (Tangent Elements)
/com,**********************************

mat,1
type,1
secnum,1

en,1,15,1
en,2,1,7
en,3,7,6
en,4,6,5
en,5,5,4
en,6,4,18
en,7,16,2
en,8,2,10
en,9,10,11
en,10,11,12
en,11,12,3
en,12,3,17
en,13,12,13
en,14,13,14
en,15,14,5
en,16,7,8
en,17,8,9
en,18,9,10

/com, Mass Elements
/com,***************
```

```
mat,1
type,2

real,2
en,19,1

real,3
en,20,2

real,4
en,21,3

real,5
en,22,4

real,6
en,23,5

real,7
en,24,6

real,8
en,25,7

real,9
en,26,8

real,10
en,27,9

real,11
en,28,10

real,12
en,29,11

real,13
en,30,12

real,14
en,31,13

real,15
en,32,14

nsel,s,node,,15
nsel,a,node,,16
nsel,a,node,,17
nsel,a,node,,18
cm,fixedsu,node
allsel,all

mp,ex,1,27899996.8
mp,nuxy,1,0.3
mp,dens,1,2.587991718e-10

/com, Constraints
/com,*************

d,15,all,0
d,16,all,0
d,17,all,0
d,18,all,0
save
allsel,all
finish

/com,
/com,=============
/com,   Modal Solve
/com,=============
/com,
```

```
/solution
antype,modal
modopt,lanb,5                           ! Use LANB solver
mxpand,,,,yes
solve
save
finish

/post1
/out,
/com, ******************************
/com,  Frequencies from Modal solve
/com, ******************************
set,list
finish

/com,-----------------------------------------------------------------------

/out,scratch
/com,
/com,================
/com,   Spectrum Solve
/com,================
/com,

/solution
antype,spectr                           ! Perform Spectrum analysis
spopt,sprs                                      ! Single Point Excitation Response Spectrum
dmprat,0.02                                     ! Constant Damping Ratio
grp,0.001                                       ! Group Modes based on Significance Level
svtyp,2                                 ! Seismic Acceleration Response Loading

sed,1
freq
freq,3.1,4,5,5.8,7.1,8.8,11,14.1,17.2
freq,35,40,588
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,380,348.6,145
solve

sed,,1
freq
freq,3.1,4,5,5.8,7.1,8.8,11,14.1,17.2
freq,35,40,588
sv,0.02,266.7,580.7,580.7,466.7,792,792,293.3333,516.7,516.7
sv,0.02,253.3,232.4,96.7
solve

sed,,,1
freq
freq,3.1,4,5,5.8,7.1,8.8,11,14.1,17.2
freq,35,40,588
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,380,348.6,145
solve
fini

/com,-----------------------------------------------------------------------

/post1
/input,,mcom


/out,
/com, *=================================================================
/com, * Maximum nodal displacements and rotations from spectrum solve
/com, *=================================================================

/out,scratch

*GET,AdisX,NODE,6,U,X
```

```
*GET,AdisY,NODE,8,U,Y
*GET,AdisZ,NODE,8,U,Z
*GET,ArotX,NODE,1,ROT,X
*GET,ArotY,NODE,9,ROT,Y
*GET,ArotZ,NODE,1,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com, *=========================================================
/com, * Element Forces and Moments obtained from spectrum solve
/com, *=========================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #1 (Pipe288 element)
/com,*******************************

esel,s,elem,,1
etable,pxi_1,smisc,1
etable,vyi_1,smisc,6
etable,vzi_1,smisc,5
etable,txi_1,smisc,4
etable,myi_1,smisc,2
etable,mzi_1,smisc,3
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element1, node i
/com, ************************************************

pretab,pxi_1,vyi_1,vzi_1,txi_1,myi_1,mzi_1


/out,scratch
/com,==========
/com,  Node J
/com,==========

/com, Element #1 (Pipe288 element)
/com,*******************************

esel,s,elem,,1
etable,pxj_1,smisc,14
etable,vyj_1,smisc,19
etable,vzj_1,smisc,18
etable,txj_1,smisc,17
etable,myj_1,smisc,15
etable,mzj_1,smisc,16
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element1, node j
/com, ************************************************

pretab,pxj_1,vyj_1,vzj_1,txj_1,myj_1,mzj_1



/out,scratch
```

```
/com,==========
/com,  Node I
/com,==========

/com, Element #18 (Pipe288 element)
/com,********************************

esel,s,elem,,18
etable,pxi_18,smisc,1
etable,vyi_18,smisc,6
etable,vzi_18,smisc,5
etable,txi_18,smisc,4
etable,myi_18,smisc,2
etable,mzi_18,smisc,3
esel,all

/out,
/com, ***************************************************
/com,  Element forces and moments at element18, node i
/com, ***************************************************

pretab,pxi_18,vyi_18,vzi_18,txi_18,myi_18,mzi_18


/out,scratch
/com,==========
/com,  Node J
/com,==========



/com, Element #18 (Pipe288 element)
/com,********************************
esel,s,elem,,18

etable,pxj_18,smisc,14
etable,vyj_18,smisc,19
etable,vzj_18,smisc,18
etable,txj_18,smisc,17
etable,myj_18,smisc,15
etable,mzj_18,smisc,16
esel,all

allsel,all

/out,
/com, **************************************************
/com,  Element forces and moments at element18, node j
/com, **************************************************

pretab,pxj_18,vyj_18,vzj_18,txj_18,myj_18,mzj_18


/com,---------------------------------------------------------------------------

/com, ***************************************
/com,  Reaction forces from spectrum solve
/com, ****************************************

prrsol

finish
```

vm-nr1677-01-3a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-01-3a
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/title,vm-nr1677-01-3a,NRC Piping Benchmark Problems,Volume 1,Problem 3

/com,*************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,        NUREC/CR--1677-Vol.1
/com,                P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com, Elements used: Pipe289, Elbow290, Mass21
/com,
/com, Results:
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces and moments obtained from spectrum solution.
/com,
/com,*************************************************************************


/out,scratch

/prep7

et,1,pipe289,,,                         ! Element 1 - PIPE288 with cubic shape function

et,2,elbow290,,6                        ! Element 2 - ELBOW290

et,3,combin14                           ! Element 3 - COMBIN14
keyopt,3,2,1                            ! UX Degree of Freedom

et,4,combin14                           ! Element 4 - COMBIN14
keyopt,4,2,2                            ! UY Degree of Freedom

et,5,combin14                           ! Element 5 - COMBIN14
keyopt,5,2,3                            ! UZ Degree of Freedom

et,6,mass21                             ! Element 6 - MASS21
keyopt,6,3,2                            ! 3D Mass with Rotary Inertia

/com, Material Properties
/com,*********************

mp,ex,1,24e6
mp,prxy,1,.3
mp,dens,1,0.001057

mp,ex,2,24e6
mp,prxy,2,.3
mp,dens,2,0.001057

/com, Real Constants
/com,****************

sectype,1,pipe
secdata,7.289,0.241,24                          ! Pipe section 1

r,3,0.1e+5                                      ! Real Constant Set 3
r,4,0.1e+9                                      ! Real Constant Set 4
r,5,0.1e+11                                     ! Real Constant Set 5
r,6,1.518                                       ! Real Constant Set 6

/com, Nodes
/com,*******

k,1,0,0,0
k,2,0,54.45,0
k,3,0,108.9,0
k,301,0.675,116,0
k,101,2.76,123,0
k,302,6.13,129,0
k,4,10.632,134.568,0
```

```
k,102,22.4,142,0
k,5,36.3,145.2,0
k,6,54.15,145.2,0
k,7,72.0,145.2,0
k,701,79.1,145,0.697
k,103,85.9,145,2.76
k,702,92.2,145,6.12
k,8,97.668,145.2,10.632
k,801,102,145,16.1
k,104,106,145,22.4
k,802,108,145,29.2
k,9,108.3,145.2,36.3
k,10,108.3,145.2,56.8
k,11,108.3,145.2,77.3
k,12,108.3,145.2,97.8
k,13,108.3,145.2,118.3
k,14,108.3,145.2,188.8
k,401,108,146,196
k,201,108,148,203
k,402,108,151,209
k,105,108,156,214
k,202,108,168,222
k,15,108.3,181.5,225.1
k,16,108.3,236,225.1
k,17,108.3,290,225.1
k,18,148.3,145.2,97.8
k,19,188.3,145.2,97.8
k,203,202,145,95.1
k,106,214,145,87.2
k,601,219,145,81.7
k,204,222,145,75.4
k,602,224,145,68.6
k,20,224.6,145.2,61.5
k,21,224.6,145.2,20

/com, Elastic support Nodes
/com,**********************

k,22,1,0,0
k,23,0,1,0
k,24,0,0,1
k,25,72,145.2,-1
k,26,109.3,145.2,36.3
k,27,108.3,146.2,77.3
k,28,108.3,146.2,118.3
k,29,107.3,182.5,226.5
k,30,109.3,290,225.1
k,31,108.3,291,225.1
k,32,108.3,290,226.1
k,33,225.6,145.2,20
k,34,224.6,146.2,20
k,35,224.6,145.2,21

/com, Straight Pipe (Tangent Elements)
/com,*********************************

l,1,2
l,2,3
l,5,6
l,6,7
l,9,10
l,10,11
l,11,12
l,12,13
l,13,14
l,15,16
l,16,17
l,12,18
l,18,19
l,20,21  !Line #14

/com, Curved pipe elements
```

```
/com,**********************

larch,3,101,301 !Line #15
larch,101,4,302
larch,4,5,102
larch,7,103,701
larch,103,8,702
larch,8,104,801
larch,104,9,802
larch,14,201,401
larch,201,105,402
larch,105,15,202
larch,19,106,203
larch,106,204,601
larch,204,20,602 !Line #27


/com, *********************************
/com, Meshing for Straight pipe
/com, *********************************

type,1
secnum,1
mat,1

lsel,s,line,,1,14
allsel,below,line
lesize,all,,,2
lmesh,all

allsel,all,all

/com, *********************************
/com, Meshing for bend pipe
/com, *********************************

type,2
secnum,1
mat,1

lsel,s,,,15,27
allsel,below,line
lesize,all,,,2
lmesh,all

allsel,all,all

/com, ************************************************************
/com,  Using ELBOW, to convert some PIPE289 to ELBOW290
/com, ************************************************************

elbow,on,,,sect

/com, Elastic supports and anchors

l,11,27  !Line #28
l,13,28  !Line #29

real,3
type,4
lsel,s,,,28,29
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

l,9,26  !Line #30
l,15,29  !Line #31

real,4
type,3
lsel,s,,,30,31
```

```
allsel,below,line
lesize,all,,,1
lmesh,all
allsel


l,7,25  !Line #32
type,5
lsel,s,,,32
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

l,1,22  !Line #33
l,17,30  !Line #34
l,21,33  !Line #35

real,5
type,3

lsel,s,,,33,35
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

l,1,23  !Line #36
l,17,31  !Line #37
l,21,34  !Line #38

type,4
lsel,s,,,36,38
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

l,1,24  !Line #39
l,17,32  !Line #40
l,21,35  !Line #41

type,5
lsel,s,,,39,41
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,******************************
/com, **rotate nodes with less than 3 supports**

wplane,,108.3,181.5,225.1,107.3,182.5,226.5,108.3,236,225.1
cswplane,11,0
nrotat,40
nrotat,113
csys,0


/com, Mass Elements
/com,***************

type,6
real,6
e,18

/com, Constraints
/com,*************

ksel,s,kp,,22,35
nslk
d,all,all
```

```
allsel,all


ksel,s,kp,,1
nslk
d,all,rotx,,,,,roty,rotz
allsel

ksel,s,kp,,21
nslk
d,all,rotx,,,,,roty,rotz
allsel

/com, Loading
/com,*********

/com, **Pressure on ELBOW290 elements affects stiffness because of pressure term**
esel,s,ename,,290
sfe,all,1,pres,,350
allsel,all
save
finish

/com,
/com,=============
/com,   Modal Solve
/com,=============
/com,

/solution
antype,modal                        ! Perform Modal Analysis
modopt,lanb,10
mxpand,,,,yes                       ! Expand solution with Element Calculations ON
lumpm,on                                    ! Use Lumped Mass Approximation
solve
save
fini

/post1
/out,
/com, *******************************
/com,  Frequencies from Modal solve
/com, *******************************
set,list
finish

/out,scratch
/com,
/com,================
/com,   Spectrum Solve
/com,================
/com,

/com, **Spectrum in X, Y, and Z directions**
/com, **Spectra values in Y direction are 67% of the values for the X and Z directions**

/solution
antype,spectr                       ! Perform Spectrum Analysis
spopt,sprs                                  ! Single Point Excitation Response Spectrum
dmprat,0.02                                 ! Constant Damping Ratio
grp,0.001                                   ! Group Modes based on Significance Level
svtyp,2                             ! Seismic Acceleration Response Loading

sed,1                                       ! Excitation in X direction
freq
freq,3.1,4,5,5.81,7.09,8.77,9,10,10.99
freq,14.08,17.24,20,25,30,34.97,40,45,50
freq,588.93
sv,0.02,400,871,871,700,1188,1188,1090,733,440
sv,0.02,775,775,668,533,444,380,349,324,306
sv,0.02,145
solve
```

```
sed,,1                                  ! Excitation in Y direction
freq
freq,3.1,4,5,5.81,7.09,8.77,9,10,10.99
freq,14.08,17.24,20,25,30,34.97,40,45,50
freq,588.93
sv,0.02,267,581,581,467,792,792,727,489,293
sv,0.02,517,517,445,355,296,253,232,216,204
sv,0.02,97
solve

sed,,,1                                 ! Excitation in Z direction
freq
freq,3.1,4,5,5.81,7.09,8.77,9,10,10.99
freq,14.08,17.24,20,25,30,34.97,40,45,50
freq,588.93
sv,0.02,400,871,871,700,1188,1188,1090,733,440
sv,0.02,775,775,668,533,444,380,349,324,306
sv,0.02,145
solve
fini

/post1
/input,,mcom
*GET,AdisX,NODE,96,U,X
*GET,AdisY,NODE,78,U,Y
*GET,AdisZ,NODE,40,U,Z
*GET,ArotX,NODE,84,ROT,X
*GET,ArotY,NODE,76,ROT,Y
*GET,ArotZ,NODE,10,ROT,Z

/out,
/com, *=======================================================
/com, * Maximum nodal displacements and rotations comparsion
/com, *=======================================================
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ


/com, *=======================================================
/com, * Element Forces and Moments Comparison
/com, *=========================================================
/out,scratch

/com,==========
/com,    Node I
/com,==========

/com, Element #28 (Pipe289 elements)
/com,************************


esel,s,elem,,28
etable,pxi_28,smisc,1
etable,vyi_28,smisc,6
etable,vzi_28,smisc,5
etable,txi_28,smisc,4
etable,myi_28,smisc,2
etable,mzi_28,smisc,3
esel,all

/com, Element #50 (Elbow 290 elements)
/com,*************************

esel,s,elem,,50

etable,pxi_50,smisc,1
etable,vyi_50,smisc,6
```

```
etable,vzi_50,smisc,5
etable,txi_50,smisc,4
etable,myi_50,smisc,2
etable,mzi_50,smisc,3
esel,all


/com,==========
/com,  Node J
/com,==========

/com, Element #28 (Pipe289 elements)
/com,************************

esel,s,elem,,28

etable,pxj_28,smisc,14
etable,vyj_28,smisc,19
etable,vzj_28,smisc,18
etable,txj_28,smisc,17
etable,myj_28,smisc,15
etable,mzj_28,smisc,16
esel,all


/com, Element #50 (Elbow290 elements)
/com,************************
esel,s,elem,,50

etable,pxj_50,smisc,36
etable,vyj_50,smisc,41
etable,vzj_50,smisc,40
etable,txj_50,smisc,39
etable,myj_50,smisc,37
etable,mzj_50,smisc,38
esel,all

allsel,all
/out,

/com, **********************************************
/com,  Element forces and moments at element 28, node i
/com, ************************************************

pretab,pxi_28,vyi_28,vzi_28,txi_28,myi_28,mzi_28

/com, **********************************************
/com,  Element forces and moments at element 28, node j
/com, ************************************************

pretab,pxj_28,vyj_28,vzj_28,txj_28,myj_28,mzj_28

/com, **********************************************
/com,  Element forces and moments at element 50, node i
/com, ************************************************

pretab,pxi_50,vyi_50,vzi_50,txi_50,myi_50,mzi_50

/com, **********************************************
/com,  Element forces and moments at element 50, node j
/com, ************************************************
pretab,pxj_50,vyj_50,vzj_50,txj_50,myj_50,mzj_50



/com,----------------------------------------------------------------------------

/com, *****************************
/com,  Reaction forces
/com, ******************************

prrsol
```



```
finish
```

vm-nr1677-01-4a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-01-4a
/title,vm-nr1677-01-4a,NRC Piping Benchmark Problems,Volume 1,Problem 4
/com,****************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,            NUREG/CR--1677-Vol.1
/com,            P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com, Elements used: Pipe289, Elbow290, Mass21
/com,
/com, Results:
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces and moments obtained from spectrum solution.
/com,
/com,****************************************************************************

/out,scratch

/prep7
et,2,combin14                                         ! COMBIN14 Spring-damper element
et,3,pipe289,,,                                       ! Pipe288 element
et,5,elbow290,,3                                      ! Elbow290 element
et,7,mass21                                           ! Mass21 element


/com, Real Constants
/com,****************

r,      1,       0.1000E+11,      0.00000000,      0.00000000,      0.00000000,      0.00000000,      0.000000
r,      2,       50000000.0,      0.00000000,      0.00000000,      0.00000000,      0.00000000,      0.000000
r,      3,       10000000.0,      0.00000000,      0.00000000,      0.00000000,      0.00000000,      0.000000

sectype,4,pipe
secdata,144,3

sectype,5,pipe
secdata,36,2.5,,,,


sectype,7,pipe
secdata,48,3.75,,,,


sectype,9,pipe
secdata,72,4

sectype,10,pipe
secdata,192,8

sectype,11,pipe
secdata,135,0.4

sectype,12,pipe
secdata,100,0.38

r,     13,       518.000000,      518.000000,      518.000000,      0.00000000,      0.00000000,      0.000000
r,     14,       259.000000,      259.000000,      259.000000,      0.00000000,      0.00000000,      0.000000
r,     15,       906.000000,      906.000000,      906.000000,      0.00000000,      0.00000000,      0.000000
r,     16,       233.000000,      233.000000,      233.000000,      0.00000000,      0.00000000,      0.000000
```

```
r,      17,        130.000000,      130.000000,      130.000000,      0.00000000,      0.00000000,      0.00000000
r,      18,        389.000000,      389.000000,      389.000000,      0.00000000,      0.00000000,      0.00000000
r,      19,        2073.00000,      2073.00000,      2073.00000,      0.00000000,      0.00000000,      0.00000000
r,      20,        1943.00000,      1943.00000,      1943.00000,      0.00000000,      0.00000000,      0.00000000
r,      21,        1295.00000,      1295.00000,      1295.00000,      0.00000000,      0.00000000,      0.00000000

/com,------------------------------------------------------------------------
/com,

/com, Keypoints
/com,*******

k,       1,               384.000000,      696.000000,
k,       2,               384.000000,      552.000000,
k,       3,               384.000000,      456.000000,
k,       4,               384.000000,      276.000000,
k,       5,               384.000000,      96.0000000,
k,       6,               384.000000,     -180.000000,
k,       7,               399.000000,      26.9000000,     -56.0000000
k,       8,               399.000000,      26.9000000,      56.0000000
k,       9,               338.800000,      42.1000000,
k,      10,               402.600000,     -11.6000000,     -69.5000000
k,      11,               248.400000,
k,      12,               402.600000,     -11.6000000,      69.5000000
k,      13,               402.600000,     -72.0000000,     -69.5000000
k,      14,               402.600000,     -72.0000000,      69.5000000
k,      15,               354.700000,     -132.000000,     -105.600000
k,      16,               354.700000,     -132.000000,      105.600000
k,      17,               335.900000,     -132.000000,     -119.900000
k,      18,               335.900000,     -132.000000,      119.900000
k,      19,               288.000000,     -72.0000000,     -156.000000
k,      20,               288.000000,     -72.0000000,      156.000000
k,      21,               288.000000,      0.00000000,     -156.000000
k,      22,               288.000000,      0.00000000,      156.000000
k,      23,               288.000000,     -180.000000,     -156.000000
k,      24,               288.000000,     -180.000000,      156.000000
k,      25,               288.000000,      126.000000,     -156.000000
k,      26,               288.000000,      126.000000,      156.000000
k,      27,               253.200000,      0.00000000,     -146.700000
k,      28,               253.200000,      0.00000000,      146.700000
k,      29,               187.300000,      0.00000000,     -128.500000
k,      30,               177.000000,
k,      31,               187.300000,      0.00000000,      128.500000
k,      32,               121.400000,      0.00000000,     -110.200000
k,      33,               96.0000000,
k,      34,               121.400000,      0.00000000,      110.200000
k,      35,               94.6000000,      0.00000000,     -94.6000000
k,      36,               94.6000000,      0.00000000,      94.6000000
k,      37,               0.00000000,
k,      38,               0.00000000,     -192.000000,
k,      39,               0.00000000,      84.0000000,
k,      40,               0.00000000,      156.000000,
k,      41,               0.00000000,      288.000000,
k,      42,              -94.6000000,      0.00000000,     -94.6000000
k,      43,              -96.0000000,
k,      44,              -94.6000000,      0.00000000,      94.6000000
k,      45,              -121.400000,      0.00000000,     -110.200000
k,      46,              -121.400000,      0.00000000,      110.200000
k,      47,              -187.300000,      0.00000000,     -128.500000
k,      48,              -177.000000,
k,      49,              -187.300000,      0.00000000,      128.500000
k,      50,              -253.200000,      0.00000000,     -146.700000
k,      51,              -248.400000,
k,      52,              -253.200000,      0.00000000,      146.700000
k,      53,              -288.000000,      0.00000000,     -156.000000
k,      54,              -288.000000,      0.00000000,      156.000000
k,      55,              -288.000000,      126.000000,     -156.000000
k,      56,              -288.000000,      126.000000,      156.000000
k,      57,              -288.000000,     -180.000000,     -156.000000
k,      58,              -288.000000,     -180.000000,      156.000000
k,      59,              -288.000000,     -72.0000000,     -156.000000
k,      60,              -288.000000,     -72.0000000,      156.000000
```

```
k,      61,              -335.900000,     -132.000000,     -119.900000
k,      62,              -335.900000,     -132.000000,      119.900000
k,      63,              -354.700000,     -132.000000,     -105.600000
k,      64,              -354.700000,     -132.000000,      105.600000
k,      65,              -402.600000,     -72.0000000,     -69.5000000
k,      66,              -402.600000,     -72.0000000,      69.5000000
k,      67,              -402.600000,     -11.6000000,     -69.5000000
k,      68,              -402.600000,     -11.6000000,      69.5000000
k,      69,              -399.000000,      26.9000000,     -56.0000000
k,      70,              -338.800000,      42.1000000,
k,      71,              -399.000000,      26.9000000,      56.0000000
k,      72,              -384.000000,      96.0000000,
k,      73,              -384.000000,     -180.000000,
k,      74,              -384.000000,      276.000000,
k,      75,              -384.000000,      456.000000,
k,      76,              -384.000000,      552.000000,
k,      77,              -384.000000,      696.000000,
k,     126,               387.131997,     -11.7130035,     -11.4949905
k,     127,               248.496000,      117.900000,
k,     128,               387.131997,     -11.7130035,      11.4949905
k,     129,               354.700000,     -72.0000000,     -105.600000
k,     130,               354.700000,     -72.0000000,      105.600000
k,     131,               335.900000,     -72.0000000,     -119.900000
k,     132,               335.900000,     -72.0000000,      119.900000
k,     133,               137.244000,      0.00000000,     -52.3916000
k,     134,               137.244000,      0.00000000,      52.3916000
k,     135,              -137.244000,      0.00000000,     -52.3916000
k,     136,              -137.244000,      0.00000000,      52.3916000
k,     137,              -335.900000,     -72.0000000,     -119.900000
k,     138,              -335.900000,     -72.0000000,      119.900000
k,     139,              -354.700000,     -72.0000000,     -105.600000
k,     140,              -354.700000,     -72.0000000,      105.600000
k,     141,              -387.164784,     -11.6665558,     -11.6179404
k,     142,              -248.538000,      117.810000,     -4.59695000
k,     143,              -387.164784,     -11.6665558,      11.6179404
k,     205,               383.000000,      276.000000,      0.00000000
k,     206,               384.000000,      276.000000,      1.00000000
k,     207,               385.000000,      276.000000,      0.00000000
k,     208,               384.000000,      276.000000,     -1.00000000
k,     241,               95.6000000,      0.00000000,     -93.6000000
k,     242,               96.0000000,      0.00000000,      1.00000000
k,     243,               93.6000000,      0.00000000,      95.6000000
k,     244,               94.6000000,     -1.00000000,     -94.6000000
k,     245,               96.0000000,     -1.00000000,      0.00000000
k,     246,               94.6000000,     -1.00000000,      94.6000000
k,     252,              -94.6000000,     -1.00000000,     -94.6000000
k,     253,              -96.0000000,     -1.00000000,      0.00000000
k,     254,              -94.6000000,     -1.00000000,      94.6000000
k,     255,              -95.6000000,      0.00000000,     -93.6000000
k,     256,              -96.0000000,      0.00000000,      1.00000000
k,     257,              -93.6000000,      0.00000000,      95.6000000
k,     291,              -383.000000,      276.000000,      0.00000000
k,     292,              -385.000000,      276.000000,      0.00000000
k,     293,              -384.000000,      276.000000,      1.00000000
k,     294,              -384.000000,      276.000000,     -1.00000000

k,300,402,8.88,-66
k,301,402,8.88,66
k,302,389,-114,-80.1
k,303,389,-114,80.1
k,304,302,-114,-145
k,305,302,-114,145
k,306,107,0,-104
k,307,107,0,104
k,308,-107,0,-104
k,309,-107,0,104
k,310,-302,-114,-145
k,311,-302,-114,145
k,312,-389,-114,-80.1
k,313,-389,-114,80.1
k,314,-402,8.88,-66
k,315,-402,8.88,66
```

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k,316,298,11,0
k,317,-298,11,0.476
k,318,320,24.3,0
k,319,274,2.80,0
k,320,399,-94.7,-72.4
k,321,373,-127,-91.8
k,322,399,-94.7,72.4
k,323,373,-127,91.8
k,324,317,-127,-133
k,325,292,-94.8,-153
k,326,317,-127,133
k,327,292,-94.8,153
k,328,-292,-94.8,-153
k,329,-317,-127,-133
k,330,-292,-94.8,153
k,331,-317,-127,133
k,332,-373,-127,-91.8
k,333,-399,-94.7,-72.4
k,334,-373,-127,91.8
k,335,-399,-94.7,72.4
k,336,-274,2.8,0.355
k,337,-320,24.3,0.358

/com,---------------------------------------------------------------------------
/com,

/com, Material Properties

mp,ex,1,2.9e7                          ! Young's Modulus for Mat ID 1
mp,nuxy,1,.3                           ! Minor Poisson's Ratio for Mat ID 1
mp,dens,2,0.28138E-03                  ! Density of the internal fluid
mp,dens,3,0.32972E-03                  ! Density of the internal fluid

/com,---------------------------------------------------------------------------
/com,

/com, Straight Pipe (Tangent Elements)
/com,**********************************

mat,1
type,3
secnum,4
l,1,2
l,2,3
l,3,4
l,4,5
l,5,7
l,5,8
l,5,9
l,69,72
l,70,72
l,71,72
l,72,74
l,74,75
l,75,76
l,76,77  !Line #14

lsel,s,line,,1,14
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,****************
/com,

mat,1
type,3
secnum,5
l,10,13
l,12,14
l,15,17
```

```
l,16,18
l,27,29
l,28,31
l,29,32
l,31,34
l,45,47
l,46,49
l,47,50
l,49,52
l,61,63
l,62,64
l,65,67
l,66,68  !Line #30

lsel,s,line,,15,30
allsel,below,line
lesize,all,,,1
lmesh,all
allsel
/com,****************
/com,

mat,1
type,3
secnum,7
l,11,30
l,30,33
l,43,48
l,48,51  !Line #34

lsel,s,line,,31,34
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,****************
/com,

mat,1
type,3
secnum,9
l,19,21
l,20,22
l,21,25
l,22,26
l,21,27
l,22,28
l,50,53
l,52,54
l,55,53
l,56,54
l,53,59
l,54,60  !Line #46

lsel,s,line,,31,46
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,****************
/com,

mat,1
type,3
secnum,10
l,35,37
l,33,37
l,36,37
l,38,37
l,37,39
```

```
l,39,40
l,40,41
l,37,42
l,37,43
l,37,44  !Line #56

lsel,s,line,,47,56
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,****************
/com,

mat,1
type,3
secnum,11
l,5,6
l,73,72  !Line #58

lsel,s,line,,57,58
allsel,below,line
lesize,all,,,1
lmesh,all
allsel


/com,****************
/com,

mat,1
type,3
secnum,12
l,23,21
l,24,22
l,53,57
l,54,58  !Line #62

lsel,s,line,,59,62
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,
/com, Pipe Bend Elements
/com,*********************

mat,1
type,5
secnum,5
larch,7,10,300
larch,8,12,301
larch,13,302,320
larch,302,15,321
larch,14,303,322
larch,303,16,323
larch,17,304,324
larch,304,19,325
larch,18,305,326
larch,305,20,327
larch,32,35,306
larch,34,36,307
larch,42,45,308
larch,44,46,309
larch,59,310,328
larch,310,61,329
larch,60,311,330
larch,311,62,331
larch,63,312,332
larch,312,65,333
```

```
larch,64,313,334
larch,313,66,335
larch,67,69,314
larch,68,71,315  !Line  #86

lsel,s,line,,59,86
allsel,below,line
lesize,all,,,1
lmesh,all
allsel


/com,****************
/com,

mat,1
type,5
secnum,7
larch,9,316,318
larch,316,11,319
larch,51,317,336
larch,317,70,337  !Line #90

lsel,s,line,,87,90
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,
/com, Spring Elements
/com,*****************

type,2
real,1
l,4,206
l,4,207
l,4,208
l,74,292
l,74,293
l,74,294    !Line #96

lsel,s,line,,91,96
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,****************
/com,

type,2
real,2
l,35,244
l,33,245
l,36,246
l,42,252
l,43,253
l,44,254    !Line #102


lsel,s,line,,97,102
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,****************
/com,

type,2
real,3
```

```
l,35,241
l,33,242
l,36,243
l,42,255
l,43,256
l,44,257    !Line #108

lsel,s,line,,103,108
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,****************
/com,

type,2
real,1
l,4,205    !Line #109
l,74,291    !Line #110

lsel,s,line,,109,110
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,------------------------------------------------------------------------
/com,

/com, Mass Elements
/com,***************

type,7

real,13
en,1129,1

real,14
en,1130,2

real,14
en,1131,4

real,15
en,1132,6

real,16
en,1133,8

real,17
en,1134,86

real,17
en,1135,89

real,18
en,1136,91

real,18
en,1137,93

real,19
en,1138,110

real,20
en,1139,115

real,21
en,1140,117

real,13
```

```
en,1141,119

real,18
en,1142,121

real,18
en,1143,101

real,18
en,1144,103

real,17
en,1145,97

real,17
en,1146,99

real,16
en,1147,17

real,15
en,1148,23

real,14
en,1149,25

real,14
en,1150,27

real,13
en,1151,29


/com, ************************************************************
/com,  Using ELBOW, to convert some PIPE289 to ELBOW290
/com, ************************************************************

elbow,on,,,sect


/com,-------------------------------------------------------------------------
/com,

/com, Constraints
/com,*************

dk,6,all,0
dk,23,all,0
dk,24,all,0
dk,57,all,0
dk,58,all,0
dk,73,all,0
dk,205,all,0
dk,206,all,0
dk,207,all,0
dk,208,all,0
dk,241,all,0
dk,242,all,0
dk,243,all,0
dk,244,all,0
dk,245,all,0
dk,246,all,0
dk,252,all,0
dk,253,all,0
dk,254,all,0
dk,255,all,0
dk,256,all,0
dk,257,all,0
dk,291,all,0
dk,292,all,0
dk,293,all,0
dk,294,all,0
```

```
allsel,all

/com,--------------------------------------------------------------------------------
/com,

/com, Loads
/com,*******
esel,s,type,,5
sfe,all,1,pres,1,2400.00
allsel

esel,s,sec,,5
sfe,all,3,pres,,15.5
allsel


esel,s,sec,,7
sfe,all,3,pres,,15.5
allsel

save
finish

/com,--------------------------------------------------------------------------------
/com,

/com,
/com,=============
/com,   Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,30
mxpand,,,,yes                           ! Expand Solution with Element Calculations ON
solve
save

/post1
/out,
/com, *******************************
/com,  Frequencies from Modal solve
/com, *******************************
set,list
finish



/out,scratch
/com,
/com,================
/com,   Spectrum Solve
/com,================
/com,

/solution
spopt,sprs                                      ! Perform Spectrum Analysis
dmprat,0.02                                     ! Constant Damping Ratio
grp,0.001                                       ! Grouping based on Significance Level
svtyp,2

sed,1                                           ! Excitation along X direction
freq
freq,1,1.05,1.15,1.28,1.60,1.62,1.9,1.92,2.4
freq,2.55,2.8,2.89,3.15,3.28,3.42,4.18,4.41,5.2
freq,5.33,6.52,6.75,7.08,8.65,10,14.07,14.90,17
freq,18.09,21.697,23.8,30,37.5,41,46.21,52,58.82
freq,71.89,98.04,200
sv,0.02,600,662,662,905,905,865,865,914,914
sv,0.02,812,812,855,855,1023,1057,1057,1140,1140
sv,0.02,1399,1399,1150,1222,1222,865,865,755,755
```

```
sv,0.02,652,555,475,437,407,255,255,170,243
sv,0.02,243,160,160
solve

sed,,1                                          ! Excitation along Y direction
freq
freq,1,1.05,1.15,1.28,1.6,1.62,1.9,1.92,2.4
freq,2.55,2.8,2.89,3.15,3.28,3.42,4.18,4.41,5.2
freq,5.33,6.52,6.75,7.08,8.65,10,14.07,14.90,17
freq,18.09,21.70,23.80,30,37.50,41,46.21,52,58.82
freq,71.89,98.04,200
sv,0.02,400,441.3,441.3,603.3,603.3,576.7,576.7,609.3,609.3
sv,0.02,541.3,541.3,570,570,682,704.7,704.7,760,760
sv,0.02,932.7,932.7,766.7,814.7,814.7,576.7,576.7,503.3,503.3
sv,0.02,434.7,370,316.7,292.5,271.3,170,170,113.3,162
sv,0.02,162,106.7,106.7
solve

sed,,,1                                         ! Excitation along Z direction
freq
freq,1,1.05,1.15,1.28,1.60,1.62,1.9,1.92,2.4
freq,2.55,2.8,2.89,3.15,3.28,3.42,4.18,4.41,5.2
freq,5.33,6.52,6.75,7.08,8.65,10,14.07,14.90,17
freq,18.09,21.697,23.8,30,37.5,41,46.21,52,58.82
freq,71.89,98.04,200
sv,0.02,600,662,662,905,905,865,865,914,914
sv,0.02,812,812,855,855,1023,1057,1057,1140,1140
sv,0.02,1399,1399,1150,1222,1222,865,865,755,755
sv,0.02,652,555,475,437,407,255,255,170,243
sv,0.02,243,160,160
solve
fini

/com,-----------------------------------------------------------------------------
/com,

/post1
/input,,mcom
/com,-----------------------------------

/com, *=========================================================
/com, * Maximum nodal displacements and rotations comparsion
/com, *===========================================================

/com, Solution obtained from Mechanical APDL
/com, ****************************

*GET,AdisX,NODE,103,U,X
*GET,AdisY,NODE,140,U,Y
*GET,AdisZ,NODE,103,U,Z
*GET,ArotX,NODE,103,ROT,X
*GET,ArotY,NODE,57,ROT,Y
*GET,ArotZ,NODE,103,ROT,Z
/out,
/com, *=========================================================
/com, * Maximum nodal displacements and rotations comparsion
/com, *=========================================================
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ


/com,-------------------------------------------------------------

/com, *=========================================================
/com, * Element Forces and Moments Comparison
/com, *===========================================================
```

```
/out,scratch

/com,==========
/com,    Node I
/com,==========

/com, Element #28 (Pipe289 elements)
/com,************************


esel,s,elem,,28
etable,pxi_28,smisc,1
etable,vyi_28,smisc,6
etable,vzi_28,smisc,5
etable,txi_28,smisc,4
etable,myi_28,smisc,2
etable,mzi_28,smisc,3
esel,all

/com, Element #80 (Elbow 290 elements)
/com,*************************

esel,s,elem,,80

etable,pxi_80,smisc,1
etable,vyi_80,smisc,6
etable,vzi_80,smisc,5
etable,txi_80,smisc,4
etable,myi_80,smisc,2
etable,mzi_80,smisc,3
esel,all


/com,==========
/com,  Node J
/com,==========

/com, Element #28 (Pipe289 elements)
/com,************************

esel,s,elem,,28

etable,pxj_28,smisc,14
etable,vyj_28,smisc,19
etable,vzj_28,smisc,18
etable,txj_28,smisc,17
etable,myj_28,smisc,15
etable,mzj_28,smisc,16
esel,all


/com, Element #80 (Elbow290 elements)
/com,************************
esel,s,elem,,80

etable,pxj_80,smisc,36
etable,vyj_80,smisc,41
etable,vzj_80,smisc,40
etable,txj_80,smisc,39
etable,myj_80,smisc,37
etable,mzj_80,smisc,38
esel,all

allsel,all
/out,

/com, **********************************************
/com,  Element forces and moments at element 28, node i
/com, ************************************************

pretab,pxi_28,vyi_28,vzi_28,txi_28,myi_28,mzi_28
```

```
/com, **********************************************
/com,  Element forces and moments at element 28, node j
/com, ************************************************

pretab,pxj_28,vyj_28,vzj_28,txj_28,myj_28,mzj_28

/com, **********************************************
/com,  Element forces and moments at element 80, node i
/com, ************************************************

pretab,pxi_80,vyi_80,vzi_80,txi_80,myi_80,mzi_80

/com, **********************************************
/com,  Element forces and moments at element 80, node j
/com, ************************************************
pretab,pxj_80,vyj_80,vzj_80,txj_80,myj_80,mzj_80



/com,--------------------------------------------------------------------------------

/com, *****************************
/com,  Reaction forces
/com, ******************************

prrsol

allsel
finish
```

vm-nr1677-01-5a Input Listing

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/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-01-5a
/title,vm-nr1677-01-5a,NRC Piping Benchmark Problems,Volume 1,Problem 5

/com,*********************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,        NUREC/CR--1677-Vol.1
/com,                P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com, Elements used: Pipe289, Elbow290, Mass21
/com,
/com, Results:
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces and moments obtained from spectrum solution.
/com,
/com,*********************************************************************************

/out,scratch

/prep7
et,1,pipe289,,,                                                ! Element 1 - PIPE289   (Straight Pipe Element)
et,2,pipe289,,,                                                ! Element 2 - PIPE289   (Straight Pipe Element)
et,3,elbow290,,3                                                ! Element 3 - ELBOW290  (Pipe Bend Element)

et,4,combin14                                                 ! Element 4 - COMBIN14  (Spring Damper Element)
et,5,mass21                                                     ! Element 5 - MASS21    (Mass Element)


/com, Real Constants
/com,****************

r,      1,      1.00e7, 0.0,           0.0                                   ! Real Constant Set 1
```

```
r,      2,      450.00, 0.0,            0.0
r,      3,      800.00, 0.0,            0.0
r,      4,      600.00, 0.0,            0.0

sectype,5,pipe
secdata,14,0.438,16

sectype,7,pipe
secdata,12.75,0.375,16

sectype,8,pipe
secdata,12.75,1.312,16

sectype,10,pipe
secdata,12.75,2,16

r,      11,     2.8116, 2.8116, 2.8116
r,      12,     4.0432, 4.0432, 4.0432
r,      13,     2.5489, 2.5489, 2.5489
r,      14,     1.4063, 1.4063, 1.4063
r,      15,     1.4503, 1.4503, 1.4503
r,      16,     1.8685, 1.8685, 1.8685
r,      17,     2.8566, 2.8566, 2.8566
r,      18,     2.0246, 2.0246, 2.0246
r,      19,     6.7857, 6.7857, 6.7857
r,      20,     0.63406,        0.63406,        0.63406
r,      21,     0.59369,        0.59369,        0.59369
r,      22,     6.95390,        6.95390,        6.95390
r,      23,     3.73960,        3.73960,        3.73960

/com,------------------------------------------------------------------------------

/com, Material Properties
/com,**********************

mp,ex,1,2.62e7
mp,nuxy,1,.3

mp,ex,2,7.56e7
mp,nuxy,2,.3

mp,ex,3,2.52e7
mp,nuxy,3,.3

/com,------------------------------------------------------------------------------

/com, Nodes
/com,*******

k,1,0.0,0.0,0.0
k,2,18.636,0.0,-4.3680
k,3,23.424,0.0,-4.9200
k,4,26.400,0.0,-4.9200
k,5,47.400,0.0,-25.920
k,6,47.400,0.0,-79.920
k,7,68.400,0.0,-100.920
k,8,89.400,0.0,-79.920
k,9,89.400,0.0,-25.920
k,10,110.400,0.0,-4.920
k,11,146.400,0.0,-4.920
k,12,206.400,0.0,-4.920
k,13,245.400,0.0,-4.920
k,14,266.400,0.0,-25.920
k,15,266.400,0.0,-72.480
k,16,266.400,0.0,-87.732
k,17,272.436,-1.452,-102.636
k,18,323.280,-13.680,-154.560
k,19,327.960,-14.760,-159.360
k,20,336.816,-16.944,-168.396
k,21,349.884,-18.264,-173.856
k,22,370.884,-18.264,-173.856
k,23,391.884,-18.264,-173.856
```

```
k,24,370.884,30.696,-173.856
k,25,404.844,-18.264,-173.856
k,26,417.804,-18.264,-173.856
k,27,438.804,-18.264,-173.856
k,28,459.804,-18.264,-173.856
k,29,438.804,30.696,-173.856
k,30,472.236,-18.264,-173.856
k,31,485.148,-18.264,-179.316
k,32,507.300,-18.264,-202.128
k,33,519.840,-0.264,-215.040
k,34,245.400,12.000,-4.920
k,35,404.844,12.000,173.856
k,36,485.148,12.000,179.376
k,37,68.400,12.000,-100.920
k,38,323.280,12.000,-154.560
k,39,323.280,-13.680,-166.560
k,52,23.4192,0.000,16.080
k,53,26.400,0.000,-25.920
k,54,68.400,0.000,-79.920
k,55,68.400,0.000,-79.920
k,56,110.400,0.000,-25.920
k,57,245.400,0.000,-25.920
k,58,286.818,-4.91158,-87.7295
k,59,349.880,-14.0342,-156.360
k,60,472.2350,-18.2640,-191.856
k,61,507.299,-0.2640,-202.127

k,100,21,0,-4.78

k,111,31.835,0.0000,-5.6356
k,112,36.900,0.0000,-7.7335
k,113,41.249,0.0000,-11.071
k,114,44.587,0.0000,-15.420
k,115,46.684,0.0000,-20.485

k,121,48.116,0.0000,-85.355
k,122,50.213,0.0000,-90.420
k,123,53.551,0.0000,-94.769
k,124,57.900,0.0000,-98.107
k,125,62.965,0.0000,-100.20

k,131,73.835,0.0000,-100.20
k,132,78.900,0.0000,-98.107
k,133,83.249,0.0000,-94.769
k,134,86.587,0.0000,-90.420
k,135,88.684,0.0000,-85.355


k,141,90.116,0.0000,-20.485
k,142,92.213,0.0000,-15.420
k,143,95.551,0.0000,-11.071
k,144,99.900,0.0000,-7.7335
k,145,104.96,0.0000,-5.6356

k,151,250.84,0.0000,-5.6356
k,152,255.90,0.0000,-7.7335
k,153,260.25,0.0000,-11.071
k,154,263.59,0.0000,-15.420
k,155,265.68,0.0000,-20.485

k,106,268,-0.378,-95.8
k,107,343,-17.9,-172

k,181,474.63,-18.264,-174.02
k,182,476.98,-18.264,-174.49
k,183,479.25,-18.264,-175.28
k,184,481.39,-18.264,-176.36
k,185,483.37,-18.264,-177.71

k,191,510.55,-17.650,-205.47
k,192,513.57,-15.852,-208.58
k,193,516.17,-12.991,-211.26
```

```
k,194,518.16,-9.2633,-213.31
k,195,519.41,-4.9220,-214.60

/com,------------------------------------------------------------------------------

/com, Straight Pipe (Tangent Elements)
/com,**********************************

mat,1
type,1
secnum,5

l,1,2
l,3,4
l,5,6
l,8,9
l,10,11
l,11,12
l,12,13
l,14,15
l,15,16
l,17,18
l,18,19
l,19,20  !#12

lsel,s,line,,1,12
allsel,below,line
lesize,all,,,1
lmesh,all
allsel


/com,-----------------

mat,2
type,2
secnum,8

l,21,22
l,22,23
l,26,27
l,27,28  !#16

lsel,s,line,,13,16
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,-----------------

mat,3
type,1
secnum,8

l,23,25
l,25,26
l,28,30
l,31,32  !20

lsel,s,line,,17,20
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,-----------------

mat,3
type,2
secnum,10
```

```
l,22,24
l,27,29  !22

lsel,s,line,,21,22
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,-----------------

type,4
real,1

l,7,37  !23

lsel,s,line,,23
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,-----------------

type,4
real,1

l,18,38  !24

lsel,s,line,,24
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,-----------------

type,4
real,1

l,18,39  !25

lsel,s,line,,25
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,-----------------

type,4
real,2

l,13,34  !26

lsel,s,line,,26
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,-----------------

type,4
real,3

l,25,35  !27

lsel,s,line,,27
allsel,below,line
lesize,all,,,1
lmesh,all
```

```
allsel

/com,----------------

type,4
real,4

l,31,36  !28

lsel,s,line,,28
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,-------------------------------

/com, Pipe Bend Elements
/com,************************

mat,1
type,3
secnum,5

larch,2,3,100
larch,4,112,111
larch,112,114,113
larch,114,5,115
larch,6,122,121
larch,122,124,123
larch,124,7,125
larch,7,132,131
larch,132,134,133
larch,134,8,135
larch,9,142,141
larch,142,144,143
larch,144,10,145
larch,13,152,151
larch,152,154,153
larch,154,14,155
larch,16,17,106   !45

lsel,s,line,,29,45
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,----------------------

mat,1
type,3
secnum,7

larch,20,21,107   !46

lsel,s,line,,46
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,----------------------

mat,3
type,3
secnum,8

larch,30,182,181
larch,182,184,183
larch,184,31,185
larch,32,192,191
```

```
larch,192,194,193
larch,194,33,195  !52

lsel,s,line,,47,52
allsel,below,line
lesize,all,,,1
lmesh,all
allsel
/com,----------------------

/com, Mass Elements
/com,***************

type,5

real,11
en,351,5

real,12
en,352,54

real,13
en,353,13

real,14
en,354,14

real,15
en,355,16

real,16
en,356,18

real,17
en,357,21

real,18
en,358,26

real,19
en,359,33

real,20
en,360,50

real,21
en,361,42

real,22
en,362,38

real,20
en,363,52

real,23
en,364,47


/com, ************************************************************
/com,  Using ELBOW, to convert some PIPE289 to ELBOW290
/com, ************************************************************

elbow,on,,,sect



/com, ************************************************************
/com,  Manually convert some PIPE289 to ELBOW290 for different sect ID
/com, ************************************************************

esel,s,sec,,7
nsle
```

```
esln
esel,u,sec,,7
esel,u,ename,,21
esel,u,ename,,14
emodif,all,type,3
allsel

/com,----------------

/com, Constraints
/com,*************

dk,1,all,0.0,0.0
dk,33,all,0.0,0.0
dk,34,all,0.0,0.0
dk,35,all,0.0,0.0
dk,36,all,0.0,0.0
dk,37,all,0.0,0.0
dk,38,all,0.0,0.0
dk,39,all,0.0,0.0

save
finish

/com,----------------------------------------------------------------------------

/com,
/com,=============
/com,   Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,11
mxpand,,,,yes                                    ! Expand solutions with Element Calculation ON
solve
save
finish

/post1
/out,
/com, ******************************
/com,  Frequencies from Modal solve
/com, ******************************
set,list
finish

/out,scratch

/com,----------------------------------------------------------------------------

/com,
/com,================
/com,   Spectrum Solve
/com,================
/com,

/solution
antype,spectr                            ! Perform Spectrum Analysis
spopt,sprs                                       ! Single Point Excitation Response Spectrum
dmprat,0.02                                      ! Constant Damping Ratio
grp,0.0                                  ! Group Modes based on significance level
svtyp,2                                  ! Seismic Acceleration Response Loading
save

sed,1                                            ! Excitation in X direction
freq
freq,1,1.67,3.03,4,4.25,5,5.26,5.261,6.45
freq,6.451,7.14,10,11.76,15,20,25,30,35
freq,40,100
sv,0.02,4.64,9.27,27.82,46.37,66.83,115.92,185.47,425.04,425.04
```

```
sv,0.02,193.2,115.92,65.34,46.37,43.53,40.96,39.41,38.38,37.64
sv,0.02,37.09,37.09
solve

sed,,1                                          ! Excitation in Y direction
freq
freq,1,1.67,3.03,4,4.25,5,5.26,5.261,6.45
freq,6.451,7.14,10,11.76,15,20,25,30,35
freq,40,100
sv,0.02,3.09,6.18,18.55,30.91,44.55,77.28,123.65,283.36,283.36
sv,0.02,128.8,77.28,43.56,30.91,29.02,27.30,26.27,25.59,25.09
sv,0.02,24.73,24.73
solve

sed,,,1                                         ! Excitation in Z direction
freq
freq,1,1.67,3.03,4,4.25,5,5.26,5.261,6.45
freq,6.451,7.14,10,11.76,15,20,25,30,35
freq,40,100
sv,0.02,4.64,9.27,27.82,46.37,66.83,115.92,185.47,425.04,425.04
sv,0.02,193.2,115.92,65.34,46.37,43.53,40.96,39.41,38.38,37.64
sv,0.02,37.09,37.09
solve

/com,------------------------------------------------------------------------------

/post1
/input,,mcom

*GET,AdisX,NODE,54,U,X
*GET,AdisY,NODE,83,U,Y
*GET,AdisZ,NODE,81,U,Z
*GET,ArotX,NODE,20,ROT,X
*GET,ArotY,NODE,8,ROT,Y
*GET,ArotZ,NODE,10,ROT,Z
/out
/com, *=======================================================
/com, * Maximum nodal displacements and rotations comparsion
/com, *=======================================================
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com,---------------------------------------------------------------
/com,
/com, *=======================================================
/com, * Element Forces and Moments Comparison
/com, *=========================================================

/out,scratch
/com,==========
/com,    Node I
/com,==========

/com, Element #20 (Pipe289 elements)
/com,************************


esel,s,elem,,20
etable,pxi_20,smisc,1
etable,vyi_20,smisc,6
etable,vzi_20,smisc,5
etable,txi_20,smisc,4
etable,myi_20,smisc,2
etable,mzi_20,smisc,3
esel,all

/com, Element #50 (Elbow 290 elements)
/com,*************************
```

```
esel,s,elem,,50

etable,pxi_50,smisc,1
etable,vyi_50,smisc,6
etable,vzi_50,smisc,5
etable,txi_50,smisc,4
etable,myi_50,smisc,2
etable,mzi_50,smisc,3
esel,all


/com,==========
/com,  Node J
/com,==========

/com, Element #20 (Pipe289 elements)
/com,************************

esel,s,elem,,20

etable,pxj_20,smisc,14
etable,vyj_20,smisc,19
etable,vzj_20,smisc,18
etable,txj_20,smisc,17
etable,myj_20,smisc,15
etable,mzj_20,smisc,16
esel,all


/com, Element #50 (Elbow290 elements)
/com,************************
esel,s,elem,,50

etable,pxj_50,smisc,36
etable,vyj_50,smisc,41
etable,vzj_50,smisc,40
etable,txj_50,smisc,39
etable,myj_50,smisc,37
etable,mzj_50,smisc,38
esel,all

allsel,all
/out,

/com, **********************************************
/com,  Element forces and moments at element 20, node i
/com, ************************************************

pretab,pxi_20,vyi_20,vzi_20,txi_20,myi_20,mzi_20

/com, **********************************************
/com,  Element forces and moments at element 20, node j
/com, ************************************************

pretab,pxj_20,vyj_20,vzj_20,txj_20,myj_20,mzj_20

/com, **********************************************
/com,  Element forces and moments at element 50, node i
/com, ************************************************

pretab,pxi_50,vyi_50,vzi_50,txi_50,myi_50,mzi_50

/com, **********************************************
/com,  Element forces and moments at element 50, node j
/com, ************************************************
pretab,pxj_50,vyj_50,vzj_50,txj_50,myj_50,mzj_50



/com,----------------------------------------------------------------------------
```

```
/com, *****************************
/com,  Reaction forces
/com, ******************************

prrsol
finish
```

vm-nr1677-01-6a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-01-6a
/title,vm-nr1677-01-6a,NRC Piping Benchmark Problems,Volume 1,Problem 6

/com,****************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,        NUREC/CR--1677-Vol.1
/com,                P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com, Elements used: Pipe289, Elbow290, Mass21
/com,
/com, Results:
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces and moments obtained from spectrum solution.
/com,****************************************************************************

/out,scratch

/prep7

et,1,pipe289,,,                       ! Element 1 - PIPE289

et,2,pipe289,,,                       ! Element 2 - PIPE289
keyopt,2,1,1                           ! Temperatures represent Diametral Gradient

et,3,elbow290,,3                               ! Element 3 - ELBOW290

et,4,elbow290,,3                               ! Element 4 - ELBOW290
keyopt,4,1,1                           ! Temperatures represent Diametral Gradient

et,5,combin14                          ! Element 5 - COMBIN14

et,105,combin14                        ! Element 105 - COMBIN14
keyopt,105,3,1                         ! Torsional Spring Damper

et,6,mass21                                    ! Element 6 - MASS21


/com, *Real Constants*
/com,******************

sectype,6,pipe
secdata,30,0.85


sectype,8,pipe
secdata,32,0.905


r,      11,         9.92500000,      9.92500000,      9.92500000,
r,      12,         5.45300000,      5.45300000,      5.45300000,
r,      13,         4.88800000,      4.88800000,      4.88800000,
r,      14,         5.88800000,      5.88800000,      5.88800000,
r,      15,         5.37300000,      5.37300000,      5.37300000,
r,      16,         3.95000000,      3.95000000,      3.95000000,
```

```
r,      17,         2.43000000,      2.43000000,      2.43000000,
r,      18,         3.94100000,      3.94100000,      3.94100000,
r,      19,         7.60920000,      7.60920000,      7.60920000,
r,      20,         7.61200000,      7.61200000,      7.61200000,
r,      21,         7.61110000,      7.61110000,      7.61110000,
r,      22,         7.60100000,      7.60100000,      7.60100000,
r,      23,         10.2930000,      10.2930000,      10.2930000,
r,      24,         7.51800000,      7.51800000,      7.51800000,
r,      25,         3.87700000,      3.87700000,      3.87700000,
r,      26,         10.5280000,      10.5280000,      10.5280000,
r,     101,        0.1000000E20,     0.00000000,      0.00000000,
r,     102,        0.1000000E07,     0.00000000,      0.00000000,
r,     103,        0.2500000E06,     0.00000000,      0.00000000,
r,     104,        0.2000000E07,     0.00000000,      0.00000000,
r,     105,        0.4500000E06,     0.00000000,      0.00000000,
r,     106,        0.8000000E06,     0.00000000,      0.00000000,
r,     107,        0.1000000E10,     0.00000000,      0.00000000,
r,     108,        0.1000000E12,     0.00000000,      0.00000000,

/com,-----------------------------------------------------------------
/com,

/com, *Nodes*
/com,*********

k,       1,               126.000000,      483.996000,      705.840000
k,       2,               126.000000,      483.996000,      704.640000
k,       3,               126.000000,      528.996000,      659.640000
k,       4,               126.000000,      497.176195,      672.820195
k,       5,               126.000000,      567.996000,      659.640000
k,       6,               126.000000,      651.996000,      659.640000
k,       7,               126.000000,      735.996000,      659.640000
k,       8,               126.000000,      802.596000,      659.640000
k,       9,               126.000000,      869.196000,      659.640000
k,      10,               126.000000,      917.196000,      659.640000
k,      11,               126.000000,      965.196000,      659.640000
k,      12,               126.000000,      968.196000,      659.640000
k,      13,               169.860000,      1013.19600,      649.560000
k,      14,               138.846498,      1000.01701,      656.687590
k,      15,               173.928000,      1013.19600,      648.624000
k,      16,               229.836000,      1013.19600,      630.996000
k,      17,               283.992000,      1013.19600,      608.556000
k,      18,               335.988000,      1013.19600,      581.484000
k,      19,               385.428000,      1013.19600,      550.080000
k,      20,               431.940000,      1013.19600,      514.392000
k,      21,               475.164000,      1013.19600,      474.780000
k,      22,               514.776000,      1013.19600,      431.556000
k,      23,               550.464000,      1013.19600,      385.044000
k,      24,               581.964000,      1013.19600,      335.604000
k,      25,               609.036000,      1013.19600,      283.608000
k,      26,               631.474000,      1013.19600,      229.452000
k,      27,               649.104000,      1013.19600,      173.544000
k,      28,               661.788000,      1013.19600,      116.304000
k,      29,               669.444000,      1013.19600,      58.1760000
k,      30,               672.000000,      1013.19600,     -0.39600000
k,      31,               669.444000,      1013.19600,     -58.9680000
k,      32,               661.788000,      1013.19600,     -117.096000
k,      33,               649.104000,      1013.19600,     -174.336000
k,      34,               631.476000,      1013.19600,     -230.244000
k,      35,               609.036000,      1013.19600,     -284.400000
k,      36,               581.964000,      1013.19600,     -336.396000
k,      37,               550.596000,      1013.19600,     -385.572000
k,      38,               375.312000,      1013.19600,     -446.736000
k,      39,               473.553150,      1013.19600,     -446.529080
k,      40,               345.576000,      1013.19600,     -436.500000
k,      41,               262.368000,      1013.19600,     -407.844000
k,      42,               221.700000,      1013.19600,     -393.840000
k,      43,               179.160000,      968.196000,     -379.188000
k,      44,               191.619252,      1000.01318,     -383.479325
k,      45,               179.160000,      968.172000,     -379.188000
k,      76,               126.000000,      528.996000,      704.640000
k,      77,               169.857000,      968.196000,      649.561000
```

```
k,       78,                424.134000,      1013.20000,     -304.904000
k,       79,                221.707000,      968.196000,     -393.842000
k,      142,                127.000000,      965.196000,      659.640000
k,      143,                126.000000,      965.196000,      660.640000
k,      144,                515.776000,      1013.19600,      431.556000
k,      145,                514.776000,      1014.19600,      431.556000
k,      146,                514.776000,      1013.19600,      432.556000
k,      147,                662.788000,      1013.19600,      116.304000
k,      148,                661.788000,      1014.19600,      116.304000
k,      149,                661.788000,      1013.19600,      117.304000
k,      150,                661.788000,      1014.19600,     -117.096000
k,      151,                582.223000,      1013.19600,     -337.362000
k,      152,                180.160000,      968.196000,     -379.188000
k,      153,                179.160000,      969.196000,     -379.188000
k,      154,                179.160000,      968.196000,     -378.188000
k,      155,                180.160000,      968.196000,     -379.188000
k,      156,                179.160000,      969.196000,     -379.188000
k,      157,                179.160000,      968.196000,     -378.188000
k,      158,                127.000000,      483.996000,      705.840000
k,      159,                126.000000,      484.996000,      705.840000
k,      160,                126.000000,      483.996000,      706.840000

k,211,126.00,484.38,698.77
k,212,126.00,485.53,692.99
k,213,126.00,487.42,687.42
k,214,126.00,490.02,682.14
k,215,126.00,493.30,677.25

k,221,126.38,974.07,659.55
k,222,127.49,979.84,659.30
k,223,129.34,985.42,658.87
k,224,131.88,990.70,658.29
k,225,135.06,995.59,657.56


k,201,126,512,663


k,231,143.16,1003.9,655.70
k,232,147.93,1007.2,654.60
k,233,153.08,1009.8,653.42
k,234,158.51,1011.7,652.17
k,235,164.14,1012.8,650.88


k,241,216.15,1012.8,-391.93
k,242,210.69,1011.7,-390.05
k,243,205.42,1009.8,-388.23
k,244,200.43,1007.2,-386.51
k,245,195.80,1003.9,-384.92


k,251,187.95,995.59,-382.22
k,252,184.86,990.69,-381.15
k,253,182.40,985.42,-380.30
k,254,180.61,979.84,-379.69
k,255,179.52,974.07,-379.31


k,206,517,1010,-423
k,207,424,1010,-455


/com,------------------------------------------------------------------
/com,

/com, *Material Properties*
/com,**********************

mp,ex,1,29900000
mp,nuxy,1,.3
```

```
/com,-----------------------------------------------------------------
/com,

/com, *Straight Pipe (Tangent) Elements*
/com,***********************************
/com,

mat,1
type,1
secnum,6
l,1,2
l,3,5
l,5,6
l,6,7
l,7,8
l,8,9
l,9,10
l,10,11
l,11,12

l,13,15
l,15,16
l,16,17
l,17,18
l,18,19
l,19,20
l,20,21
l,21,22
l,22,23
l,23,24
l,24,25
l,25,26
l,26,27
l,27,28
l,28,29
l,29,30
l,30,31
l,31,32
l,32,33
l,33,34
l,34,35
l,35,36
l,36,37

l,38,40
l,40,41
l,41,42  !line #35

lsel,s,line,,1,35
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,----------------

mat,1
type,1
secnum,8
l,43,45  !36

lsel,s,line,,36
allsel,below,line
lesize,all,,,1
lmesh,all
allsel


/com,----------------
/com,

/com, *Pipe Bend Elements*
```

```
/com,**********************

mat,1
type,3
secnum,6
larch,2,212,211
larch,212,214,213
larch,214,4,215
larch,4,3,201
larch,12,222,221
larch,222,224,223
larch,224,14,225
larch,14,232,231
larch,232,234,233
larch,234,13,235  !46

lsel,s,line,,37,46
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,----------------

mat,1
type,3
secnum,8
larch,42,242,241
larch,242,244,243
larch,244,44,245
larch,44,252,251
larch,252,254,253
larch,254,43,255  !52

lsel,s,line,,47,52
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,----------------

mat,1
type,3
secnum,6
larch,37,39,206
larch,39,38,207  !54

lsel,s,line,,53,54
allsel,below,line
lesize,all,,,1
lmesh,all
allsel


/com,----------------
/com,

/com, *Spring Elements*
/com,********************


mat,1
type,5
real,101
l,1,158
l,1,159
l,1,160  !57


lsel,s,line,,55,57
allsel,below,line
```

```
lesize,all,,,1
lmesh,all
allsel

/com,----------------

mat,1
type,5
real,102
l,11,142
l,11,143  !59


lsel,s,line,,58,59
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,----------------

mat,1
type,5
real,103
l,22,144
l,22,146  !61


lsel,s,line,,60,61
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,----------------

mat,1
type,5
real,104
l,22,145
l,28,148
l,32,150  !64


lsel,s,line,,62,64
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,----------------

mat,1
type,5
real,105
l,28,147
l,28,149  !66


lsel,s,line,,65,66
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,----------------

mat,1
type,5
real,106
l,36,151  !67
```

```
lsel,s,line,,67
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,----------------

mat,1
type,5
real,107
l,45,152
l,45,153
l,45,154  !70


lsel,s,line,,68,70

allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,----------------

mat,1
type,105
real,108
l,45,155
l,45,156
l,45,157  !73

lsel,s,line,,71,73
allsel,below,line
lesize,all,,,1
lmesh,all
allsel


/com,----------------
/com,

/com, *Mass Elements*
/com,*****************

mat,1
type,6

real,11
en,975,5

real,12
en,976,7

real,13
en,977,9

real,14
en,978,11

real,15
en,979,15

real,16
en,980,19

real,17
en,981,21

real,18
en,982,22
```

```
real,19
en,983,26

real,19
en,984,30

real,20
en,985,34

real,21
en,986,38

real,21
en,987,42

real,21
en,988,46

real,21
en,989,50
real,21
en,990,54

real,21
en,991,58

real,22
en,992,62

real,23
en,993,66

real,24
en,994,68

real,25
en,995,69

real,26
en,996,71

/com,------------------------------------------------------------------
/com,


/com, ************************************************************
/com,  Using ELBOW, to convert some PIPE289 to ELBOW290
/com, ************************************************************

elbow,on,,,sect


/com, *Constraints*
/com,***************

dk,142,all,0
dk,143,all,0
dk,144,all,0
dk,145,all,0
dk,146,all,0
dk,147,all,0
dk,148,all,0
dk,149,all,0
dk,150,all,0
dk,151,all,0
dk,152,all,0
dk,153,all,0
dk,154,all,0
dk,155,all,0
dk,156,all,0
dk,157,all,0
```

```
dk,158,all,0
dk,159,all,0
dk,160,all,0

allsel,all
save
finish

/com,-------------------------------------------------------------------

/com,
/com,=============
/com,   Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,31
mxpand,,,,yes
solve
save

/post1
/out,
/com, ******************************
/com,  Frequencies from Modal solve
/com, ******************************
set,list
finish

/out,scratch
/com,
/com,================
/com,   Spectrum Solve
/com,================
/com,

/solution
antype,spectr                                    ! Perform Spectrum Analysis
spopt,sprs                                               ! Single Point Excitation Response Spectrum
dmprat,0.02                                              ! Constant Damping Ratio
grp,0.001                                                ! Group Modes based on Singificance Level
svtyp,2                                          ! Seismic Acceleration Response Loading

sed,1                                                    ! Excitation in X direction
freq
freq,0.5,1.1,1.11,8.0,8.01,10,15,20,25
freq,30,35,40,45,50,55,60,65,70
freq,75,80,85,90,95,100,200
sv,0.02,27.05,135.20,649.10,649.10,81.14,75.73,68.52,64.92,62.75
sv,0.02,61.31,60.28,59.51,58.91,58.43,58.03,57.71,57.43,57.19
sv,0.02,56.98,56.80,56.64,56.50,56.38,56.26,54.53
solve

sed,,1                                           ! Excitation in Y direction
freq
freq,0.5,1.56,1.563,4.76,4.762,200
sv,0.02,108.2,143,1190,1190,73.42,73.42
solve

sed,,,1                                          ! Excitation in Z direction
freq
freq,0.5,1.1,1.11,8.0,8.01,10,15,20,25
freq,30,35,40,45,50,55,60,65,70
freq,75,80,85,90,95,100,200
sv,0.02,27.05,135.20,649.10,649.10,81.14,75.73,68.52,64.92,62.75
sv,0.02,61.31,60.28,59.51,58.91,58.43,58.03,57.71,57.43,57.19
sv,0.02,56.98,56.80,56.64,56.50,56.38,56.26,54.53

solve
finish
```

```
/com,------------------------------------------------------------------

/post1
/input,,mcom                     ! Compute SSRS
*GET,AdisX,NODE,58,U,X
*GET,AdisY,NODE,107,U,Y
*GET,AdisZ,NODE,10,U,Z
*GET,ArotX,NODE,1,ROT,X
*GET,ArotY,NODE,1,ROT,Y
*GET,ArotZ,NODE,71,ROT,Z
/out
/com, *=========================================================
/com, * Maximum nodal displacements and rotations comparsion
/com, *=========================================================
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com, *=========================================================
/com, * Element Forces and Moments Comparison
/com, *===========================================================

/out,scratch
/com,==========
/com,    Node I
/com,==========

/com, Element #28 (Pipe289 elements)
/com,************************


esel,s,elem,,28
etable,pxi_28,smisc,1
etable,vyi_28,smisc,6
etable,vzi_28,smisc,5
etable,txi_28,smisc,4
etable,myi_28,smisc,2
etable,mzi_28,smisc,3
esel,all

/com, Element #50 (Elbow 290 elements)
/com,*************************

esel,s,elem,,50

etable,pxi_50,smisc,1
etable,vyi_50,smisc,6
etable,vzi_50,smisc,5
etable,txi_50,smisc,4
etable,myi_50,smisc,2
etable,mzi_50,smisc,3
esel,all


/com,==========
/com,  Node J
/com,==========

/com, Element #28 (Pipe289 elements)
/com,************************

esel,s,elem,,28

etable,pxj_28,smisc,14
etable,vyj_28,smisc,19
etable,vzj_28,smisc,18
etable,txj_28,smisc,17
etable,myj_28,smisc,15
```

```
etable,mzj_28,smisc,16
esel,all


/com, Element #50 (Elbow290 elements)
/com,************************
esel,s,elem,,50

etable,pxj_50,smisc,36
etable,vyj_50,smisc,41
etable,vzj_50,smisc,40
etable,txj_50,smisc,39
etable,myj_50,smisc,37
etable,mzj_50,smisc,38
esel,all

allsel,all
/out,

/com, **********************************************
/com,  Element forces and moments at element 28, node i
/com, ************************************************

pretab,pxi_28,vyi_28,vzi_28,txi_28,myi_28,mzi_28

/com, **********************************************
/com,  Element forces and moments at element 28, node j
/com, ************************************************

pretab,pxj_28,vyj_28,vzj_28,txj_28,myj_28,mzj_28

/com, **********************************************
/com,  Element forces and moments at element 50, node i
/com, ************************************************

pretab,pxi_50,vyi_50,vzi_50,txi_50,myi_50,mzi_50

/com, **********************************************
/com,  Element forces and moments at element 50, node j
/com, ************************************************
pretab,pxj_50,vyj_50,vzj_50,txj_50,myj_50,mzj_50


/com,------------------------------------------------------------------------

/com, *****************************
/com,  Reaction forces
/com, ******************************

prrsol

finish
```

vm-nr1677-01-7a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-01-7a
/title,vm-nr1677-01-7a,NRC Piping Benchmark Problems,Volume 1,Problem 7
/com,*****************************************************************************
/com,
/com, Reference: Piping Benchmark Problems
/com,        NUREC/CR--1677-Vol.1
/com,                P.Bezier, M.Hartzman, M.Reich
/com,            August 1980
/com,
/com, Elements used: Pipe288, Elbow290, Mass21, Combin14
/com,
/com, Results comparsion:
```

```
/com, The following results are compared against NRC piping benchmark values
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces and moments obtained from spectrum solution.
/com,
/com,*******************************************************************************

/out,scratch

/prep7
et,1,pipe289                            ! Element 1 - PIPE289
et,3,pipe289                            ! Element 3 - PIPE289
et,5,pipe289                            ! Element 5 - PIPE289
et,7,elbow290,,3                            ! Element 7 - ELBOW290
et,9,mass21                                 ! Element 9 - MASS21
et,10,combin14                         ! Element 10 - COMBIN14
et,11,combin14                         ! Element 11 - COMBIN14
keyopt,11,3,1                               ! Torsional Spring

/com,-------------------------------------------------------------------------------

/com, Real Constants
/com,****************


sectype,2,pipe
secdata,4.5,0.337

sectype,4,pipe
secdata,3.5,0.3


r,       1,         1.00000000,     0.000000000,     0.000000000
r,       6,         0.47179000,     0.471790000,     0.471790000
r,       7,         0.37604000,     0.376040000,     0.376040000
r,       8,         0.40399000,     0.403990000,     0.403990000
r,       9,         0.35016000,     0.350160000,     0.350160000
r,      10,         0.22179000,     0.221790000,     0.221790000
r,      11,         0.33799000,     0.337990000,     0.337990000
r,      12,         0.14441000,     0.144410000,     0.144410000
r,      13,         0.26889000,     0.268890000,     0.268890000
r,      14,         0.29011000,     0.290110000,     0.290110000
r,      15,         0.12733000,     0.127330000,     0.127330000
r,      16,         0.22386000,     0.223860000,     0.223860000
r,      17,         0.20990000,     0.209900000,     0.209900000
r,      18,         0.28620000,     0.286200000,     0.286200000
r,      19,         0.19358000,     0.193580000,     0.193580000
r,      20,         0.18737000,     0.187370000,     0.187370000
r,      21,         0.31366000,     0.313660000,     0.313660000
r,      22,         0.29736000,     0.297360000,     0.297360000
r,      23,         1.00000E09,     0.000000000,     0.000000000
r,      24,         1.00000E11,     0.000000000,     0.000000000

/com,-------------------------------------------------------------------------------

/com, Nodes
/com,*******

k,       1,                0.00000000,      0.00000000,      0.00000000
k,       2,                0.00000000,     -6.00000000,      0.00000000
k,       3,                0.00000000,     -12.0000000,     -6.00000000
k,       4,                0.00000000,     -12.0000000,     -38.0400000
k,       5,                0.00000000,     -12.0000000,     -54.0000000
k,       6,                0.00000000,     -18.0000000,     -60.0000000
k,       7,                0.00000000,     -36.0000000,     -60.0000000
k,       8,                0.00000000,     -65.0400000,     -60.0000000
k,       9,                0.00000000,     -71.0400000,     -54.0000000
k,      10,                0.00000000,     -71.0400000,     -36.0000000
k,      11,                0.00000000,     -71.0400000,     -6.00000000
k,      12,               -6.00000000,     -71.0400000,      0.00000000
k,      13,               -21.9600000,     -71.0400000,      0.00000000
k,      14,               -57.9600000,     -71.0400000,      0.00000000
```

```
k,      15,              -117.000000,     -71.0400000,      0.00000000
k,      16,              -165.000000,     -71.0400000,      0.00000000
k,      17,              -139.680000,     -71.0400000,     -22.6800000
k,      18,              -141.000000,     -71.0400000,     -25.8600000
k,      19,              -141.000000,     -71.0400000,     -46.5600000
k,      20,              -141.000000,     -71.0400000,     -82.5600000
k,      21,              -141.000000,     -71.0400000,     -102.060000
k,      22,              -136.500000,     -71.0400000,     -106.560000
k,      23,              -122.460000,     -71.0400000,     -106.560000
k,      24,              -97.4400000,     -71.0400000,     -106.560000
k,      25,              -92.9400000,     -75.5400000,     -106.560000
k,      26,              -92.9400000,     -91.0800000,     -106.560000
k,      27,              -92.9400000,     -107.040000,     -106.560000
k,      28,              -213.000000,     -71.0400000,      0.00000000
k,      29,              -255.000000,     -71.0400000,      0.00000000
k,      30,              -259.080000,     -71.0400000,      0.00000000
k,      31,              -277.680000,     -71.0400000,     -22.6800000
k,      32,              -279.000000,     -71.0400000,     -25.8600000
k,      33,              -279.000000,     -71.0400000,     -46.5600000
k,      34,              -279.000000,     -71.0400000,     -82.5600000
k,      35,              -279.000000,     -71.0400000,     -102.060000
k,      36,              -274.500000,     -71.0400000,     -106.560000
k,      37,              -260.460000,     -71.0400000,     -106.560000
k,      38,              -235.440000,     -71.0400000,     -106.560000
k,      39,              -230.940000,     -75.5400000,     -106.560000
k,      40,              -230.940000,     -91.0800000,     -106.560000
k,      41,              -230.940000,     -107.040000,     -106.560000
k,      42,              -263.040000,     -71.0400000,      0.00000000
k,      43,              -315.000000,     -71.0400000,      0.00000000
k,      44,              -375.000000,     -71.0400000,      0.00000000
k,      45,              -412.500000,     -71.0400000,      0.00000000
k,      46,              -417.000000,     -71.0400000,     -4.50000000
k,      47,              -417.000000,     -71.0400000,     -18.1200000
k,      48,              -417.000000,     -71.0400000,     -78.1200000
k,      49,              -417.000000,     -71.0400000,     -102.180000
k,      50,              -412.500000,     -71.0400000,     -106.680000
k,      51,              -398.460000,     -71.0400000,     -106.680000
k,      52,              -373.440000,     -71.0400000,     -106.680000
k,      53,              -368.940000,     -75.5400000,     -106.680000
k,      54,              -368.940000,     -91.0800000,     -106.680000
k,      55,              -368.940000,     -107.040000,     -106.680000
k,      68,               0.00000000,     -6.00000000,     -6.00000000
k,      69,               0.00000000,     -18.0000000,     -54.0000000
k,      70,               0.00000000,     -65.0400000,     -54.0000000
k,      71,              -6.00000000,     -71.0400000,     -6.00000000
k,      72,              -136.500000,     -71.0400000,     -102.060000
k,      73,              -97.4400000,     -75.5400000,     -106.560000
k,      74,              -136.500000,     -71.0400000,     -25.8640000
k,      75,              -274.500000,     -71.0400000,     -102.060000
k,      76,              -235.440000,     -75.5400000,     -106.560000
k,      77,              -274.500000,     -71.0400000,     -25.8640000
k,      78,              -412.500000,     -71.0400000,     -4.50000000
k,      79,              -412.500000,     -71.0400000,     -102.180000
k,      80,              -373.440000,     -75.5400000,     -106.680000
k,     141,               0.00000000,     -37.0000000,     -60.0000000
k,     142,              -141.000000,     -72.0400000,     -82.5600000
k,     143,              -279.000000,     -72.0400000,     -82.5600000
k,     144,              -417.000000,     -72.0400000,     -78.1200000
k,     145,              -21.9600000,     -72.0400000,      0.00000000
k,     146,              -375.000000,     -72.0400000,      0.00000000
k,     147,              -93.9400000,     -107.040000,     -106.560000
k,     148,              -93.9400000,     -107.040000,     -106.560000
k,     149,              -92.9400000,     -108.040000,     -106.560000
k,     150,              -92.9400000,     -108.040000,     -106.560000
k,     151,              -92.9400000,     -107.040000,     -107.560000
k,     152,              -92.9400000,     -107.040000,     -107.560000
k,     153,              -214.000000,     -71.0400000,      0.00000000
k,     154,              -214.000000,     -71.0400000,      0.00000000
k,     155,              -213.000000,     -72.0400000,      0.00000000
k,     156,              -213.000000,     -72.0400000,      0.00000000
k,     157,              -213.000000,     -71.0400000,     -1.00000000
k,     158,              -213.000000,     -71.0400000,     -1.00000000
```

```
k,     159,              -231.940000,     -107.040000,     -106.560000
k,     160,              -231.940000,     -107.040000,     -106.560000
k,     161,              -230.940000,     -108.040000,     -106.560000
k,     162,              -230.940000,     -108.040000,     -106.560000
k,     163,              -230.940000,     -107.040000,     -107.560000
k,     164,              -230.940000,     -107.040000,     -107.560000
k,     165,              -369.940000,     -107.040000,     -106.680000
k,     166,              -369.940000,     -107.040000,     -106.680000
k,     167,              -368.940000,     -108.040000,     -106.680000
k,     168,              -368.940000,     -108.040000,     -106.680000
k,     169,              -368.940000,     -107.040000,     -107.680000
k,     170,              -368.940000,     -107.040000,     -107.680000

k,231,0,-7.5529,-0.20445
k,232,0,-9,-0.80385
k,233,0,-10.243,-1.7574
k,234,0,-11.196,-3
k,235,0,-11.796,-4.4471

k,561,0,-12.204,-55.553
k,562,0,-12.804,-57
k,563,0,-13.757,-58.243
k,564,0,-15,-59.196
k,565,0,-16.447,-59.796

k,891,0,-66.593,-59.796
k,892,0,-68.04,-59.196
k,893,0,-69.283,-58.243
k,894,0,-70.236,-57
k,895,0,-70.836,-55.553

k,281,-0.20445,-71.04,-4.4471
k,282,-0.80385,-71.04,-3
k,283,-1.7574,-71.04,-1.7574
k,284,-3,-71.04,-0.80385
k,285,-4.4471,-71.04,-0.20445

k,291,-140.85,-71.04,-103.22
k,292,-140.4,-71.04,-104.31
k,293,-139.68,-71.04,-105.24
k,294,-138.75,-71.04,-105.96
k,295,-137.66,-71.04,-106.41

k,301,-96.275,-71.193,-106.56
k,302,-95.19,-71.643,-106.56
k,303,-94.258,-72.358,-106.56
k,304,-93.543,-73.29,-106.56
k,305,-93.093,-74.375,-106.56

k,311,-140.07,-71.04,-23.122
k,312,-140.4,-71.04,-23.611
k,313,-140.66,-71.04,-24.139
k,314,-140.85,-71.04,-24.696
k,315,-140.96,-71.04,-25.273


k,321,-278.85,-71.04,-103.22
k,322,-278.4,-71.04,-104.31
k,323,-277.68,-71.04,-105.24
k,324,-276.75,-71.04,-105.96
k,325,-275.66,-71.04,-106.41

k,331,-234.28,-71.193,-106.56
k,332,-233.19,-71.643,-106.56
k,333,-232.26,-72.358,-106.56
k,334,-231.54,-73.29,-106.56
k,335,-231.09,-74.375,-106.56

k,341,-278.07,-71.040,-23.122
k,342,-278.40,-71.040,-23.611
k,343,-278.66,-71.040,-24.139
k,344,-278.85,-71.040,-24.696
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k,345,-278.96,-71.040,-25.273

k,351,-413.66,-71.040,-0.15333
k,352,-414.75,-71.040,-0.60289
k,353,-415.68,-71.040,-1.3180
k,354,-416.40,-71.040,-2.2500
k,355,-416.85,-71.040,-3.3353

k,361,-416.85,-71.040,-103.34
k,362,-416.40,-71.040,-104.43
k,363,-415.68,-71.040,-105.36
k,364,-414.75,-71.040,-106.08
k,365,-413.66,-71.040,-106.53

k,371,-372.28,-71.193,-106.68
k,372,-371.19,-71.643,-106.68
k,373,-370.26,-72.358,-106.68
k,374,-369.54,-73.290,-106.68
k,375,-369.09,-74.375,-106.68

/com,---------------------------------------------------------------------------

/com, Material Properties
/com,********************

mp,ex,1,2.7e7
mp,nuxy,1,.3

mp,ex,2,8.1e7
mp,nuxy,2,.3

/com,---------------------------------------------------------------------------

/com, Straight Pipe (Tangent Elements)
/com,*********************************

mat,1
type,1
secnum,2
l,1,2
l,3,4
l,6,7
l,7,8
l,9,10
l,10,11
l,13,14
l,16,28
l,30,42  !Line #9

lsel,s,line,,1,9
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,----------------

mat,1
type,1
secnum,4
l,18,19
l,19,20
l,20,21
l,23,24
l,25,26
l,32,33
l,33,34
l,34,35
l,37,38
l,39,40
l,42,43
l,43,44
```

```
l,44,45
l,46,47
l,47,48
l,48,49
l,51,52
l,53,54  !#27

lsel,s,line,,10,27
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,-----------------

mat,1
type,5
secnum,2
l,14,15
l,15,16
l,28,29
l,29,30  !#31

lsel,s,line,,28,31
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,-----------------

mat,1
type,5
secnum,4
l,15,17
l,29,31  !#33

lsel,s,line,,32,33
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,-----------------

mat,2
type,1
secnum,4
l,26,27
l,40,41
l,54,55  !#36

lsel,s,line,,34,36
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,-----------------

mat,2
type,3
secnum,2
l,4,5
l,12,13  !#38

lsel,s,line,,37,38
allsel,below,line
lesize,all,,,1
lmesh,all
allsel
```

```
/com,-----------------

mat,2
type,3
secnum,4
l,22,23
l,36,37
l,50,51  !#41

lsel,s,line,,39,41
allsel,below,line
lesize,all,,,1
lmesh,all
allsel


/com, Pipe Bend Elements
/com,********************

mat,1
type,7
secnum,2
larch,2,232,231
larch,232,234,233
larch,234,3,235
larch,5,562,561
larch,562,564,563
larch,564,6,565
larch,8,892,891
larch,892,894,893
larch,894,9,895
larch,11,282,281
larch,282,284,283
larch,284,12,285  !#53

lsel,s,line,,42,53
allsel,below,line
lesize,all,,,1
lmesh,all
allsel

/com,-----------------

mat,1
type,7
secnum,4
larch,21,292,291
larch,292,294,293
larch,294,22,295
larch,24,302,301
larch,302,304,303
larch,304,25,305
larch,17,312,311
larch,312,314,313
larch,314,18,315
larch,35,322,321
larch,322,324,323
larch,324,36,325
larch,38,332,331
larch,332,334,333
larch,334,39,335
larch,31,342,341
larch,342,344,343
larch,344,32,345
larch,45,352,351
larch,352,354,353
larch,354,46,355
larch,49,362,361
larch,362,364,363
larch,364,50,365
larch,52,372,371
larch,372,374,373
```

```
larch,374,53,375 !#80

lsel,s,line,,54,80
allsel,below,line
lesize,all,,,1
lmesh,all
allsel



/com, *Spring Elements*
/com,******************

mat,1
type,10
real,1
l,7,141
l,20,142
l,34,143
l,48,144  !#84

lsel,s,line,,81,84
allsel,below,line
lesize,all,,,1
lmesh,all
allsel


/com,-----------------

mat,1
type,10
real,23
l,13,145
l,44,146
l,27,147
l,27,149
l,27,151
l,28,153
l,28,155
l,28,157
l,41,159
l,41,161
l,41,163
l,55,165
l,55,167
l,55,169  !#98

lsel,s,line,,85,98
allsel,below,line
lesize,all,,,1
lmesh,all
allsel


/com,-----------------

mat,1
type,11
real,24
l,27,148
l,27,150
l,27,152
l,28,154
l,28,156
l,28,158
l,41,160
l,41,162
l,41,164
l,55,166
l,55,168
l,55,170  !#110
```

```
lsel,s,line,,99,110
allsel,below,line
lesize,all,,,1
lmesh,all
allsel


/com, Mass Elements
/com,***************

type,9

real,6
en,967,5

real,7
en,968,8

real,8
en,969,13

real,9
en,970,17

real,10
en,971,18

real,11
en,972,71

real,12
en,973,27

real,13
en,974,29

real,14
en,975,33

real,15
en,976,37

real,16
en,977,20

real,17
en,978,21

real,18
en,979,74

real,12
en,980,40

real,11
en,981,42

real,14
en,982,46

real,15
en,983,50

real,19
en,984,52

real,20
en,985,54

real,20
en,986,59
```

```
real,21
en,987,61

real,22
en,988,65

real,15
en,989,69

/com,--------------------------------------------------------------------------------
/com, ************************************************************
/com,  Using ELBOW, to convert some PIPE289 to ELBOW290
/com, ************************************************************

elbow,on,,,sect

/com, Constraints
/com,*************

dk,1,all,0
dk,141,all,0
dk,142,all,0
dk,143,all,0
dk,144,all,0
dk,145,all,0
dk,146,all,0
dk,147,all,0
dk,148,all,0
dk,149,all,0
dk,150,all,0
dk,151,all,0
dk,152,all,0
dk,153,all,0
dk,154,all,0
dk,155,all,0
dk,156,all,0
dk,157,all,0
dk,158,all,0
dk,159,all,0
dk,160,all,0
dk,161,all,0
dk,162,all,0
dk,163,all,0
dk,164,all,0
dk,165,all,0
dk,166,all,0
dk,167,all,0
dk,168,all,0
dk,169,all,0
dk,170,all,0

allsel,all
save
finish

/com,--------------------------------------------------------------------------------

/com,
/com,=============
/com,   Modal Solve
/com,=============
/com,

/solution
antype,modal
modopt,lanb,22
mxpand,,,,yes
solve
finish

/post1
```

```
/out,
/com, ******************************
/com,  Frequencies from Modal solve
/com, ******************************
set,list
finish

/out,scratch
/com,------------------------------------------------------------------------

/com,
/com,================
/com,   Spectrum Solve
/com,================
/com,

/solution
antype,spectr                            ! Perform Spectrum Analysis
spopt,sprs                                      ! Single Point Excitation Response Spectrum
dmprat,0.02                                     ! Constant Damping Ratio
grp,0.001                                       ! Group Modes based on Significance level
svtyp,2                                  ! Seismic Acceleration Response Loading

sed,1                                           ! Excitation in X direction
freq
freq,0.83,0.91,1,1.11,1.24,1.72,2,2.86,3.23
freq,5,6,7,7.8,8.2,9,9.3,10,100
sv,0.02,27.05,38.64,69.55,173.88,656.88,734.16,212.52,135.24,637.56
sv,0.02,329.5,236.4,169.9,129.0,111.54,81.26,71.25,50.23,50.23
solve

sed,,1                                   ! Excitation in Y direction
freq
freq,0.91,1.25,1.43,1.67,1.92,2.38,2.70,3.13,4.55
freq,5,6,7,7.8,8.2,9,9.3,10,100
sv,0.02,46.37,77.28,115.92,231.84,985.32,830.76,830.76,386.4,115.92
sv,0.02,109.48,98.75,91.08,86.36,84.35,80.86,79.70,77.28,77.28
solve

sed,,,1                                  ! Excitation in Z direction
freq
freq,0.83,0.91,1,1.11,1.24,1.72,2,2.86,3.23
freq,5,6,7,7.8,8.2,9,9.3,10,100
sv,0.02,27.05,38.64,69.55,173.88,656.88,734.16,212.52,135.24,637.56
sv,0.02,329.5,236.4,169.9,129.0,111.54,81.26,71.25,50.23,50.23
solve
fini

/com,------------------------------------------------------------------------

/post1
/input,,mcom


/com,-----------------------------------

/com, *=======================================================
/com, * Maximum nodal displacements and rotations comparsion
/com, *=========================================================

/com, Solution obtained from Mechanical APDL
/com, ***************************

*GET,AdisX,NODE,8,U,X
*GET,AdisY,NODE,8,U,Y
*GET,AdisZ,NODE,11,U,Z
*GET,ArotX,NODE,7,ROT,X
*GET,ArotY,NODE,14,ROT,Y
*GET,ArotZ,NODE,50,ROT,Z

/out,
/com, *=======================================================
```

```
/com, * Maximum nodal displacements and rotations comparsion
/com, *========================================================
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com, *========================================================
/com, * Element Forces and Moments Comparison
/com, *==========================================================

/out,scratch
/com,==========
/com,    Node I
/com,==========

/com, Element #28 (Pipe289 elements)
/com,************************


esel,s,elem,,28
etable,pxi_28,smisc,1
etable,vyi_28,smisc,6
etable,vzi_28,smisc,5
etable,txi_28,smisc,4
etable,myi_28,smisc,2
etable,mzi_28,smisc,3
esel,all

/com, Element #50 (Elbow 290 elements)
/com,*************************

esel,s,elem,,50

etable,pxi_50,smisc,1
etable,vyi_50,smisc,6
etable,vzi_50,smisc,5
etable,txi_50,smisc,4
etable,myi_50,smisc,2
etable,mzi_50,smisc,3
esel,all


/com,==========
/com,  Node J
/com,==========

/com, Element #28 (Pipe289 elements)
/com,************************

esel,s,elem,,28

etable,pxj_28,smisc,14
etable,vyj_28,smisc,19
etable,vzj_28,smisc,18
etable,txj_28,smisc,17
etable,myj_28,smisc,15
etable,mzj_28,smisc,16
esel,all


/com, Element #50 (Elbow290 elements)
/com,************************
esel,s,elem,,50

etable,pxj_50,smisc,36
etable,vyj_50,smisc,41
etable,vzj_50,smisc,40
etable,txj_50,smisc,39
etable,myj_50,smisc,37
```

```
etable,mzj_50,smisc,38
esel,all

allsel,all
/out,

/com, **********************************************
/com,  Element forces and moments at element 28, node i
/com, ************************************************

pretab,pxi_28,vyi_28,vzi_28,txi_28,myi_28,mzi_28

/com, **********************************************
/com,  Element forces and moments at element 28, node j
/com, ************************************************

pretab,pxj_28,vyj_28,vzj_28,txj_28,myj_28,mzj_28

/com, **********************************************
/com,  Element forces and moments at element 50, node i
/com, ************************************************

pretab,pxi_50,vyi_50,vzi_50,txi_50,myi_50,mzi_50

/com, **********************************************
/com,  Element forces and moments at element 50, node j
/com, ************************************************
pretab,pxj_50,vyj_50,vzj_50,txj_50,myj_50,mzj_50


/com,---------------------------------------------------------------------------

/com, *****************************
/com,  Reaction forces
/com, ******************************

prrsol

finish
```

vm-nr1677-02-1a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-02-1a
/title,vm-nr1677-02-1a,NRC piping benchmarks problems,Volume II,Problem 1a
/com, ***************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com, Element used: Pipe289, Elbow290, Combin14
/com,
/com, Results :
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, *******************************************************************************

/out,scratch


/PREP7

YoungModulus1 = .258e+8                       ! Young's Modulus
```

```
Nu = 0.3                                        ! Poissons ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu))        ! Shear Modulus
WMass = 1.042868e-03                            ! Density

WTick=0.216                                     ! Wall Thickness
OD=3.5                                          ! Outer Diameter

RADCUR=48.003                                   ! Radius curvature
temp=60                                         ! Temperature
maxm=15                                         ! Number of modes to extract

et,1,pipe289,,,                                 ! Straight pipe elements
et,2,elbow290,,6                                ! Curved pipe elements

et,3,combin14                               ! Spring-damper elements
keyopt,3,2,1                                    ! UX Degree Of Freedom
et,4,combin14,                                  ! Spring-damper elements
keyopt,4,2,2                                    ! UY Degree Of Freedom
et,5,combin14                               ! Spring-damper elements
keyopt,5,2,3                                    ! UZ Degree Of Freedom
et,6,combin14                                   ! Spring-damper elements
keyopt,6,2,1                                    ! UX Degree Of Freedom
et,7,combin14                                   ! Spring-damper elements
keyopt,7,2,2                                    ! UY Degree Of Freedom

/com,
/com, Real Constants
/com,****************

sectype,1,PIPE,ctube
secdata,OD,WTick,24

r,3,0.2e+8                                      ! Stiffness
r,4,0.2e+8                                      ! Stiffness
r,5,0.2e+8                                      ! Stiffness
r,6,0.2e+5                                      ! Stiffness
r,7,0.2e+5                                      ! Stiffness


/com,------------------------------------------------------------------------------

/com,
/com, Material Properties
/com,*********************

mp,ex,1,YoungModulus1
mp,nuxy,1,Nu
mp,gxy,1,ShearModulus1
mp,dens,1,WMass

mp,ex,2,YoungModulus1
mp,nuxy,2,Nu
mp,gxy,2,ShearModulus1
mp,dens,2,WMass

/com,------------------------------------------------------------------------------

/com, Keypoints
/com,***********

k,1,0,0,0
k,2,0,12,0
k,3,35.687,60,32.110
k,4,55,60,49.5
k,5,74.329,60,66.882
k,6,110,12,99
k,7,110,0,99
k,8,110,-24,99,
k,9,110,-48,99,
k,10,110,-72,99
k,11,110,-96,99
k,12,110,-120,99
```

```
k,13,110,-144,99
k,14,110,-168,99
k,15,110,-198,99
k,16,110,-228,99
k,17,110,-252,99
k,18,110,-276,99
k,19,110,-300,99
k,20,110,-324,99
k,21,99.6,-349.4,99
k,22,89.2,-374.8,99
k,23,78.8,-400,99
k,24,68.4,-425.6,99
k,25,58,-451,99
k,26,58,-475,99
k,27,58,-487,99
k,28,103.537,-535,114.179
k,29,124.269,-535,121.1
k,30,145,-535,128
k,31,184.975,-535,123.615
k,32,214.8,-536,102.8
k,33,254.585,-535,81.849
k,34,279.312,-535,75
k,35,331,-535,75
k,36,383,-535,75

/com,
/com, Elastic support Keypoints
/com,***************************

k,37,10,0,0
k,38,0,10,0
k,39,0,0,10
k,40,55,70,49.5
k,41,110,0,109
k,42,120,0,99
k,43,110,-168,109
k,44,120,-168,109
k,45,110,-324,109
k,46,120,-324,99
k,47,58,-475,109
k,48,68,-475,99
k,49,103.537,-545,114.179
k,50,103.537,-535,104.179
k,51,393,-535,75
k,52,383,-545,75
k,53,383,-535,85

/com,----------------------------------------------------------------------------

/com,
/com, Modeling of Straight Pipe (Tangent)
/com,************************************

l, 1, 2
l, 3, 4
l, 4, 5
l, 6, 7
l, 7, 8
l, 8, 9
l, 9,10
l,10,11
l,11,12
l,12,13
l,13,14
l,14,15
l,15,16
l,16,17
l,17,18
l,18,19
l,19,20
l,20,21
l,21,22
```

```
l,22,23
l,23,24
l,24,25
l,25,26
l,26,27
l,28,29
l,29,30
l,31,32
l,32,33
l,34,35
l,35,36             ! line number 30

/com,
/com, Modeling of Pipe Bend
/com,**********************

larch,2,3,4,RADCUR
larch,5,6,4,RADCUR
larch,27,28,26,RADCUR
larch,30,31,29,RADCUR
larch,33,34,32,RADCUR           ! line number 35

/com, Elastic supports and anchors
/com,*****************************

l,1,37                      ! 36
l,36,51                     ! 37
l,4,40                      ! 38
l,7,41                      ! 39
l,26,47                     ! 40
l,28,49                     ! 41

l,1,38                      ! 42
l,36,52                     ! 43
l,7,42                      ! 44
l,26,48                     ! 45
l,28,50                     ! 46

l,1,39                      ! 47
l,36,53                     ! 48

l,14,43                     ! 49
l,20,45                     ! 50

l,14,44                     ! 51
l,20,46                     ! 52

/com, **********************************
/com, Meshing for Straight pipe
/com, **********************************

type,1
secnum,1
mat,1


lsel,s,line,,1,30
allsel,below,line
lesize,all,,,4
lmesh,all

allsel,all,all

/com, **********************************
/com, Meshing for bend pipe
/com, **********************************

type,2
secnum,1
mat,2

lsel,s,,,31,35
```

```
allsel,below,line
lesize,all,,,4
lmesh,all

allsel,all,all


/com, *****************************************************************
/com,  Converting Straight pipes with smaller lengths into bend pipes for
/com,  better accuracy
/com, *****************************************************************

elbow,on,,,sect

esel,s,ename,,290
nsle,s
esln,s
nsle,s
esln,s
nsle,s
esln,s
esel,u,ename,,290
emodif,all,type,2
allsel,all


/com, ***************************
/com,  Spring - damper elements
/com, *****************************

type,3
real,3

lsel,s,,,36,41
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,4
real,4

lsel,s,,,42,46
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,5
real,5

lsel,s,,,47,48
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,6
real,6

lsel,s,,,49,50
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,7
real,7
```

```
lsel,s,,,51,52
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all



n1 = 11
n2 = 284
n3 = 10
ics = 11
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0

n1 = 28
n2 = 285
n3 = 290
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 84
n2 = 295
n3 = 297
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 132
n2 = 296
n3 = 298
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 180
n2 = 286
n3 = 291
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 196
n2 = 287
n3 = 292
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
```

```
nrotat,n3
csys,0

allsel,all,all

/com,-------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,,node,,282,298
d,all,all
allsel

d,1,rotx,,,,,roty,rotz
d,239,rotx,,,,,roty,rotz
allsel,all,all

finish


/com
/com,==============
/com, Modal solve
/com,==============
/com,

/solution
antype,modal       ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on        ! Use Lumped Mass Approximation
mxpand,maxm,,,yes       ! Expand solution with Element Calculations ON
solve
finish

/post1
/out,
/com, ******************************
/com,  Frequencies from Modal solve
/com, ******************************
set,list
finish


/com,-------------------------------------------------------------------------------

/out,scratch
/com,
/com,==================
/com, Spectrum solve
/com,==================
/com,

/solution
antype,spectrum       ! Perform Spectrum Analysis
spopt,sprs,15       ! Single Point Excitation Response Spectrum
srss,0.0        ! SRSS mode combination

gval = 386.4

svtyp, 2, gval
freq, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83,  23.25,  29.41
sv,,  2.275, 2.275,  1.0,    0.8,  0.925,  0.925,   0.8 ,   1.0 ,    1.0
freq,  34.48
sv,,   0.875
sed,1,0,0        ! Excitation in X direction
SOLVE

svtyp, 2, gval
freq
freq, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83,  23.25,  29.41
```

```
sv,, 1.517, 1.517, 0.667,  0.534,  0.617,  0.617,   0.534, 0.667,  0.667
freq,  34.48
sv,,   0.584
sed,0,1,0        ! Excitation in Y direction
SOLVE
fini

/com,-----------------------------------------------------------------------

/post1
/input,,mcom


/out,
/com, *===============================================================
/com, * Maximum nodal displacements and rotations from spectrum solve
/com, *================================================================

/out,scratch

*GET,AdisX,NODE,19,U,X
*GET,AdisY,NODE,275,U,Y
*GET,AdisZ,NODE,11,U,Z
*GET,ArotX,NODE,220,ROT,X
*GET,ArotY,NODE,11,ROT,Y
*GET,ArotZ,NODE,265,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ


/com, *=======================================================
/com, * Element Forces and Moments from spectrum solve
/com, *=========================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #120 (Pipe289 element)
/com,************************


esel,s,elem,,120
etable,pxi_120,smisc,1
etable,vyi_120,smisc,6
etable,vzi_120,smisc,5
etable,txi_120,smisc,4
etable,myi_120,smisc,2
etable,mzi_120,smisc,3
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element120, node i
/com, ************************************************

pretab,pxi_120,vyi_120,vzi_120,txi_120,myi_120,mzi_120


/out,scratch
/com,==========
/com,  Node J
/com,==========
```

```
/com, Element #120 (Pipe289 element)
/com,************************

esel,s,elem,,120
etable,pxj_120,smisc,14
etable,vyj_120,smisc,19
etable,vzj_120,smisc,18
etable,txj_120,smisc,17
etable,myj_120,smisc,15
etable,mzj_120,smisc,16
esel,all

/out,
/com, *********************************************
/com,  Element forces and moments at element120, node j
/com, ***********************************************

pretab,pxj_120,vyj_120,vzj_120,txj_120,myj_120,mzj_120



/out,scratch


/com,==========
/com,  Node I
/com,==========

/com, Element #131 (Elbow 290 element1)
/com,*************************

esel,s,elem,,131
etable,pxi_131,smisc,1
etable,vyi_131,smisc,6
etable,vzi_131,smisc,5
etable,txi_131,smisc,4
etable,myi_131,smisc,2
etable,mzi_131,smisc,3
esel,all

/out,
/com, *********************************************
/com,  Element forces and moments at element131, node i
/com, ***********************************************

pretab,pxi_131,vyi_131,vzi_131,txi_131,myi_131,mzi_131


/out,scratch
/com,==========
/com,  Node J
/com,==========



/com, Element #131 (Elbow290 element)
/com,************************
esel,s,elem,,131

etable,pxj_131,smisc,36
etable,vyj_131,smisc,41
etable,vzj_131,smisc,40
etable,txj_131,smisc,39
etable,myj_131,smisc,37
etable,mzj_131,smisc,38
esel,all

allsel,all

/out,
/com, *********************************************
/com,  Element forces and moments at element131, node j
```

```
/com, ************************************************

pretab,pxj_131,vyj_131,vzj_131,txj_131,myj_131,mzj_131



/com,-----------------------------------------------------------------------

/com, ***************************************
/com,  Reaction forces from spectrum solve
/com, ****************************************

prrsol

finish
```

vm-nr1677-02-1b Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-02-1b
/title,vm-nr1677-02-1b,NRC piping benchmarks problems,Volume II, Problem 1b

/com, ***************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com, Elements used: Pipe289, Elbow290 and Combin14
/com,
/com, Results :
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, *******************************************************************************


/out,scratch


/PREP7

YoungModulus1 = .258e+8                         ! Young's Modulus
Nu = 0.3                                        ! Poissons ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu))        ! Shear Modulus
WMass = 1.042868e-03                            ! Density

WTick=0.216                                     ! Wall Thickness
OD=3.5                                          ! Outer Diameter

RADCUR=48.003                                   ! Radius curvature
temp=60                                         ! Temperature
maxm=15                                         ! Number of modes to extract

et,1,pipe289,,,                                 ! Straight pipe elements
et,2,elbow290,,6                                ! Curved pipe elements

et,3,combin14                               ! Spring-damper elements
keyopt,3,2,1                                    ! UX Degree Of Freedom
et,4,combin14,                                  ! Spring-damper elements
keyopt,4,2,2                                    ! UY Degree Of Freedom
et,5,combin14                               ! Spring-damper elements
keyopt,5,2,3                                    ! UZ Degree Of Freedom
et,6,combin14                                   ! Spring-damper elements
keyopt,6,2,1                                    ! UX Degree Of Freedom
```

```
et,7,combin14                                    ! Spring-damper elements
keyopt,7,2,2                                     ! UY Degree Of Freedom

/com,
/com, Real Constants
/com,****************

sectype,1,PIPE,ctube
secdata,OD,WTick,24

r,3,0.2e+8                                       ! Stiffness
r,4,0.2e+8                                       ! Stiffness
r,5,0.2e+8                                       ! Stiffness
r,6,0.2e+5                                       ! Stiffness
r,7,0.2e+5                                       ! Stiffness


/com,----------------------------------------------------------------------------

/com,
/com, Material Properties
/com,********************

mp,ex,1,YoungModulus1
mp,nuxy,1,Nu
mp,gxy,1,ShearModulus1
mp,dens,1,WMass

mp,ex,2,YoungModulus1
mp,nuxy,2,Nu
mp,gxy,2,ShearModulus1
mp,dens,2,WMass

/com,----------------------------------------------------------------------------

/com, Keypoints
/com,***********

k,1,0,0,0
k,2,0,12,0
k,3,35.687,60,32.110
k,4,55,60,49.5
k,5,74.329,60,66.882
k,6,110,12,99
k,7,110,0,99
k,8,110,-24,99,
k,9,110,-48,99,
k,10,110,-72,99
k,11,110,-96,99
k,12,110,-120,99
k,13,110,-144,99
k,14,110,-168,99
k,15,110,-198,99
k,16,110,-228,99
k,17,110,-252,99
k,18,110,-276,99
k,19,110,-300,99
k,20,110,-324,99
k,21,99.6,-349.4,99
k,22,89.2,-374.8,99
k,23,78.8,-400,99
k,24,68.4,-425.6,99
k,25,58,-451,99
k,26,58,-475,99
k,27,58,-487,99
k,28,103.537,-535,114.179
k,29,124.269,-535,121.1
k,30,145,-535,128
k,31,184.975,-535,123.615
k,32,214.8,-536,102.8
k,33,254.585,-535,81.849
k,34,279.312,-535,75
```

```
k,35,331,-535,75
k,36,383,-535,75

/com,
/com, Elastic support Keypoints
/com,***************************

k,37,10,0,0
k,38,0,10,0
k,39,0,0,10
k,40,55,70,49.5
k,41,110,0,109
k,42,120,0,99
k,43,110,-168,109
k,44,120,-168,109
k,45,110,-324,109
k,46,120,-324,99
k,47,58,-475,109
k,48,68,-475,99
k,49,103.537,-545,114.179
k,50,103.537,-535,104.179
k,51,393,-535,75
k,52,383,-545,75
k,53,383,-535,85

/com,----------------------------------------------------------------------------

/com,
/com, Modeling of Straight Pipe (Tangent)
/com,************************************

l, 1, 2
l, 3, 4
l, 4, 5
l, 6, 7
l, 7, 8
l, 8, 9
l, 9,10
l,10,11
l,11,12
l,12,13
l,13,14
l,14,15
l,15,16
l,16,17
l,17,18
l,18,19
l,19,20
l,20,21
l,21,22
l,22,23
l,23,24
l,24,25
l,25,26
l,26,27
l,28,29
l,29,30
l,31,32
l,32,33
l,34,35
l,35,36             ! line number 30

/com,
/com, Modeling of Pipe Bend
/com,***********************

larch,2,3,4,RADCUR
larch,5,6,4,RADCUR
larch,27,28,26,RADCUR
larch,30,31,29,RADCUR
larch,33,34,32,RADCUR           ! line number 35
```

```
/com, Elastic supports and anchors
/com,******************************

l,1,37                      ! 36
l,36,51                     ! 37
l,4,40                      ! 38
l,7,41                      ! 39
l,26,47                     ! 40
l,28,49                     ! 41

l,1,38                      ! 42
l,36,52                     ! 43
l,7,42                      ! 44
l,26,48                     ! 45
l,28,50                     ! 46

l,1,39                      ! 47
l,36,53                     ! 48

l,14,43                     ! 49
l,20,45                     ! 50

l,14,44                     ! 51
l,20,46                     ! 52

/com, *********************************
/com, Meshing for Straight pipe
/com, *********************************

type,1
secnum,1
mat,1


lsel,s,line,,1,30
allsel,below,line
lesize,all,,,4
lmesh,all

allsel,all,all

/com, *********************************
/com, Meshing for bend pipe
/com, *********************************

type,2
secnum,1
mat,2

lsel,s,,,31,35
allsel,below,line
lesize,all,,,4
lmesh,all

allsel,all,all


/com, *****************************************************************
/com,  Converting Straight pipes with smaller lengths into bend pipes for
/com,  better accuracy
/com, *****************************************************************

elbow,on,,,sect

esel,s,ename,,290
nsle,s
esln,s
nsle,s
esln,s
nsle,s
esln,s
esel,u,ename,,290
```

```
emodif,all,type,2
allsel,all


/com, ****************************
/com,  Spring - damper elements
/com, ******************************

type,3
real,3

lsel,s,,,36,41
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,4
real,4

lsel,s,,,42,46
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,5
real,5

lsel,s,,,47,48
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,6
real,6

lsel,s,,,49,50
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,7
real,7

lsel,s,,,51,52
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all



n1 = 11
n2 = 284
n3 = 10
ics = 11
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0

n1 = 28
n2 = 285
```

```
n3 = 290
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 84
n2 = 295
n3 = 297
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 132
n2 = 296
n3 = 298
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 180
n2 = 286
n3 = 291
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 196
n2 = 287
n3 = 292
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

allsel,all,all

/com,-----------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,,node,,282,298
d,all,all
allsel

d,1,rotx,,,,,roty,rotz
d,239,rotx,,,,,roty,rotz
allsel,all,all

finish
```

```
/com
/com,==============
/com, Modal solve
/com,==============
/com,

/solution
antype,modal       ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on        ! Use Lumped Mass Approximation
mxpand,maxm,,,yes       ! Expand solution with Element Calculations ON
solve
finish

/post1
/out,
/com, ******************************
/com,  Frequencies from Modal solve
/com, ******************************
set,list
finish


/com,---------------------------------------------------------------------------

/out,scratch
/com,
/com,==================
/com, Spectrum solve
/com,==================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,mprs,15     ! Multi Point Excitation Response Spectrum

gval = 386.4

/com,
/com, spectrum 1 (group 1 - upperLevel - X)
/com,***************************************

spunit,1,accg, gval
spfrq,1, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83
spval,1,,  2.275, 2.275,  1.0,    0.8,  0.925,  0.925,   0.8
spfrq,1,  23.25,  29.41,  34.48
spval,1,,    1.0 ,    1.0, 0.875

/com,
/com, spectrum 2 (group 1 - upperLevel - Y=0.667X)
/com,**********************************************

spunit,2,accg, gval
spfrq,2, 2.5  , 5.0  ,   8.0,  12.35,  13.51,  16.95,  20.83
spval,2,,  1.517, 1.517, 0.667,  0.534,  0.617,  0.617,   0.534
spfrq,2,  23.25,  29.41,  34.48
spval,2,,  0.667 ,  0.667,  0.584

/com,
/com, spectrum 3 (group 2 - lowerLevel - X)
/com,***************************************

spunit, 3,accg, gval
spfrq,3, 3.0  , 4.0  ,  7.0,  12.5,   14.1,  15.87,  21.74
spval,3,,  1.4  , 1.4  , 0.75, 0.875,    0.7,    0.7,   0.8
spfrq,3,  23.25,  27.03,  31.25, 34.48
spval,3,,    0.75,   0.75,    0.7,  0.6

/com,
/com, spectrum 4 (group 2 - lowerLevel - Y=0.667X)
/com,**********************************************
```

```
spunit,4,accg, gval
spfrq,4, 3.0  , 4.0  ,  7.0,  12.5,   14.1,  15.87,  21.74
spval,4,,  0.934, 0.934, 0.5 , 0.584,  0.467, 0.467,  0.534
spfrq,4,  23.25,  27.03,  31.25, 34.48
spval,4,,    0.5,     0.5,  0.467,  0.4

/com,
/com, node components for excitation points
/com,*************************************

nsel,s,node,,282
nsel,a,node,,284,285
nsel,a,node,,288
nsel,a,node,,290
nsel,a,node,,293
cm,upperLevel,node
allsel,all,all

nsel,s,node,,283
nsel,a,node,,286,287
nsel,a,node,,289
nsel,a,node,,291,292
nsel,a,node,,294,298
cm,lowerLevel,node
allsel,all,all

/com, -- upper level - spectrum 1
d,282,ux,1
d,288,ux,1
d,293,ux,1
d,285,uy,1
d,290,uy,1
pfact,1
d,upperLevel,all,0

/com, -- upper level - spectrum 2
d,282,uy,1
d,288,uy,1
d,293,uy,1
d,284,ux,1
d,285,uz,1
d,290,uz,1
pfact,2
d,upperLevel,all,0

/com, -- lower level - spectrum 3
d,295,uy,1,,298
d,291,uy,1
d,286,uy,1
d,287,uz,1
d,292,uz,1
d,283,ux,1
d,289,ux,1
d,294,ux,1
pfact,3
d,lowerLevel,all,0

/com, -- lower level - spectrum 4
d,295,uz,1,,298
d,291,uz,1
d,286,uz,1
d,287,ux,-1
d,292,ux,-1
d,283,uy,1
d,289,uy,1
d,294,uy,1
pfact,4
d,lowerLevel,all,0

srss,0.0      ! Combine modes using SRSS mode combination
solve
```

```
finish

/com,--------------------------------------------------------------------------------

/post1
/input,,mcom

/out,
/com, *=================================================================
/com, * Maximum nodal displacements and rotations from spectrum solve
/com, *=================================================================

/out,scratch

*GET,AdisX,NODE,19,U,X
*GET,AdisY,NODE,226,U,Y
*GET,AdisZ,NODE,224,U,Z
*GET,ArotX,NODE,196,ROT,X
*GET,ArotY,NODE,208,ROT,Y
*GET,ArotZ,NODE,211,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ


/com, *=========================================================
/com, * Element Forces and Moments from spectrum solve
/com, *===========================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #120 (Pipe289 element)
/com,************************


esel,s,elem,,120
etable,pxi_120,smisc,1
etable,vyi_120,smisc,6
etable,vzi_120,smisc,5
etable,txi_120,smisc,4
etable,myi_120,smisc,2
etable,mzi_120,smisc,3
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element120, node i
/com, ************************************************

pretab,pxi_120,vyi_120,vzi_120,txi_120,myi_120,mzi_120


/out,scratch
/com,==========
/com,  Node J
/com,==========

/com, Element #120 (Pipe289 element)
/com,************************

esel,s,elem,,120
etable,pxj_120,smisc,14
etable,vyj_120,smisc,19
```

```
etable,vzj_120,smisc,18
etable,txj_120,smisc,17
etable,myj_120,smisc,15
etable,mzj_120,smisc,16
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element120, node j
/com, ************************************************

pretab,pxj_120,vyj_120,vzj_120,txj_120,myj_120,mzj_120



/out,scratch


/com,==========
/com,  Node I
/com,==========

/com, Element #131 (Elbow 290 element)
/com,*************************

esel,s,elem,,131
etable,pxi_131,smisc,1
etable,vyi_131,smisc,6
etable,vzi_131,smisc,5
etable,txi_131,smisc,4
etable,myi_131,smisc,2
etable,mzi_131,smisc,3
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element131, node i
/com, ************************************************

pretab,pxi_131,vyi_131,vzi_131,txi_131,myi_131,mzi_131


/out,scratch
/com,==========
/com,  Node J
/com,==========



/com, Element #131 (Elbow290 element)
/com,************************
esel,s,elem,,131

etable,pxj_131,smisc,36
etable,vyj_131,smisc,41
etable,vzj_131,smisc,40
etable,txj_131,smisc,39
etable,myj_131,smisc,37
etable,mzj_131,smisc,38
esel,all

allsel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element131, node j
/com, ************************************************

pretab,pxj_131,vyj_131,vzj_131,txj_131,myj_131,mzj_131
```

```
/com,-------------------------------------------------------------------------------

/com, ****************************************
/com,  Reaction forces from spectrum solve
/com, ****************************************

prrsol

finish
```

vm-nr1677-02-1c Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-02-1c
/title,vm-nr1677-02-1c,NRC piping benchmarks from NUREG/CR1677 VOL II, Problem 1c

/com, ***********************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, August 1985.
/com,
/com, Elements used: Pipe289, Elbow290 and Combin14
/com,
/com, Results :
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, ***************************************************************************

/out,scratch
/out,scratch


/PREP7

YoungModulus1 = .258e+8                          ! Young's Modulus
Nu = 0.3                                         ! Poissons ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu))         ! Shear Modulus
WMass = 1.042868e-03                             ! Density

WTick=0.216                                      ! Wall Thickness
OD=3.5                                           ! Outer Diameter

RADCUR=48.003                                    ! Radius curvature
temp=60                                          ! Temperature
maxm=15                                          ! Number of modes to extract

et,1,pipe289,,,                                  ! Straight pipe elements
et,2,elbow290,,6                                 ! Curved pipe elements

et,3,combin14                                ! Spring-damper elements
keyopt,3,2,1                                     ! UX Degree Of Freedom
et,4,combin14,                                   ! Spring-damper elements
keyopt,4,2,2                                     ! UY Degree Of Freedom
et,5,combin14                                ! Spring-damper elements
keyopt,5,2,3                                     ! UZ Degree Of Freedom
et,6,combin14                                    ! Spring-damper elements
keyopt,6,2,1                                     ! UX Degree Of Freedom
et,7,combin14                                    ! Spring-damper elements
keyopt,7,2,2                                     ! UY Degree Of Freedom

/com,
/com, Real Constants
/com,***************
```

```
sectype,1,PIPE,ctube
secdata,OD,WTick,24

r,3,0.2e+8                                      ! Stiffness
r,4,0.2e+8                                      ! Stiffness
r,5,0.2e+8                                      ! Stiffness
r,6,0.2e+5                                      ! Stiffness
r,7,0.2e+5                                      ! Stiffness


/com,-------------------------------------------------------------------------------

/com,
/com, Material Properties
/com,********************

mp,ex,1,YoungModulus1
mp,nuxy,1,Nu
mp,gxy,1,ShearModulus1
mp,dens,1,WMass

mp,ex,2,YoungModulus1
mp,nuxy,2,Nu
mp,gxy,2,ShearModulus1
mp,dens,2,WMass

/com,-------------------------------------------------------------------------------

/com, Keypoints
/com,***********

k,1,0,0,0
k,2,0,12,0
k,3,35.687,60,32.110
k,4,55,60,49.5
k,5,74.329,60,66.882
k,6,110,12,99
k,7,110,0,99
k,8,110,-24,99,
k,9,110,-48,99,
k,10,110,-72,99
k,11,110,-96,99
k,12,110,-120,99
k,13,110,-144,99
k,14,110,-168,99
k,15,110,-198,99
k,16,110,-228,99
k,17,110,-252,99
k,18,110,-276,99
k,19,110,-300,99
k,20,110,-324,99
k,21,99.6,-349.4,99
k,22,89.2,-374.8,99
k,23,78.8,-400,99
k,24,68.4,-425.6,99
k,25,58,-451,99
k,26,58,-475,99
k,27,58,-487,99
k,28,103.537,-535,114.179
k,29,124.269,-535,121.1
k,30,145,-535,128
k,31,184.975,-535,123.615
k,32,214.8,-536,102.8
k,33,254.585,-535,81.849
k,34,279.312,-535,75
k,35,331,-535,75
k,36,383,-535,75

/com,
/com, Elastic support Keypoints
/com,***************************
```

```
k,37,10,0,0
k,38,0,10,0
k,39,0,0,10
k,40,55,70,49.5
k,41,110,0,109
k,42,120,0,99
k,43,110,-168,109
k,44,120,-168,109
k,45,110,-324,109
k,46,120,-324,99
k,47,58,-475,109
k,48,68,-475,99
k,49,103.537,-545,114.179
k,50,103.537,-535,104.179
k,51,393,-535,75
k,52,383,-545,75
k,53,383,-535,85

/com,----------------------------------------------------------------------------

/com,
/com, Modeling of Straight Pipe (Tangent)
/com,************************************

l, 1, 2
l, 3, 4
l, 4, 5
l, 6, 7
l, 7, 8
l, 8, 9
l, 9,10
l,10,11
l,11,12
l,12,13
l,13,14
l,14,15
l,15,16
l,16,17
l,17,18
l,18,19
l,19,20
l,20,21
l,21,22
l,22,23
l,23,24
l,24,25
l,25,26
l,26,27
l,28,29
l,29,30
l,31,32
l,32,33
l,34,35
l,35,36             ! line number 30

/com,
/com, Modeling of Pipe Bend
/com,***********************

larch,2,3,4,RADCUR
larch,5,6,4,RADCUR
larch,27,28,26,RADCUR
larch,30,31,29,RADCUR
larch,33,34,32,RADCUR           ! line number 35

/com, Elastic supports and anchors
/com,******************************

l,1,37                       ! 36
l,36,51                      ! 37
l,4,40                       ! 38
l,7,41                       ! 39
```

```
l,26,47                     ! 40
l,28,49                     ! 41

l,1,38                      ! 42
l,36,52                     ! 43
l,7,42                      ! 44
l,26,48                     ! 45
l,28,50                     ! 46

l,1,39                      ! 47
l,36,53                     ! 48

l,14,43                     ! 49
l,20,45                     ! 50

l,14,44                     ! 51
l,20,46                     ! 52

/com, **********************************
/com, Meshing for Straight pipe
/com, **********************************

type,1
secnum,1
mat,1


lsel,s,line,,1,30
allsel,below,line
lesize,all,,,4
lmesh,all

allsel,all,all

/com, **********************************
/com, Meshing for bend pipe
/com, **********************************

type,2
secnum,1
mat,2

lsel,s,,,31,35
allsel,below,line
lesize,all,,,4
lmesh,all

allsel,all,all


/com, *****************************************************************
/com,  Converting Straight pipes with smaller lengths into bend pipes for
/com,  better accuracy
/com, *****************************************************************

elbow,on,,,sect

esel,s,ename,,290
nsle,s
esln,s
nsle,s
esln,s
nsle,s
esln,s
esel,u,ename,,290
emodif,all,type,2
allsel,all


/com, ***************************
/com,  Spring - damper elements
/com, ******************************
```

```
type,3
real,3

lsel,s,,,36,41
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,4
real,4

lsel,s,,,42,46
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,5
real,5

lsel,s,,,47,48
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,6
real,6

lsel,s,,,49,50
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,7
real,7

lsel,s,,,51,52
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all



n1 = 11
n2 = 284
n3 = 10
ics = 11
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0

n1 = 28
n2 = 285
n3 = 290
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
```

```
csys,0

n1 = 84
n2 = 295
n3 = 297
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 132
n2 = 296
n3 = 298
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 180
n2 = 286
n3 = 291
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 196
n2 = 287
n3 = 292
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

allsel,all,all

/com,------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,,node,,282,298
d,all,all
allsel

d,1,rotx,,,,,roty,rotz
d,239,rotx,,,,,roty,rotz
allsel,all,all

finish


/com
/com,==============
/com, Modal solve
/com,==============
/com,

/solution
```

```
antype,modal       ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on        ! Use Lumped Mass Approximation
mxpand,maxm,,,yes       ! Expand solution with Element Calculations ON
solve
finish

/post1
/out,
/com, ******************************
/com,  Frequencies from Modal solve
/com, ******************************
set,list
finish


/com,------------------------------------------------------------------------------

/out,scratch
/com,
/com,==================
/com, Spectrum solve
/com,==================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,mprs,15     ! Multi Point Excitation Response Spectrum

gval = 386.4

/com,
/com, spectrum 1 (group 1 - upperLevel - X)
/com,*************************************

spunit,1,accg,gval
spfrq,1, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83
spval,1,,  2.275, 2.275,  1.0,    0.8,  0.925,  0.925,   0.8
spfrq,1,  23.25,  29.41,  34.48
spval,1,,    1.0 ,    1.0, 0.875

/com,
/com, spectrum 2 (group 1 - upperLevel - Y = 0.667X)
/com,**********************************************

spunit,2,accg,gval
spfrq,2, 2.5  , 5.0  ,   8.0,  12.35,  13.51,  16.95,  20.83
spval,2,,  1.517, 1.517, 0.667,  0.534,  0.617,  0.617,   0.534
spfrq,2,  23.25,  29.41,  34.48
spval,2,,  0.667 ,  0.667,  0.584

/com,
/com, spectrum 3 (group 2 - lowerLevel - X)
/com,*************************************

spunit,3,accg,gval
spfrq,3, 3.0  , 4.0  ,  7.0,  12.5,   14.1,  15.87,  21.74
spval,3,,  1.4  , 1.4  , 0.75, 0.875,    0.7,    0.7,   0.8
spfrq,3,  23.25,  27.03,  31.25, 34.48
spval,3,,    0.75,   0.75,    0.7,  0.6

/com,
/com, spectrum 4 (group 2 - lowerLevel - Y = 0.667X)
/com,**********************************************

spunit,4,accg,gval
spfrq,4, 3.0  , 4.0  ,  7.0,  12.5,   14.1,  15.87,  21.74
spval,4,,  0.934, 0.934, 0.5 , 0.584,  0.467, 0.467,  0.534
spfrq,4,  23.25,  27.03,  31.25, 34.48
spval,4,,    0.5,     0.5,  0.467,  0.4

/com,
```

```
/com, node components for excitation points
/com,***************************************

nsel,s,node,,282,283
nsel,a,node,,286,287
nsel,a,node,,290,291
cm,upperLevel,node
allsel,all,all

nsel,s,node,,284,285
nsel,a,node,,288,289
nsel,a,node,,292,293
nsel,a,node,,294,298
cm,lowerLevel,node
allsel,all,all

/com, ***************************************************
/com, -- upper level - spectrum 1 (Along X - direction)

sed,1,,,upperLevel
pfact,1
sed,0,,,upperLevel

/com, -- lower level - spectrum 3 (Along X - direction)

sed,1,,,lowerLevel
pfact,3
sed,0,,,lowerLevel

/com, -- upper level - spectrum 2 (Along Y - direction)

sed,,1,,upperLevel
pfact,2
sed,,0,,upperLevel

/com, -- lower level - spectrum 4 (Along Y - direction)

sed,,1,,lowerLevel
pfact,4
sed,,0,,lowerLevel

srss,0.0,,YES ! activate Absolute Sum for MPRS
solve

finish

/com,-----------------------------------------------------------------------------------------

/post1

/input,,mcom


/out,

/com, *=================================================================
/com, * Maximum nodal displacements and rotations from spectrum solve
/com, *==================================================================

/out,scratch

*GET,AdisX,NODE,19,U,X
*GET,AdisY,NODE,229,U,Y
*GET,AdisZ,NODE,11,U,Z
*GET,ArotX,NODE,254,ROT,X
*GET,ArotY,NODE,11,ROT,Y
*GET,ArotZ,NODE,254,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
```

```
*stat,ArotX
*stat,ArotY
*stat,ArotZ


/com, *==========================================================
/com, * Element Forces and Moments from spectrum solve
/com, *============================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #120 (Pipe289 element)
/com,************************


esel,s,elem,,120
etable,pxi_120,smisc,1
etable,vyi_120,smisc,6
etable,vzi_120,smisc,5
etable,txi_120,smisc,4
etable,myi_120,smisc,2
etable,mzi_120,smisc,3
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element120, node i
/com, ************************************************

pretab,pxi_120,vyi_120,vzi_120,txi_120,myi_120,mzi_120


/out,scratch
/com,==========
/com,  Node J
/com,==========

/com, Element #120 (Pipe289 element)
/com,************************

esel,s,elem,,120
etable,pxj_120,smisc,14
etable,vyj_120,smisc,19
etable,vzj_120,smisc,18
etable,txj_120,smisc,17
etable,myj_120,smisc,15
etable,mzj_120,smisc,16
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element120, node j
/com, ************************************************

pretab,pxj_120,vyj_120,vzj_120,txj_120,myj_120,mzj_120



/out,scratch


/com,==========
/com,  Node I
/com,==========

/com, Element #131 (Elbow 290 element1)
/com,*************************
```

```
esel,s,elem,,131
etable,pxi_131,smisc,1
etable,vyi_131,smisc,6
etable,vzi_131,smisc,5
etable,txi_131,smisc,4
etable,myi_131,smisc,2
etable,mzi_131,smisc,3
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element131, node i
/com, ************************************************

pretab,pxi_131,vyi_131,vzi_131,txi_131,myi_131,mzi_131


/out,scratch
/com,==========
/com,  Node J
/com,==========



/com, Element #131 (Elbow290 element)
/com,***********************
esel,s,elem,,131

etable,pxj_131,smisc,36
etable,vyj_131,smisc,41
etable,vzj_131,smisc,40
etable,txj_131,smisc,39
etable,myj_131,smisc,37
etable,mzj_131,smisc,38
esel,all

allsel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element131, node j
/com, ************************************************

pretab,pxj_131,vyj_131,vzj_131,txj_131,myj_131,mzj_131



/com,-----------------------------------------------------------------------

/com, **************************************
/com,  Reaction forces from spectrum solve
/com, **************************************

prrsol

finish
```

vm-nr1677-02-2a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-02-2a
/title,vm-nr1677-02-2a,NRC piping benchmarks problems,Volume II, Problem 2a

/com, ***************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
```

```
/com,
/com, Elements used: PIPE289, ELBOW290, COMBIN14 and MASS21
/com,
/com, Results:
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, ********************************************************************************

/out,scratch

/prep7

YoungModulus1 = .240e+8    ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu)) ! Shear Modulus
WMass = 0.001056893    ! Density
WTick = 0.241     ! Wall Thickness
K = 0.71e-5

OD = 7.288      ! Outer Diameter
RADCUR = 36.30     ! Radius of Curvature

temp = 80      ! Temperature
maxm = 25      ! No. of Modes to Extract

et,1,pipe289,,,     ! Element 1 - PIPE289
et,2,elbow290,,6    ! Element 2 - ELBOW290

et,3,combin14     ! Element 3 - COMBIN14
keyopt,3,2,1     ! X Degree of Freedom
et,4,combin14     ! Element 4 - COMBIN14
keyopt,4,2,2     ! Y Degree of Freedom
et,5,combin14     ! Element 5 - COMBIN14
keyopt,5,2,3     ! Z Degree of Freedom
et,6,mass21      ! Element 6 - MASS21
keyopt,6,3,2     ! 3D mass without inertia

/com,------------------------------------------------------------------------------------

/com, Real Constants
/com,****************

sectype,1,PIPE,ctube
secdata,OD,WTick,24

r,3,0.1e+5
r,4,0.1e+9
r,5,0.1e+11
r,6,1.518

/com,------------------------------------------------------------------------------------

/com, Material Properties
/com,*********************

mp,ex,  1, YoungModulus1
mp,nuxy,1, Nu
mp,gxy ,1, ShearModulus1
mp,dens,1, WMass
mp,kxx,1, K

mp,ex,  2, YoungModulus1
mp,nuxy,2, Nu
mp,gxy ,2, ShearModulus1
mp,dens,2, WMass
mp,kxx,2, K

/com,------------------------------------------------------------------------------------
```

```
/com, Keypoints
/com,**********

k,1,0,0,0
k,2,0,54.45,0
k,3,0,108.9,0
k,4,10.632,134.568,0
k,5,36.3,145.2,0
k,6,54.15,145.2,0
k,7,72.0,145.2,0
k,8,97.668,145.2,10.632
k,9,108.3,145.2,36.3
k,10,108.3,145.2,56.8
k,11,108.3,145.2,77.3
k,12,108.3,145.2,97.8
k,13,108.3,145.2,118.3
k,14,108.3,145.2,188.8
k,15,108.3,181.5,225.1
k,16,108.3,236,225.1
k,17,108.3,290,225.1
k,18,148.3,145.2,97.8
k,19,188.3,145.2,97.8
k,20,224.6,145.2,61.5
k,21,224.6,145.2,20

/com,
/com, Elastic Support Keypoints
/com,**************************

k,22,1,0,0
k,23,0,1,0
k,24,0,0,1
k,25,72,145.2,-1
k,26,109.3,145.2,36.3
k,27,108.3,146.2,77.3
k,28,108.3,146.2,118.3
k,29,107.3,182.5,226.5
k,30,109.3,290,225.1
k,31,108.3,291,225.1
k,32,108.3,290,226.1
k,33,225.6,145.2,20
k,34,224.6,146.2,20
k,35,224.6,145.2,21

/com,-----------------------------------------------------------------------------------

/com,
/com, Modeling for Straight Pipe
/com,**********************************

l, 1, 2
l, 2, 3
l, 5, 6
l, 6, 7
l, 9,10
l,10,11
l,11,12
l,12,13
l,13,14
l,15,16
l,16,17
l,12,18
l,18,19
l,20,21

/com,
/com, Modeling for Pipe Bend
/com,************************

larc, 3, 4, 2, RADCUR
larc, 4, 5, 6, RADCUR
```

```
larc, 7, 8, 6, RADCUR
larc, 8, 9,10, RADCUR
larc,14,15,16, RADCUR
larc,19,20,18, RADCUR

/com,
/com, Modeling for Elastic Supports and Anchors
/com,*******************************************

l,11,27
l,13,28

l,9,26
l,15,29

l,7,25

l,1,22
l,17,30
l,21,33

l,1,23
l,17,31
l,21,34

l,1,24
l,17,32
l,21,35

/com, **********************************
/com, Meshing for Straight pipe
/com, **********************************

type,1
secnum,1
mat,1

lsel,r,,,1,14
allsel,below,line
lesize,all,,,2
lmesh,all

allsel,all,all

type,2
secnum,1
mat,2

lsel,r,,,15,20
allsel,below,line
lesize,all,,,4
lmesh,all

allsel,all,all

/com, *****************************************************************
/com,  Converting some PIPE289 into ELBOW290 using ELBOW command
/com, *****************************************************************

elbow,on,,,sect
allsel,all

/com, ****************************
/com, Elastic supports and anchors
/com, ****************************

type,3     !local x
real,4     ! 0.1e+9

lsel,r,,,23,24
allsel,below,line
lesize,all,,,1
```

```
lmesh,all

allsel,all,all

real,5     ! 0.1e+11

lsel,r,,,26,28
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,4     ! local y
real,3     ! 0.1e+5

lsel,r,,,21,22
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

real,5

lsel,r,,,29,31
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,5     !local z
real,4     ! 0.1e+9

lsel,r,,,25
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

real,5

lsel,r,,,32,34
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all


n1 = 40
n2 = 107
n3 = 41

wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,11,0
nrotat,n1
nrotat,n2
csys,0

/com
/com, Mass Elements
/com,***************

type,6
real,6
e,49

/com,------------------------------------------------------------------------------------
```

```
/com,
/com, Constraints
/com,*************

nsel,,node,,106,119
d,all,all
allsel
d,1,rotx,,,,,roty,rotz
d,58,rotx,,,,,roty,rotz

allsel,all
finish

/com,------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal    ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on     ! Use Lumped Mass Matrix Approximation
mxpand,maxm,,,yes    ! Expand Solutions with Element Calculations ON
solve
finish

/post1
/out,
/com, *******************************************
/com,  Frequencies obtained from modal solution
/com, ********************************************
set,list
finish


/com,------------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,
/out,scratch

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,sprs,maxm     ! Single Point Excitation Response Spectrum
srss,0.0

gval = 386.4

/com,
/com, spectrum 1 (X)
/com,****************

svtyp, 2, gval
freq,0.4,0.630119723,0.64516129,1.124985938,1.374948439,1.705029838,2.420135528,2.750275028,3.41997264
SV,,2.7,0.814,0.81,4.15,4.15,2.4,1.7,1.46,1.6,
freq,4.679457183,5.720823799,6.600660066,9.900990099,15.12859304,16.50165017,39.0625
sv,,2.05,2.05,1.75,0.9,0.77,0.65,0.65,,
sed,1,0,0      ! Excitation in X direction
solve

/com,
/com, spectrum 2 (Y) - coef 1
/com,************************

svtyp, 2, gval
freq
```

```
FREQ,0.4,0.740740741,1.124985938,1.374948439,1.759943682,2.474634991,3.571428571,5.399568035,6.600660066
SV,,0.34,1.15,2.87,2.87,1.5,0.9,0.87,1.32,1.32
FREQ,8.802816901,10.20408163,15.50387597,39.0625
Sv,,0.73,0.55,0.37,0.37
sed,0,1,0      ! Excitation in Y direction
solve

/com
/com, spectrum 2 (Z) - coef 1
/com,************************

svtyp, 2, gval
freq
FREQ,0.4,0.689655172,1.124985938,1.374948439,1.766160367,2.699784017,4.500450045,5.500550055,6.501950585
SV,,0.34,1.06,3.55,3.55,1.95,1.08,1.38,1.38,1.3
FREQ,7.974481659,13.00390117,17.51313485,39.0625
SV,,1,0.65,0.55,0.55
sed,0,0,1      ! Excitation in Z direction
solve

finish

/com,------------------------------------------------------------------------------------

/post1
/input,,mcom


/out,

/com,
/com,===============================================================
/com, Maximum nodal displacements and rotations from spectrum solution
/com,===============================================================
/com,

/out,scratch

*GET,AdisX,NODE,95,U,X
*GET,AdisY,NODE,84,U,Y
*GET,AdisZ,NODE,40,U,Z
*GET,ArotX,NODE,6,ROT,X
*GET,ArotY,NODE,79,ROT,Y
*GET,ArotZ,NODE,45,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com,==============================================================
/com, Element Forces and Moments obtained from spectrum solution
/com,==============================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #1 (Pipe289 element)
/com,***********************


esel,s,elem,,1
etable,pxi_1,smisc,1
etable,vyi_1,smisc,6
etable,vzi_1,smisc,5
etable,txi_1,smisc,4
```

```
etable,myi_1,smisc,2
etable,mzi_1,smisc,3
esel,all

/out,
/com, ************************************************
/com,  Element forces and moments at element1, node i
/com, ************************************************

pretab,pxi_1,vyi_1,vzi_1,txi_1,myi_1,mzi_1


/out,scratch
/com,==========
/com,  Node J
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************

esel,s,elem,,1
etable,pxj_1,smisc,14
etable,vyj_1,smisc,19
etable,vzj_1,smisc,18
etable,txj_1,smisc,17
etable,myj_1,smisc,15
etable,mzj_1,smisc,16
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element1, node j
/com, ************************************************

pretab,pxj_1,vyj_1,vzj_1,txj_1,myj_1,mzj_1



/out,scratch


/com,==========
/com,  Node I
/com,==========

/com, Element #41 (Elbow 290 element)
/com,*************************

esel,s,elem,,41
etable,pxi_41,smisc,1
etable,vyi_41,smisc,6
etable,vzi_41,smisc,5
etable,txi_41,smisc,4
etable,myi_41,smisc,2
etable,mzi_41,smisc,3
esel,all

/out,
/com, *************************************************
/com,  Element forces and moments at element 41, node i
/com, ************************************************

pretab,pxi_41,vyi_41,vzi_41,txi_41,myi_41,mzi_41


/out,scratch
/com,==========
/com,  Node J
/com,==========
```

```
/com, Element #41 (Elbow290 element)
/com,********************************
esel,s,elem,,41

etable,pxj_41,smisc,36
etable,vyj_41,smisc,41
etable,vzj_41,smisc,40
etable,txj_41,smisc,39
etable,myj_41,smisc,37
etable,mzj_41,smisc,38
esel,all

allsel,all

/out,
/com, ***********************************************
/com,  Element forces and moments at element 41, node j
/com, *************************************************

pretab,pxj_41,vyj_41,vzj_41,txj_41,myj_41,mzj_41



/com,----------------------------------------------------------------------------

/com, ****************************************
/com,  Reaction forces from spectrum solution
/com, *****************************************

prrsol

finish
```

vm-nr1677-02-2b Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-02-2b
/title,vm-nr1677-02-2b,NRC piping benchmarks problems,Volume II,Problem 2b

/com, ***************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com, Elements used: PIPE289, ELBOW290, COMBIN14 and MASS21
/com,
/com, Results :
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, *******************************************************************************

/out,scratch

/prep7

YoungModulus1 = .240e+8    ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu)) ! Shear Modulus
WMass = 0.001056893    ! Density
WTick = 0.241     ! Wall Thickness
K = 0.71e-5

OD = 7.288      ! Outer Diameter
```

```
RADCUR = 36.30     ! Radius of Curvature

temp = 80      ! Temperature
maxm = 25      ! No. of Modes to Extract

et,1,pipe289,,,     ! Element 1 - PIPE289
et,2,elbow290,,6    ! Element 2 - ELBOW290

et,3,combin14     ! Element 3 - COMBIN14
keyopt,3,2,1     ! X Degree of Freedom
et,4,combin14     ! Element 4 - COMBIN14
keyopt,4,2,2     ! Y Degree of Freedom
et,5,combin14     ! Element 5 - COMBIN14
keyopt,5,2,3     ! Z Degree of Freedom
et,6,mass21      ! Element 6 - MASS21
keyopt,6,3,2     ! 3D mass without inertia

/com,-------------------------------------------------------------------------------

/com, Real Constants
/com,****************

sectype,1,PIPE,ctube
secdata,OD,WTick,24

r,3,0.1e+5
r,4,0.1e+9
r,5,0.1e+11
r,6,1.518

/com,-------------------------------------------------------------------------------

/com, Material Properties
/com,*********************

mp,ex,  1, YoungModulus1
mp,nuxy,1, Nu
mp,gxy ,1, ShearModulus1
mp,dens,1, WMass
mp,kxx,1, K

mp,ex,  2, YoungModulus1
mp,nuxy,2, Nu
mp,gxy ,2, ShearModulus1
mp,dens,2, WMass
mp,kxx,2, K

/com,-------------------------------------------------------------------------------

/com, Keypoints
/com,**********

k,1,0,0,0
k,2,0,54.45,0
k,3,0,108.9,0
k,4,10.632,134.568,0
k,5,36.3,145.2,0
k,6,54.15,145.2,0
k,7,72.0,145.2,0
k,8,97.668,145.2,10.632
k,9,108.3,145.2,36.3
k,10,108.3,145.2,56.8
k,11,108.3,145.2,77.3
k,12,108.3,145.2,97.8
k,13,108.3,145.2,118.3
k,14,108.3,145.2,188.8
k,15,108.3,181.5,225.1
k,16,108.3,236,225.1
k,17,108.3,290,225.1
k,18,148.3,145.2,97.8
k,19,188.3,145.2,97.8
k,20,224.6,145.2,61.5
```

```
k,21,224.6,145.2,20

/com,
/com, Elastic Support Keypoints
/com,**************************

k,22,1,0,0
k,23,0,1,0
k,24,0,0,1
k,25,72,145.2,-1
k,26,109.3,145.2,36.3
k,27,108.3,146.2,77.3
k,28,108.3,146.2,118.3
k,29,107.3,182.5,226.5
k,30,109.3,290,225.1
k,31,108.3,291,225.1
k,32,108.3,290,226.1
k,33,225.6,145.2,20
k,34,224.6,146.2,20
k,35,224.6,145.2,21

/com,-----------------------------------------------------------------------------------

/com,
/com, Modeling for Straight Pipe
/com,**********************************

l, 1, 2
l, 2, 3
l, 5, 6
l, 6, 7
l, 9,10
l,10,11
l,11,12
l,12,13
l,13,14
l,15,16
l,16,17
l,12,18
l,18,19
l,20,21

/com,
/com, Modeling for Pipe Bend
/com,************************

larc, 3, 4, 2, RADCUR
larc, 4, 5, 6, RADCUR
larc, 7, 8, 6, RADCUR
larc, 8, 9,10, RADCUR
larc,14,15,16, RADCUR
larc,19,20,18, RADCUR

/com,
/com, Modeling for Elastic Supports and Anchors
/com,*******************************************

l,11,27
l,13,28

l,9,26
l,15,29

l,7,25

l,1,22
l,17,30
l,21,33

l,1,23
l,17,31
l,21,34
```

```
l,1,24
l,17,32
l,21,35

/com, **********************************
/com, Meshing for Straight pipe
/com, **********************************

type,1
secnum,1
mat,1

lsel,r,,,1,14
allsel,below,line
lesize,all,,,2
lmesh,all

allsel,all,all

type,2
secnum,1
mat,2

lsel,r,,,15,20
allsel,below,line
lesize,all,,,4
lmesh,all

allsel,all,all

/com, *****************************************************************
/com,  Converting some PIPE289 into ELBOW290 using ELBOW command
/com, *****************************************************************

elbow,on,,,sect
allsel,all

/com, ****************************
/com, Elastic supports and anchors
/com, ****************************

type,3     !local x
real,4     ! 0.1e+9

lsel,r,,,23,24
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

real,5     ! 0.1e+11

lsel,r,,,26,28
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,4     ! local y
real,3     ! 0.1e+5

lsel,r,,,21,22
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

real,5
```

```
lsel,r,,,29,31
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,5     !local z
real,4     ! 0.1e+9

lsel,r,,,25
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

real,5

lsel,r,,,32,34
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all


n1 = 40
n2 = 107
n3 = 41

wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,11,0
nrotat,n1
nrotat,n2
csys,0

/com
/com, Mass Elements
/com,***************

type,6
real,6
e,49

/com,-----------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,,node,,106,119
d,all,all
allsel
d,1,rotx,,,,,roty,rotz
d,58,rotx,,,,,roty,rotz

allsel,all
finish

/com,-----------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal    ! Perform Modal Analysis
modopt,lanb,maxm
```

```
lumpm,on     ! Use Lumped Mass Matrix Approximation
mxpand,maxm,,,yes    ! Expand Solutions with Element Calculations ON
solve
finish

/post1
/out,
/com, *******************************************
/com,  Frequencies obtained from modal solution
/com, ********************************************
set,list
finish


/com,------------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,
/out,scratch

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,mprs,maxm     ! Multi Point Excitation Response Spectrum

gval = 386.4

/com,
/com, spectrum 1 (group 1 - X)
/com,**************************

spunit,1,accg, gval

spfrq,1,0.4,0.719942405,0.900090009,1.099989,1.350074254,1.800180018,2.200220022
spval,1,, 0.13,0.22,0.57,0.57,0.38,0.63,0.63

spfrq,1,2.699784017,3.51000351,4.679457183,5.720823799,6.600660066,8.576329331,11.00110011
spval,1,, 0.75,1.15,1.42,1.42,1.29,0.85,0.42

spfrq,1,33.00330033,34.96503497,39.0625
spval,1,,0.25,0.22,0.22

/com,
/com, spectrum 2 (group 1 - Y)
/com,**************************

spunit,2,accg, gval
spfrq,2,0.4,0.639795266,0.900090009,1.099989,1.43000143,1.649892757,1.800180018
spval,2,,0.18,0.18,0.995,0.995,0.715,0.35,0.42,

spfrq,2, 3.500175009,4.500450045,5.500550055,6.600660066,8.703220191,9.35453695,15.40832049
spval,2,,0.77,0.998,0.998,0.9,0.68,0.42,0.22

spfrq,2,16,28.49002849,31.94888179,39.0625
spval,2,,0.205,0.205,0.19,0.19

/com,
/com, spectrum 3 (group 1 - Z)
/com,**************************

spunit,3,accg, gval

spfrq,3,0.4,0.599880024,1.124985938,1.374948439,1.539882969,2.200220022,2.5
spval,3,, 0.17,0.17,1.6,1.6,0.78,0.3,0.3

spfrq,3,3.599712023,4.500450045,5.500550055,8.051529791,14.30615165,21.97802198,25.97402597
spval,3,,0.51,0.63,0.63,0.47,0.24,0.2,0.17

spfrq,3,39.0625
spval,3,,0.17
```

```
/com,
/com, spectrum 4 (group 2 - X)
/com,**************************

spunit,4,accg, gval

spfrq,4,0.4,0.480076812,0.539956803,1.17000117,1.43000143,1.649892757,2
spval,4,,0.17,0.17,0.23,2.25,2.25,1.07,0.75

spfrq,4,3.300330033,17.6056338,21.97802198,39.0625
spval,4,,0.38,0.03,0.23,0.23

/com,
/com, spectrum 5 (group 2 - Y)
/com,**************************

spunit,5,accg, gval

spfrq,5,0.4,0.610128127,1.124985938,1.374948439,1.759943682,2.474634991,4.500450045
spval,5,,0.17,0.3,2.87,2.87,1.5,0.9,0.85

spfrq,5,5.500550055,8,15.50387597,39.0625
spval,5,,0.85,0.65,0.37,0.37

/com,
/com, spectrum 6 (group 2 - Z)
/com,**************************

spunit,6,accg, gval

spfrq,6,0.4,0.5,0.599880024,1.124985938,1.374948439,1.700102006,2.699784017
spval,6,,0.2,0.2,0.362,3.55,3.55,1.95,1.08

spfrq,6,4.500450045,5.500550055,6.501950585,7.974481659,13.00390117,17.51313485,39.0625
spval,6,,1.38,1.38,1.3,1,0.65,0.55,0.55

/com,
/com, spectrum 7 (group 3 - X)
/com,**************************

spunit,7,accg, gval

spfrq,7,0.4,0.60204696,1.124985938,1.374948439,1.705029838,2.420135528,2.750275028
spval,7,,0.18,0.42,4.15,4.15,2.4,1.7,1.46

spfrq,7,3.41997264,4.679457183,5.720823799,6.600660066,9.900990099,15.12859304,16.50165017
spval,7,,1.6,2.05,2.05,1.75,0.9,0.77,0.65

spfrq,7,39.0625
spval,7,,0.65

/com,
/com, spectrum 8 (group 3 - Y)
/com,**************************

spunit,8,accg, gval

spfrq,8,0.4,0.576036866,0.704225352,0.900090009,1.080030241,1.800180018,2.610284521
spval,8,,0.14,0.28,0.28,0.17,0.28,0.53,0.56

spfrq,8,5.399568035,6.600660066,8.802816901,11.00110011,24.75247525,27.47252747,40
spval,8,,1.32,1.32,0.73,0.42,0.25,0.23,0.23

/com,
/com, spectrum 9 (group 3 - Z)
/com,**************************

spunit,9,accg, gval

spfrq,9,0.4,0.603136309,0.736919676,0.934579439,1.099989,1.374948439,1.425110446
spval,9,,0.224,0.535,0.535,0.498,0.25,0.195,0.125
```

```
spfrq,9,1.619957881,2.66028199,3.599712023,5.399568035,6.600660066,8.802816901,14.02524544
spval,9,,0.17,0.214,0.33,0.55,0.55,0.346,0.18

spfrq,9,17.00680272,28.65329513,31.94888179,39.0625
spval,9,,0.135,0.125,0.112,0.112

/com,
/com, spectrum 10 (group 4 - X)
/com,***************************

spunit,10,accg, gval

spfrq,10,0.4,0.630119723,0.765110941,0.934579439,1.319957761,2.035002035,2.699784017
spval,10,, 0.27,0.814,0.85,0.85,0.536,0.335,0.265

spfrq,10,5.399568035,6.600660066,8.802816901,14.85884101,18.01801802,39.0625
spval,10,, 0.31,0.31,0.215,0.14,0.126,0.126

/com,
/com, spectrum 11 (group 4 - Y)
/com,***************************

spunit,11,accg, gval

spfrq,11,0.4,0.765110941,0.934579439,1.374948439,1.665001665,2.035002035,4.319654428
spval,11,,0.34,1.2,1.2,0.85,0.68,0.68,0.85

spfrq,11,5.399568035,6.600660066,8.250825083,9.68054211,14.85884101,18.48428835,28.01120448
spval,11,,1.02,1.02,0.73,0.42,0.36,0.26,0.21

spfrq,11,39.0625
spval,11,,0.21

/com,
/com, spectrum 12 (group 4 - Z)
/com,***************************

spunit,12,accg, gval

spfrq,12,0.4,0.765110941,0.934579439,1.374948439,1.665001665,2.035002035,4.319654428
spval,12,,0.34,1.2,1.2,0.85,0.68,0.68,0.85

spfrq,12,5.399568035,6.600660066,8.250825083,9.68054211,14.85884101,18.48428835,28.01120448
spval,12,,1.02,1.02,0.73,0.42,0.36,0.26,0.21

spfrq,12,39.0625
spval,12,,0.21



/com,
/com, node components for excitation points
/com,***************************************

nsel,s,node,,108
nsel,a,node,,113
nsel,a,node,,117
cm,gp1,node
allsel,all,all

nsel,s,node,,116
nsel,a,node,,106,107
nsel,a,node,,111,112
cm,gp2,node
allsel,all,all

nsel,s,node,,109
nsel,a,node,,114
nsel,a,node,,118
cm,gp3,node
allsel,all,all
```

```
nsel,s,node,,110
nsel,a,node,,115
nsel,a,node,,119
cm,gp4,node
allsel,all,all

/com,-----------------------------------------------------------------------------------

/com, -- level #1 - spectrum 1
d,gp1,ux,1
pfact,1
d,gp1,all,0

/com, -- level #1 - spectrum 2
d,gp1,uy,1
pfact,2
d,gp1,all,0

/com, -- level #1 - spectrum 3
d,gp1,uz,1
pfact,3
d,gp1,all,0

/com, -- level #2 - spectrum 4
d,106,ux,-1
d,107,ux,0.5025
pfact,4
d,106,all,0
d,107,all,0

/com, -- level #2 - spectrum 5
d,111,uy,-1
d,112,uy,-1
d,107,ux,-0.5025
pfact,5
d,111,all,0
d,112,all,0
d,107,all,0

/com, -- level #2 - spectrum 6
d,116,uz,1
d,107,ux,0.7035
pfact,6
d,116,all,0
d,107,all,0

/com, -- level #3 - spectrum 7
d,gp3,ux,1
pfact,7
d,gp3,all,0

/com, -- level #3 - spectrum 8
d,gp3,uy,1
pfact,8
d,gp3,all,0

/com, -- level #3 - spectrum 9
d,gp3,uz,1
pfact,9
d,gp3,all,0


/com, -- level #4 - spectrum 10
d,gp4,ux,1
pfact,10
d,gp4,all,0

/com, -- level #4 - spectrum 11
d,gp4,uy,1
pfact,11
d,gp4,all,0
```

```
/com, -- level #4 - spectrum 12
d,gp4,uz,1
pfact,12
d,gp4,all,0

srss,0.0     ! Combine modes using SRSS combination
solve

/com,------------------------------------------------------------------------------

/post1
/input,,mcom


/out,

/com,
/com,==============================================================
/com, Maximum nodal displacements and rotations from spectrum solution
/com,==============================================================
/com,

/out,scratch

*GET,AdisX,NODE,95,U,X
*GET,AdisY,NODE,83,U,Y
*GET,AdisZ,NODE,40,U,Z
*GET,ArotX,NODE,6,ROT,X
*GET,ArotY,NODE,79,ROT,Y
*GET,ArotZ,NODE,45,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com,=============================================================
/com, Element Forces and Moments obtained from spectrum solution
/com,=============================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #1 (Pipe289 element)
/com,***********************


esel,s,elem,,1
etable,pxi_1,smisc,1
etable,vyi_1,smisc,6
etable,vzi_1,smisc,5
etable,txi_1,smisc,4
etable,myi_1,smisc,2
etable,mzi_1,smisc,3
esel,all

/out,
/com, ************************************************
/com,  Element forces and moments at element1, node i
/com, ************************************************

pretab,pxi_1,vyi_1,vzi_1,txi_1,myi_1,mzi_1


/out,scratch
```

```
/com,==========
/com,  Node J
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************

esel,s,elem,,1
etable,pxj_1,smisc,14
etable,vyj_1,smisc,19
etable,vzj_1,smisc,18
etable,txj_1,smisc,17
etable,myj_1,smisc,15
etable,mzj_1,smisc,16
esel,all

/out,
/com, ********************************************
/com,  Element forces and moments at element1, node j
/com, **********************************************

pretab,pxj_1,vyj_1,vzj_1,txj_1,myj_1,mzj_1



/out,scratch


/com,==========
/com,  Node I
/com,==========

/com, Element #41 (Elbow 290 element)
/com,*************************

esel,s,elem,,41
etable,pxi_41,smisc,1
etable,vyi_41,smisc,6
etable,vzi_41,smisc,5
etable,txi_41,smisc,4
etable,myi_41,smisc,2
etable,mzi_41,smisc,3
esel,all

/out,
/com, ***********************************************
/com,  Element forces and moments at element 41, node i
/com, **********************************************

pretab,pxi_41,vyi_41,vzi_41,txi_41,myi_41,mzi_41


/out,scratch
/com,==========
/com,  Node J
/com,==========



/com, Element #41 (Elbow290 element)
/com,********************************
esel,s,elem,,41

etable,pxj_41,smisc,36
etable,vyj_41,smisc,41
etable,vzj_41,smisc,40
etable,txj_41,smisc,39
etable,myj_41,smisc,37
etable,mzj_41,smisc,38
esel,all

allsel,all
```

```
/out,
/com, ***********************************************
/com,  Element forces and moments at element 41, node j
/com, *************************************************

pretab,pxj_41,vyj_41,vzj_41,txj_41,myj_41,mzj_41



/com,--------------------------------------------------------------------------

/com, ***************************************
/com,  Reaction forces from spectrum solution
/com, ****************************************

prrsol

finish
```

vm-nr1677-02-2c Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-02-2c
/title,vm-nr1677-02-2c,NRC piping benchmarks problems,Volume II,Problem 2c

/com, ********************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com, Elements used: PIPE289, ELBOW290, COMBIN14 and MASS21
/com,
/com, Results :
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, ********************************************************************************

/out,scratch

/prep7

YoungModulus1 = .240e+8    ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu)) ! Shear Modulus
WMass = 0.001056893    ! Density
WTick = 0.241     ! Wall Thickness
K = 0.71e-5

OD = 7.288      ! Outer Diameter
RADCUR = 36.30     ! Radius of Curvature

temp = 80      ! Temperature
maxm = 25      ! No. of Modes to Extract

et,1,pipe289,,,     ! Element 1 - PIPE289
et,2,elbow290,,6    ! Element 2 - ELBOW290

et,3,combin14     ! Element 3 - COMBIN14
keyopt,3,2,1     ! X Degree of Freedom
et,4,combin14     ! Element 4 - COMBIN14
keyopt,4,2,2     ! Y Degree of Freedom
et,5,combin14     ! Element 5 - COMBIN14
keyopt,5,2,3     ! Z Degree of Freedom
```

```
et,6,mass21      ! Element 6 - MASS21
keyopt,6,3,2     ! 3D mass without inertia

/com,-----------------------------------------------------------------------------------

/com, Real Constants
/com,****************

sectype,1,PIPE,ctube
secdata,OD,WTick,24

r,3,0.1e+5
r,4,0.1e+9
r,5,0.1e+11
r,6,1.518

/com,-----------------------------------------------------------------------------------

/com, Material Properties
/com,*********************

mp,ex,  1, YoungModulus1
mp,nuxy,1, Nu
mp,gxy ,1, ShearModulus1
mp,dens,1, WMass
mp,kxx,1, K

mp,ex,  2, YoungModulus1
mp,nuxy,2, Nu
mp,gxy ,2, ShearModulus1
mp,dens,2, WMass
mp,kxx,2, K

/com,-----------------------------------------------------------------------------------

/com, Keypoints
/com,**********

k,1,0,0,0
k,2,0,54.45,0
k,3,0,108.9,0
k,4,10.632,134.568,0
k,5,36.3,145.2,0
k,6,54.15,145.2,0
k,7,72.0,145.2,0
k,8,97.668,145.2,10.632
k,9,108.3,145.2,36.3
k,10,108.3,145.2,56.8
k,11,108.3,145.2,77.3
k,12,108.3,145.2,97.8
k,13,108.3,145.2,118.3
k,14,108.3,145.2,188.8
k,15,108.3,181.5,225.1
k,16,108.3,236,225.1
k,17,108.3,290,225.1
k,18,148.3,145.2,97.8
k,19,188.3,145.2,97.8
k,20,224.6,145.2,61.5
k,21,224.6,145.2,20

/com,
/com, Elastic Support Keypoints
/com,*************************

k,22,1,0,0
k,23,0,1,0
k,24,0,0,1
k,25,72,145.2,-1
k,26,109.3,145.2,36.3
k,27,108.3,146.2,77.3
k,28,108.3,146.2,118.3
k,29,107.3,182.5,226.5
```

```
k,30,109.3,290,225.1
k,31,108.3,291,225.1
k,32,108.3,290,226.1
k,33,225.6,145.2,20
k,34,224.6,146.2,20
k,35,224.6,145.2,21

/com,-----------------------------------------------------------------------------------

/com,
/com, Modeling for Straight Pipe
/com,*********************************

l, 1, 2
l, 2, 3
l, 5, 6
l, 6, 7
l, 9,10
l,10,11
l,11,12
l,12,13
l,13,14
l,15,16
l,16,17
l,12,18
l,18,19
l,20,21

/com,
/com, Modeling for Pipe Bend
/com,***********************

larc, 3, 4, 2, RADCUR
larc, 4, 5, 6, RADCUR
larc, 7, 8, 6, RADCUR
larc, 8, 9,10, RADCUR
larc,14,15,16, RADCUR
larc,19,20,18, RADCUR

/com,
/com, Modeling for Elastic Supports and Anchors
/com,******************************************

l,11,27
l,13,28

l,9,26
l,15,29

l,7,25

l,1,22
l,17,30
l,21,33

l,1,23
l,17,31
l,21,34

l,1,24
l,17,32
l,21,35

/com, *********************************
/com, Meshing for Straight pipe
/com, *********************************

type,1
secnum,1
mat,1

lsel,r,,,1,14
```

```
allsel,below,line
lesize,all,,,2
lmesh,all

allsel,all,all

type,2
secnum,1
mat,2

lsel,r,,,15,20
allsel,below,line
lesize,all,,,4
lmesh,all

allsel,all,all

/com, ****************************************************************
/com,  Converting some PIPE289 into ELBOW290 using ELBOW command
/com, ****************************************************************

elbow,on,,,sect
allsel,all

/com, ****************************
/com, Elastic supports and anchors
/com, ****************************

type,3     !local x
real,4     ! 0.1e+9

lsel,r,,,23,24
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

real,5     ! 0.1e+11

lsel,r,,,26,28
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,4     ! local y
real,3     ! 0.1e+5

lsel,r,,,21,22
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

real,5

lsel,r,,,29,31
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,5     !local z
real,4     ! 0.1e+9

lsel,r,,,25
allsel,below,line
lesize,all,,,1
```

```
lmesh,all

allsel,all,all

real,5

lsel,r,,,32,34
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all


n1 = 40
n2 = 107
n3 = 41

wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,11,0
nrotat,n1
nrotat,n2
csys,0

/com
/com, Mass Elements
/com,***************

type,6
real,6
e,49

/com,------------------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,,node,,106,119
d,all,all
allsel
d,1,rotx,,,,,roty,rotz
d,58,rotx,,,,,roty,rotz

allsel,all
finish

/com,------------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal    ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on     ! Use Lumped Mass Matrix Approximation
mxpand,maxm,,,yes    ! Expand Solutions with Element Calculations ON
solve
finish

/post1
/out,
/com, *******************************************
/com,  Frequencies obtained from modal solution
/com, ********************************************
set,list
finish
```

```
/com,------------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/out,scratch
/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,mprs,maxm     ! Multi Point Excitation Response Spectrum

gval = 386.4

/com,------------------------------------------------------------------------------------

/com,
/com, spectrum 1 (group 1 - X)
/com,**************************

spunit,1,accg, gval

spfrq,1,0.4,0.719942405,0.900090009,1.099989,1.350074254,1.800180018,2.200220022
spval,1,, 0.13,0.22,0.57,0.57,0.38,0.63,0.63

spfrq,1,2.699784017,3.51000351,4.679457183,5.720823799,6.600660066,8.576329331,11.00110011
spval,1,, 0.75,1.15,1.42,1.42,1.29,0.85,0.42

spfrq,1,33.00330033,34.96503497,39.0625
spval,1,,0.25,0.22,0.22

/com,
/com, spectrum 2 (group 1 - Y)
/com,**************************

spunit,2,accg, gval
spfrq,2,0.4,0.639795266,0.900090009,1.099989,1.43000143,1.649892757,1.800180018
spval,2,,0.18,0.18,0.995,0.995,0.715,0.35,0.42,

spfrq,2, 3.500175009,4.500450045,5.500550055,6.600660066,8.703220191,9.35453695,15.40832049
spval,2,,0.77,0.998,0.998,0.9,0.68,0.42,0.22

spfrq,2,16,28.49002849,31.94888179,39.0625
spval,2,,0.205,0.205,0.19,0.19

/com,
/com, spectrum 3 (group 1 - Z)
/com,**************************

spunit,3,accg, gval

spfrq,3,0.4,0.599880024,1.124985938,1.374948439,1.539882969,2.200220022,2.5
spval,3,, 0.17,0.17,1.6,1.6,0.78,0.3,0.3

spfrq,3,3.599712023,4.500450045,5.500550055,8.051529791,14.30615165,21.97802198,25.97402597
spval,3,,0.51,0.63,0.63,0.47,0.24,0.2,0.17

spfrq,3,39.0625
spval,3,,0.17

/com,
/com, spectrum 4 (group 2 - X)
/com,**************************

spunit,4,accg, gval

spfrq,4,0.4,0.480076812,0.539956803,1.17000117,1.43000143,1.649892757,2
spval,4,,0.17,0.17,0.23,2.25,2.25,1.07,0.75

spfrq,4,3.300330033,17.6056338,21.97802198,39.0625
spval,4,,0.38,0.03,0.23,0.23
```

```
/com,
/com, spectrum 5 (group 2 - Y)
/com,**************************

spunit,5,accg, gval

spfrq,5,0.4,0.610128127,1.124985938,1.374948439,1.759943682,2.474634991,4.500450045
spval,5,,0.17,0.3,2.87,2.87,1.5,0.9,0.85

spfrq,5,5.500550055,8,15.50387597,39.0625
spval,5,,0.85,0.65,0.37,0.37

/com,
/com, spectrum 6 (group 2 - Z)
/com,**************************

spunit,6,accg, gval

spfrq,6,0.4,0.5,0.599880024,1.124985938,1.374948439,1.700102006,2.699784017
spval,6,,0.2,0.2,0.362,3.55,3.55,1.95,1.08

spfrq,6,4.500450045,5.500550055,6.501950585,7.974481659,13.00390117,17.51313485,39.0625
spval,6,,1.38,1.38,1.3,1,0.65,0.55,0.55

/com,
/com, spectrum 7 (group 3 - X)
/com,**************************

spunit,7,accg, gval

spfrq,7,0.4,0.60204696,1.124985938,1.374948439,1.705029838,2.420135528,2.750275028
spval,7,,0.18,0.42,4.15,4.15,2.4,1.7,1.46

spfrq,7,3.41997264,4.679457183,5.720823799,6.600660066,9.900990099,15.12859304,16.50165017
spval,7,,1.6,2.05,2.05,1.75,0.9,0.77,0.65

spfrq,7,39.0625
spval,7,,0.65

/com,
/com, spectrum 8 (group 3 - Y)
/com,**************************

spunit,8,accg, gval

spfrq,8,0.4,0.576036866,0.704225352,0.900090009,1.080030241,1.800180018,2.610284521
spval,8,,0.14,0.28,0.28,0.17,0.28,0.53,0.56

spfrq,8,5.399568035,6.600660066,8.802816901,11.00110011,24.75247525,27.47252747,40
spval,8,,1.32,1.32,0.73,0.42,0.25,0.23,0.23

/com,
/com, spectrum 9 (group 3 - Z)
/com,**************************

spunit,9,accg, gval

spfrq,9,0.4,0.603136309,0.736919676,0.934579439,1.099989,1.374948439,1.425110446
spval,9,,0.224,0.535,0.535,0.498,0.25,0.195,0.125

spfrq,9,1.619957881,2.66028199,3.599712023,5.399568035,6.600660066,8.802816901,14.02524544
spval,9,,0.17,0.214,0.33,0.55,0.55,0.346,0.18

spfrq,9,17.00680272,28.65329513,31.94888179,39.0625
spval,9,,0.135,0.125,0.112,0.112

/com,
/com, spectrum 10 (group 4 - X)
/com,**************************

spunit,10,accg, gval
```

```
spfrq,10,0.4,0.630119723,0.765110941,0.934579439,1.319957761,2.035002035,2.699784017
spval,10,, 0.27,0.814,0.85,0.85,0.536,0.335,0.265

spfrq,10,5.399568035,6.600660066,8.802816901,14.85884101,18.01801802,39.0625
spval,10,, 0.31,0.31,0.215,0.14,0.126,0.126

/com,
/com, spectrum 11 (group 4 - Y)
/com,***************************

spunit,11,accg, gval

spfrq,11,0.4,0.765110941,0.934579439,1.374948439,1.665001665,2.035002035,4.319654428
spval,11,,0.34,1.2,1.2,0.85,0.68,0.68,0.85

spfrq,11,5.399568035,6.600660066,8.250825083,9.68054211,14.85884101,18.48428835,28.01120448
spval,11,,1.02,1.02,0.73,0.42,0.36,0.26,0.21

spfrq,11,39.0625
spval,11,,0.21

/com,
/com, spectrum 12 (group 4 - Z)
/com,***************************

spunit,12,accg, gval

spfrq,12,0.4,0.765110941,0.934579439,1.374948439,1.665001665,2.035002035,4.319654428
spval,12,,0.34,1.2,1.2,0.85,0.68,0.68,0.85

spfrq,12,5.399568035,6.600660066,8.250825083,9.68054211,14.85884101,18.48428835,28.01120448
spval,12,,1.02,1.02,0.73,0.42,0.36,0.26,0.21

spfrq,12,39.0625
spval,12,,0.21

/com,
/com, node components for excitation points
/com,***************************************

nsel,s,node,,108
nsel,a,node,,113
nsel,a,node,,117
cm,gp1,node
allsel,all,all

nsel,s,node,,116
nsel,a,node,,106,107
nsel,a,node,,111,112
cm,gp2,node
allsel,all,all

nsel,s,node,,109
nsel,a,node,,114
nsel,a,node,,118
cm,gp3,node
allsel,all,all

nsel,s,node,,110
nsel,a,node,,115
nsel,a,node,,119
cm,gp4,node
allsel,all,all

/com,-------------------------------------------------------------------------------------

! -- level #1 - spectrum 1 (Along X - Direction)

sed,1,,,gp1
pfact,1
sed,0,,,gp1
```

```
! -- level #1 - spectrum 2 (Along Y - Direction)

sed,,1,,gp1
pfact,2
sed,,0,,gp1

! -- level #1 - spectrum 3 (Along Z - Direction)

sed,,,1,gp1
pfact,3
sed,,,0,gp1

! -- level #2 - spectrum 4 (Along X - Direction)

sed,1,,,gp2
pfact,4
sed,0,,,gp2

! -- level #2 - spectrum 5 (Along Y - Direction)

sed,,1,,gp2
pfact,5
sed,,0,,gp2

! -- level #2 - spectrum 6 (Along Z - Direction)

sed,,,1,gp2
pfact,6
sed,,,0,gp2

! -- level #3 - spectrum 7 (Along X - Direction)

sed,1,,,gp3
pfact,7
sed,0,,,gp3

! -- level #3 - spectrum 8 (Along Y - Direction)

sed,,1,,gp3
pfact,8
sed,,0,,gp3

! -- level #3 - spectrum 9 (Along Z - Direction)

sed,,,1,gp3
pfact,9
sed,,,0,gp3

! -- level #4 - spectrum 10 (Along X - Direction)

sed,1,,,gp4
pfact,10
sed,0,,,gp4

! -- level #4 - spectrum 11 (Along Y - Direction)

sed,,1,,gp4
pfact,11
sed,,0,,gp4

! -- level #4 - spectrum 12 (Along Z - Direction)

sed,,,1,gp4
pfact,12
sed,,,0,gp4

srss,0.0,,YES ! activate Absolute Sum for MPRS

solve

finish
```

```
/com,------------------------------------------------------------------------------------

/post1
/input,,mcom


/out,
/com,
/com,==============================================================
/com, Maximum nodal displacements and rotations from spectrum solution
/com,==============================================================
/com,

/out,scratch

*GET,AdisX,NODE,95,U,X
*GET,AdisY,NODE,84,U,Y
*GET,AdisZ,NODE,40,U,Z
*GET,ArotX,NODE,6,ROT,X
*GET,ArotY,NODE,79,ROT,Y
*GET,ArotZ,NODE,45,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com,=============================================================
/com, Element Forces and Moments obtained from spectrum solution
/com,=============================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************


esel,s,elem,,1
etable,pxi_1,smisc,1
etable,vyi_1,smisc,6
etable,vzi_1,smisc,5
etable,txi_1,smisc,4
etable,myi_1,smisc,2
etable,mzi_1,smisc,3
esel,all

/out,
/com, ***********************************************
/com,  Element forces and moments at element1, node i
/com, ***********************************************

pretab,pxi_1,vyi_1,vzi_1,txi_1,myi_1,mzi_1


/out,scratch
/com,==========
/com,  Node J
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************

esel,s,elem,,1
etable,pxj_1,smisc,14
```

```
etable,vyj_1,smisc,19
etable,vzj_1,smisc,18
etable,txj_1,smisc,17
etable,myj_1,smisc,15
etable,mzj_1,smisc,16
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element1, node j
/com, ************************************************

pretab,pxj_1,vyj_1,vzj_1,txj_1,myj_1,mzj_1



/out,scratch


/com,==========
/com,  Node I
/com,==========

/com, Element #41 (Elbow 290 element)
/com,*************************

esel,s,elem,,41
etable,pxi_41,smisc,1
etable,vyi_41,smisc,6
etable,vzi_41,smisc,5
etable,txi_41,smisc,4
etable,myi_41,smisc,2
etable,mzi_41,smisc,3
esel,all

/out,
/com, *************************************************
/com,  Element forces and moments at element 41, node i
/com, ************************************************

pretab,pxi_41,vyi_41,vzi_41,txi_41,myi_41,mzi_41


/out,scratch
/com,==========
/com,  Node J
/com,==========



/com, Element #41 (Elbow290 element)
/com,********************************
esel,s,elem,,41

etable,pxj_41,smisc,36
etable,vyj_41,smisc,41
etable,vzj_41,smisc,40
etable,txj_41,smisc,39
etable,myj_41,smisc,37
etable,mzj_41,smisc,38
esel,all

allsel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element 41, node j
/com, ************************************************

pretab,pxj_41,vyj_41,vzj_41,txj_41,myj_41,mzj_41
```

```
/com,-------------------------------------------------------------------------------

/com, ***************************************
/com,  Reaction forces from spectrum solution
/com, ****************************************

prrsol

finish
```

vm-nr1677-02-3a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-02-3a
/title,vm-nr1677-02-3a,NRC piping benchmarks problems,Volume II,Problem 3a
/com, ***********************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com, Elements used: PIPE289, ELBOW290, COMBIN14
/com,
/com, Results:
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, ***************************************************************************

/out,scratch

/prep7

YoungModulus1 = 0.277e+08   ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu)) ! Shear Modulus
WMass = 1.546e-03     ! Density
WTick=0.3750     ! Wall Thickness
OD=12.750      ! Outer Diameter

Temperature = 400
Pressue = 615
maxm=15      ! No. of Modes to Extract

radcur1 = -60              ! radius of curvature for bend pipes
radcur2 = -18              ! radius of curvature for bend pipes


/com,---------------------------------------------------------------------------------

et, 1,pipe289,,,    ! Element 1 - PIPE289
et, 2,elbow290,,6    ! Element 2 - ELBOW290
et, 3,elbow290,,6    ! Element 3 - ELBOW290

et, 4,combin14     ! Element 4 - COMBIN14
keyopt,4,2,2     ! Y Degree of Freedom
et, 5,combin14     ! Element 5 - COMBIN14
keyopt,5,2,1     ! X Degree of Freedom
et, 6,combin14     ! Element 6 - COMBIN14
keyopt,6,2,2     ! Y Degree of Freedom
et, 7,combin14     ! Element 7 - COMBIN14
keyopt,7,2,3     ! Z Degree of Freedom
et, 8,combin14     ! Element 8 - COMBIN14
keyopt,8,2,4     ! ROT-X Degree of Freedom
```

```
et, 9,combin14     ! Element 9 - COMBIN14
keyopt,9,2,5     ! ROT-Y Degree of Freedom
et,10,combin14     ! Element 10 - COMBIN14
keyopt,10,2,6     ! ROT-Z Degree of Freedom

/com,------------------------------------------------------------------------------------------

/com, Real Constants
/com,****************

sectype,1,pipe
secdata,OD,WTick,24

r, 4, 0.1e+2
r, 5, 0.1e+13
r, 6, 0.1e+13
r, 7, 0.1e+13
r, 8, 0.1e+13
r, 9, 0.1e+13
r,10, 0.1e+13

/com, ------------------------------------------------------------------------------------------

/com, Material Properties
/com,*********************

mp,ex,  1, YoungModulus1
mp,nuxy,1, Nu
mp,gxy ,1, ShearModulus1
mp,dens,1, WMass



/com,------------------------------------------------------------------------------------------

/com, key points
/com,*******

k,1,0,1226.875,0
k,2,30.021,1226.875,30.550
k,3,60.042,1226.875,61.100
k,4,90.064,1226.875,91.651
k,5,105.154,1226.875,102.817
k,6,139.302,1226.875,120.593
k,7,181.878,1226.875,142.757
k,8,224.435,1226.875,164.922
k,9,243.383,1226.875,174.774
k,10,262.311,1226.875,184.628
k,11,292.798,1226.875,191.342

k,12,334.171,1226.875,189.421
!k,120,334.171,1226.875,189.421

k,13,375.543,1226.875,187.500

k,14,405.511,1226.875,186.110
k,140,431.483,1226.875,184.904

k,15,501.172,1226.875,181.669
k,16,570.860,1226.875,178.433
k,17,579.777,1226.875,178.683
k,18,615.118,1226.875,182.316
k,20,633.028,1226.875,184.156

k,21,678.227,1226.875,188.802
k,22,723.426,1226.875,193.448
k,23,768.625,1226.875,198.095
k,24,809.602,1226.875,187.256
k,25,814.057,1226.875,184.079
k,26,852.626,1226.875,156.568
k,27,891.195,1226.875,129.058
k,28,929.764,1226.875,101.547
```

```
k,29,968.332,1226.875,74.036
k,290,978.101,1226.875,67.067

k,31,1012.600,1226.875,42.430
!k,310,1012.600,1226.875,42.430

k,32,1047.098,1226.875,17.793
k,34,1061.752,1244.875,7.340
k,35,1061.752,1272.375,7.340
k,36,1072.214,1290.375,-7.307
k,37,1081.623,1290.375,-20.48
k,38,1108.85,1290.375,-58.399
k,39,1136.077,1290.375,-96.317
k,40,1163.304,1290.375,-134.236
k,41,1190.531,1290.375,-172.154

/com,
/com, Elastic Support
/com,***********************

k,410,1190.531,1290.375,-172.154

k,43,1197.006,1290.375,-182.019
k,44,1207.729,1290.375,-209.536
k,45,1211.63,1290.375,-241.111
k,46,1215.531,1290.375,-272.687
k,47,1219.432,1290.375,-304.262
k,48,1223.333,1290.375,-335.873
k,49,1227.234,1290.375,-367.413

k,51,1232.114,1290.375,-407.115
k,52,1233.704,1295.647,-419.787
k,53,1234.945,1305.772,-429.836

k,55,1254.329,1318.500,-439.952
k,56,1279.579,1318.500,-436.387
k,57,1304.829,1318.500,-432.823
k,58,1330.078,1318.500,-429.258
k,59,1355.328,1318.500,-425.693

!k,61,431.943,1226.875,194.899
!k,62,616.14,1226.875,172.368
!k,63,974.139,1226.875,82.176
k,65,1227.234,1300.375,-367.413
!k,66,1255.726,1318.500,-449.852

!k,67,1182.401,1290.375,-177.966
k,68,105.154,1236.875,102.817
k,69,224.435,1236.875,164.922
k,70,405.511,1236.875,186.110
k,71,633.028,1236.875,184.156
k,72,814.057,1236.875,184.079
k,73,978.101,1236.875,67.067
k,74,1081.623,1300.375,-20.48
k,75,1190.531,1300.375,-172.154

!k,101,10,1226.875,0
!k,102,0,1236.875,0
!k,103,0,1226.875,10

!k,591,1345.328,1318.5,-425.693
!k,592,1355.328,1328.5,-425.693
!k,593,1355.328,1318.5,-415.693

k,601,93.495,1226.9,94.879

k,701,90.618,1226.9,92.207
k,702,91.180,1226.9,92.757
k,703,91.748,1226.9,93.298
k,704,92.324,1226.9,93.833
k,705,92.906,1226.9,94.360
```

```
k,711,94.091,1226.9,95.390
k,712,94.694,1226.9,95.894
k,713,95.304,1226.9,96.390
k,714,95.919,1226.9,96.877
k,715,96.542,1226.9,97.357

k,602,97.170,1226.9,97.828

k,721,97.804,1226.9,98.291
k,722,98.443,1226.9,98.746
k,723,99.089,1226.9,99.192
k,724,99.740,1226.9,99.630
k,725,100.40,1226.9,100.06

k,731,101.73,1226.9,100.89
k,732,102.40,1226.9,101.29
k,733,103.08,1226.9,101.69
k,734,103.77,1226.9,102.07
k,735,104.46,1226.9,102.45

k,603,101.06,1226.9,100.48

k,741,267.08,1226.9,186.85
k,742,272.03,1226.9,188.65
k,743,277.11,1226.9,190.00
k,744,282.29,1226.9,190.91
k,745,287.54,1226.9,191.36

k,751,572.35,1226.9,178.38
k,752,573.84,1226.9,178.37
k,753,575.32,1226.9,178.39
k,754,576.81,1226.9,178.45
k,755,578.29,1226.9,178.55

k,761,775.83,1226.9,198.40
k,762,783.03,1226.9,197.84
k,763,790.10,1226.9,196.41
k,764,796.95,1226.9,194.15
k,765,803.49,1226.9,191.09

k,771,1199.7,1290.4,-186.18
k,772,1202.1,1290.4,-190.55
k,773,1204.1,1290.4,-195.11
k,774,1205.7,1290.4,-199.81
k,775,1206.9,1290.4,-204.63

k,781,1050.9,1227.5,15.088
k,782,1054.4,1229.3,12.567
k,783,1057.5,1232.1,10.402
k,784,1059.8,1235.9,8.7405
k,785,1061.3,1240.2,7.6962

k,791,1062.1,1277.0,6.8409
k,792,1063.2,1281.4,5.3777
k,793,1064.8,1285.1,3.0499
k,794,1067.0,1288.0,0.16395E-01
k,795,1069.5,1289.8,-3.5163

k,801,1232.4,1290.5,-409.45
k,802,1232.7,1291.0,-411.75
k,803,1233.0,1291.7,-413.97
k,804,1233.2,1292.8,-416.08
k,805,1233.5,1294.1,-418.02

k,811,1236.0,1309.0,-432.99
k,812,1238.2,1312.1,-435.76
k,813,1241.3,1314.7,-437.97
k,814,1245.3,1316.7,-439.46
k,815,1249.7,1318.0,-440.13

/com,-------------------------------------------------------------------------------------
```

```
/com,
/com, Straight Pipe (Tangent) Elements
/com,**********************************

mat,1      ! Material ID 1
type,1      ! Element Type 1
secnum,1     ! Section 1

l,1,2                       ! line number 1
l,2,3
l,3,4

l,5,6
l,6,7
l,7,8

l,8,9
l,9,10

l,11,12
l,12,13
l,13,14
l,14,140
l,140,15
l,15,16

l,17,18

l,18,20
l,20,21
l,21,22
l,22,23

l,24,25
l,25,26
l,26,27
l,27,28
l,28,29
l,29,290
l,290,31
l,31,32

l,34,35

l,36,37
l,37,38
l,38,39
l,39,40
l,40,41
l,41,43

l,44,45
l,45,46
l,46,47
l,47,48
l,48,49
l,49,51

l,52,53

l,55,56
l,56,57
l,57,58
l,58,59              ! line number 45

lesize,all,,,1
lmesh,all
allsel,all

/com,
/com, Pipe Bend Elements
```

```
/com,********************

type,2
secnum,1
mat,1

larc,4,702,701, radcur1         ! line number 46
larc,702,704,703, radcur1
larc,704,601,705, radcur1
larc,601,712,711, radcur1
larc,712,714,713, radcur1
larc,714,602,715, radcur1
larc,602,722,721, radcur1
larc,722,724,723, radcur1
larc,724,603,725, radcur1
larc,603,732,731, radcur1
larc,732,734,733, radcur1
larc,734,5,735, radcur1
larc,10,742,741, radcur1
larc,742,744,743, radcur1
larc,744,11,745, radcur1
larc,16,752,751, radcur1
larc,752,754,753, radcur1
larc,754,17,755, radcur1
larc,23,762,761, radcur1
larc,762,764,763, radcur1
larc,764,24,765, radcur1
larc,43,772,771, radcur1
larc,772,774,773, radcur1
larc,774,44,775, radcur1            ! line number 69

lsel,s,line,,46,69,1
lesize,all,,,1
lmesh,all
allsel,all


type,3
secnum,1
mat,1

larc,32,782,781, radcur2            ! line number 70
larc,782,784,783, radcur2
larc,784,34,785, radcur2
larc,35,792,791, radcur2
larc,792,794,793, radcur2
larc,794,36,795, radcur2
larc,51,802,801, radcur2
larc,802,804,803, radcur2
larc,804,52,805, radcur2
larc,53,812,811, radcur2
larc,812,814,813, radcur2
larc,814,55,815, radcur2            ! line number 81


lsel,s,line,,70,81,1
lesize,all,,,1
lmesh,all
allsel,all
/com,

/com, Spring Elements
/com,*****************

type,4
real,4
l,49,65                         ! line number 82

lesize,82,,,1
lmesh,all
allsel,all
```

```
type,6
real,6
l,5,68                          ! line number 83
l,8,69
l,14,70
l,20,71
l,25,72
l,290,73
l,37,74
l,410,75                        ! line number 90

lsel,s,line,,83,90,1
lesize,all,,,1
lmesh,all
allsel,all


n1 = node(1254.329,1318.500,-439.952)

n,66000,1255.726,1318.500,-449.852

n3 = node(1279.579,1318.500,-436.387)
n4 = node(1190.531,1290.375,-172.154)

n, 67000,1182.401,1290.375,-177.966

n6 = node(1163.304,1290.375,-134.236)
n7 = node(375.543,1226.875,187.500)

n, 120000,334.171,1226.875,189.421

n9 = node(1355.328,1318.500,-425.693)
n10 = node(431.483,1226.875,184.904)

n,61000,431.943,1226.875,194.899

n12 = node(501.172,1226.875,181.669)
n13 = node(615.118,1226.875,182.316)

n,62000,616.14,1226.875,172.368

n15 = node(579.777,1226.875,178.683)
n16 = node(968.332,1226.875,74.036)

n,63000,974.139,1226.875,82.176

n18 = node(929.764,1226.875,101.547)
n19 = node(1047.098,1226.875,17.793)

n,310000,1012.600,1226.875,42.430

n21 = node(1061.752,1244.875,7.340)
n22 = node(1190.531,1290.375,-172.154)

!n,410000,1190.531,1290.375,-172.154

n,61000,431.943,1226.875,194.899

n,62000,616.14,1226.875,172.368

n,63000,974.139,1226.875,82.176

n27 = node(1227.234,1300.375,-367.413)

n,66000,1255.726,1318.500,-449.852

n,67000,1182.401,1290.375,-177.966


n30 = node(105.154,1236.875,102.817)
n31 = node(224.435,1236.875,164.922)
n32 = node(405.511,1236.875,186.110)
```

```
n33 = node(633.028,1236.875,184.156)
n34 = node(814.057,1236.875,184.079)
n35 = node(978.101,1236.875,67.067)
n36 = node(1081.623,1300.375,-20.48)
n37 = node(1190.531,1300.375,-172.154)

n,101000,10,1226.875,0

n,102000,0,1236.875,0

n,103000,0,1226.875,10

n,120000,334.171,1226.875,189.421

n,310000,1012.600,1226.875,42.430

n,591000,1345.328,1318.5,-425.693

n,592000,1355.328,1328.5,-425.693

n,593000,1355.328,1318.5,-415.693

n46 = node(0,1226.875,0)


type,5
real,5
n1 = 92
n2 = 66000
n3 = 93

ics = 11
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 72
n2 = 67000
n3 = 70

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

/com,
/com, Snubber Elements
/com,*****************

n1 = 22
n2 = 120000
n3 = 99

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 26
n2 = 61000
n3 = 28

ics = ics + 1
```

```
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 33
n2 = 62000
n3 = 32

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 52
n2 = 63000
n3 = 50

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 58
n2 = 310000
n3 = 60
!n3 = 59

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

/com,
/com, 3D Support at both ends
/com,*************************

type,5
real,5
e,1,101000
e,99,591000

type,6
real,6
e,1,102000
e,99,592000

type,7
real,7
e,1,103000
e,99,593000

type,8
real,8
e,1,101000
e,99,591000

type,9
real,9
e,1,102000
e,99,592000
```

```
type,10
real,10
e,1,103000
e,99,593000

/com,-------------------------------------------------------------------------------------

/com,
/com, Model Rigid Region
/com,********************

cerig,72,172,uy

/com,-------------------------------------------------------------------------------------

/com,
/com, Convert some PIPE289 into ELBOW290 using ELBOW command
/com,

elbow,on,,,sect
allsel,all


/com,
/com, Constraints
/com,*************

nsel,s,node,,61000,63000
nsel,a,node,,164
nsel,a,node,,66000,67000,1
nsel,a,node,,165,173,1
nsel,a,node,,101000,103000
nsel,a,node,,120000
nsel,a,node,,310000
nsel,a,node,,591000,593000
d,all,all,0

nsel,all

/com,-------------------------------------------------------------------------------------

/com,
/com, Loads
/com,*******

/com, Temperature Input
/com,*******************

bf,all,temp,Temperature

esel,r,type,,1
esel,a,type,,2
esel,a,type,,3

/com, Pressure Input
/com,****************

sfe,all,1,pres,,Pressue,,,

allsel,all,all
finish

/com,-------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
```

```
antype,modal       ! Perform modal solve
modopt,lanb,maxm
lump,on        ! Lumped mass formulation
mxpand,maxm,,,yes       ! Expand the modes with stress calculation
solve
save,
finish


/post1
/out,
/com, ********************************************
/com,  Frequencies obtained from modal solution
/com, *********************************************
set,list
finish


/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/out,scratch

/solution
gvalue = 386.4

sfedele,all,1,pres,,,
bfdele,all,temp,,,

antype,spectrum      ! Perform Spectrum Analysis
spopt,sprs,maxm      ! Single Point Excitation Response System

srss,,,       ! SRSS mode combination method

/com,
/com,  Excitation in X - Direction
/com,*******************************

svtyp,2,gvalue           ! Acceleration Response Spectrum

freq,1.000,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937,1.3423,1.3889
sv,,1.1620,1.2820,1.3990,1.5490,1.6060,1.6760,1.7040,1.7740,1.8390

freq,1.4104,1.4347,1.5552,1.6949,1.7825,1.9305,2.0747,2.2779,2.4752
sv,,1.8690,1.9040,2.0840,2.2460,2.3040,2.3830,2.4790,2.5920,2.6440

freq,2.6042,2.6596,2.9499,3.2362,3.3898,3.4965,3.5714,3.6101,3.6630
sv,,2.6400,2.6390,2.7820,2.9510,3.0660,3.2150,3.3840,3.5320,3.7660

freq,3.7313,3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505,5.0761
sv,,4.1890,4.7930,5.1890,5.2240,5.2320,5.2270,5.1520,3.0020,2.9230

freq,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627,7.8125,7.8740,7.9365
sv,,2.9000,2.8730,2.8490,2.8440,2.7610,2.6670,2.6350,2.7850,2.7550

freq,8.3333,8.9286,9.5238,9.6154,9.7087,10.4167,10.8696,11.6279,11.7647
sv,,2.8070,2.7970,2.7440,2.6740,2.6270,2.7810,2.9310,3.0770,3.1120

freq,12.1951,12.5000,12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
sv,,3.1340,3.1340,3.1160,2.9750,2.6870,2.5600,2.3990,2.0640,1.8550


freq,15.3846,15.6250,17.8571,18.8679,22.7273,23.8095,24.3902,25.6410,26.3158
sv,,1.5240,1.5120,1.4720,1.3350,1.0900,1.0730,1.0700,1.0490,1.0040


freq,27.0270,27.7778,28.5714,40.000,76.9231,1000.0000
sv,,0.9823,0.9669,0.9560,0.8930,0.8300,0.7710
```

```
sed,1,0,0       ! Excitation in X - Direction
solve

/com,
/com, Excitation in Y - Direction
/com,******************************

svtyp,2,gvalue
freq,,

freq,0.5,2,2.100,2.898,4,5,7.692,8.474,10.309
sv,,0.380,2.050,2.750,2.750,3.500,3.500,5.800,12.100,12.100

freq,11.494,14.104,15.384,17.605,23.255,50
sv,,10.700,10.700,5.900,5.900,2.050,1.570

sed,0,1,0       ! Excitation in Y - Direction
solve

/com,
/com, Excitation in Z - Direction
/com,******************************

svtyp,2,gvalue
freq,,,

freq,1,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937,1.3423,1.3889
sv,,1.1620,1.2820,1.3990,1.5490,1.6060,1.6760,1.7040,1.7740,1.8390

freq,1.4104,1.4347,1.5552,1.6949,1.7825,1.9305,2.0747,2.2779,2.4752
sv,,1.8690,1.9040,2.0840,2.2460,2.3040,2.3820,2.4790,2.5920,2.6440

freq,2.6042,2.6596,2.9499,3.2362,3.3898,3.4965,3.5714,3.6101,3.6630
sv,,2.6400,2.6390,2.7820,2.9510,3.0660,3.2150,3.3840,3.5320,3.7660

freq,3.7313,3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505,5.0761
sv,,4.1890,4.7930,5.1890,5.2240,5.2320,5.2270,5.1520,3.0020,2.9230

freq,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627,7.8125,7.8740,7.9365
sv,,2.900,2.8730,2.8490,2.8440,2.7610,2.6670,2.6350,2.6850,2.7550

freq,8.333,8.9286,9.5238,9.6154,9.7087,10.4167,10.8696,11.6279,11.7647
sv,,2.8070,2.7970,2.7440,2.6740,2.6270,2.7810,2.9310,3.0770,3.1120

freq,12.1951,12.5000,12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
sv,,3.1340,3.1340,3.1160,2.9750,2.6870,2.5600,2.3990,2.0640,1.8550

freq,15.3846,15.6250,17.8571,18.8679,22.7273,23.8095,24.3902,25.6410,26.3158
sv,,1.5240,1.5120,1.4720,1.3350,1.0900,1.0730,1.0700,1.0490,1.0040

freq,27.0270,27.7778,28.5714,40.000,76.9231,1000.000
sv,,0.9823,0.9669,0.9560,0.8930,0.8300,0.7710

sed,0,0,1       ! Excitation in Z - Direction
solve

finish

/com,-------------------------------------------------------------------------------------

/post1
/input,,mcom

/out,

/com,
/com,=============================================================
/com, Maximum nodal displacements and rotations from spectrum solution
/com,=============================================================
/com,

/out,scratch
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```
*GET,AdisX,NODE,151,U,X
*GET,AdisY,NODE,87,U,Y
*GET,AdisZ,NODE,92,U,Z
*GET,ArotX,NODE,92,ROT,X
*GET,ArotY,NODE,72,ROT,Y
*GET,ArotZ,NODE,160,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com,==============================================================
/com, Element Forces and Moments obtained from spectrum solution
/com,==============================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************


esel,s,elem,,1
etable,pxi_1,smisc,1
etable,vyi_1,smisc,6
etable,vzi_1,smisc,5
etable,txi_1,smisc,4
etable,myi_1,smisc,2
etable,mzi_1,smisc,3
esel,all

/out,
/com, ************************************************
/com,  Element forces and moments at element1, node i
/com, ************************************************

pretab,pxi_1,vyi_1,vzi_1,txi_1,myi_1,mzi_1


/out,scratch
/com,==========
/com,  Node J
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************

esel,s,elem,,1
etable,pxj_1,smisc,14
etable,vyj_1,smisc,19
etable,vzj_1,smisc,18
etable,txj_1,smisc,17
etable,myj_1,smisc,15
etable,mzj_1,smisc,16
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element1, node j
/com, ************************************************

pretab,pxj_1,vyj_1,vzj_1,txj_1,myj_1,mzj_1
```

```
/out,scratch


/com,==========
/com,  Node I
/com,==========

/com, Element #50 (Elbow 290 element)
/com,*************************

esel,s,elem,,50
etable,pxi_50,smisc,1
etable,vyi_50,smisc,6
etable,vzi_50,smisc,5
etable,txi_50,smisc,4
etable,myi_50,smisc,2
etable,mzi_50,smisc,3
esel,all

/out,
/com, *************************************************
/com,  Element forces and moments at element 50, node i
/com, ************************************************

pretab,pxi_50,vyi_50,vzi_50,txi_50,myi_50,mzi_50


/out,scratch
/com,==========
/com,  Node J
/com,==========



/com, Element #50 (Elbow290 element)
/com,********************************
esel,s,elem,,50

etable,pxj_50,smisc,36
etable,vyj_50,smisc,41
etable,vzj_50,smisc,40
etable,txj_50,smisc,39
etable,myj_50,smisc,37
etable,mzj_50,smisc,38
esel,all

allsel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element 50, node j
/com, ************************************************

pretab,pxj_50,vyj_50,vzj_50,txj_50,myj_50,mzj_50



/com,----------------------------------------------------------------------------

/com, ***************************************
/com,  Reaction forces from spectrum solution
/com, ****************************************

prrsol

finish
```

vm-nr1677-02-3b Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-02-3b
/title,vm-nr1677-02-3b,NRC piping benchmarks problems,Volume II,Problem 3b
/com, ***************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com, Elements used: PIPE289, ELBOW290 and COMBIN14
/com,
/com, Results :
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, *******************************************************************************

/out,scratch
/prep7

YoungModulus1 = 0.277e+08   ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu)) ! Shear Modulus
WMass = 1.546e-03     ! Density
WTick=0.3750     ! Wall Thickness
OD=12.750      ! Outer Diameter

Temperature = 400
Pressue = 615
maxm=15      ! No. of Modes to Extract

radcur1 = -60              ! radius of curvature for bend pipes
radcur2 = -18              ! radius of curvature for bend pipes


/com,-------------------------------------------------------------------------------

et, 1,pipe289,,,    ! Element 1 - PIPE289
et, 2,elbow290,,6    ! Element 2 - ELBOW290
et, 3,elbow290,,6    ! Element 3 - ELBOW290

et, 4,combin14     ! Element 4 - COMBIN14
keyopt,4,2,2     ! Y Degree of Freedom
et, 5,combin14     ! Element 5 - COMBIN14
keyopt,5,2,1     ! X Degree of Freedom
et, 6,combin14     ! Element 6 - COMBIN14
keyopt,6,2,2     ! Y Degree of Freedom
et, 7,combin14     ! Element 7 - COMBIN14
keyopt,7,2,3     ! Z Degree of Freedom
et, 8,combin14     ! Element 8 - COMBIN14
keyopt,8,2,4     ! ROT-X Degree of Freedom
et, 9,combin14     ! Element 9 - COMBIN14
keyopt,9,2,5     ! ROT-Y Degree of Freedom
et,10,combin14     ! Element 10 - COMBIN14
keyopt,10,2,6     ! ROT-Z Degree of Freedom

/com,-------------------------------------------------------------------------------

/com, Real Constants
/com,***************

sectype,1,pipe
secdata,OD,WTick,24
```

```
r, 4, 0.1e+2
r, 5, 0.1e+13
r, 6, 0.1e+13
r, 7, 0.1e+13
r, 8, 0.1e+13
r, 9, 0.1e+13
r,10, 0.1e+13

/com, ---------------------------------------------------------------------------------

/com, Material Properties
/com,********************

mp,ex,  1, YoungModulus1
mp,nuxy,1, Nu
mp,gxy ,1, ShearModulus1
mp,dens,1, WMass



/com,-------------------------------------------------------------------------------

/com, key points
/com,*******

k,1,0,1226.875,0
k,2,30.021,1226.875,30.550
k,3,60.042,1226.875,61.100
k,4,90.064,1226.875,91.651
k,5,105.154,1226.875,102.817
k,6,139.302,1226.875,120.593
k,7,181.878,1226.875,142.757
k,8,224.435,1226.875,164.922
k,9,243.383,1226.875,174.774
k,10,262.311,1226.875,184.628
k,11,292.798,1226.875,191.342

k,12,334.171,1226.875,189.421
!k,120,334.171,1226.875,189.421

k,13,375.543,1226.875,187.500

k,14,405.511,1226.875,186.110
k,140,431.483,1226.875,184.904

k,15,501.172,1226.875,181.669
k,16,570.860,1226.875,178.433
k,17,579.777,1226.875,178.683
k,18,615.118,1226.875,182.316
k,20,633.028,1226.875,184.156

k,21,678.227,1226.875,188.802
k,22,723.426,1226.875,193.448
k,23,768.625,1226.875,198.095
k,24,809.602,1226.875,187.256
k,25,814.057,1226.875,184.079
k,26,852.626,1226.875,156.568
k,27,891.195,1226.875,129.058
k,28,929.764,1226.875,101.547

k,29,968.332,1226.875,74.036
k,290,978.101,1226.875,67.067

k,31,1012.600,1226.875,42.430
!k,310,1012.600,1226.875,42.430

k,32,1047.098,1226.875,17.793
k,34,1061.752,1244.875,7.340
k,35,1061.752,1272.375,7.340
k,36,1072.214,1290.375,-7.307
k,37,1081.623,1290.375,-20.48
k,38,1108.85,1290.375,-58.399
```

```
k,39,1136.077,1290.375,-96.317
k,40,1163.304,1290.375,-134.236
k,41,1190.531,1290.375,-172.154

/com,
/com, Elastic Support
/com,***********************

k,410,1190.531,1290.375,-172.154

k,43,1197.006,1290.375,-182.019
k,44,1207.729,1290.375,-209.536
k,45,1211.63,1290.375,-241.111
k,46,1215.531,1290.375,-272.687
k,47,1219.432,1290.375,-304.262
k,48,1223.333,1290.375,-335.873
k,49,1227.234,1290.375,-367.413

k,51,1232.114,1290.375,-407.115
k,52,1233.704,1295.647,-419.787
k,53,1234.945,1305.772,-429.836

k,55,1254.329,1318.500,-439.952
k,56,1279.579,1318.500,-436.387
k,57,1304.829,1318.500,-432.823
k,58,1330.078,1318.500,-429.258
k,59,1355.328,1318.500,-425.693

!k,61,431.943,1226.875,194.899
!k,62,616.14,1226.875,172.368
!k,63,974.139,1226.875,82.176
k,65,1227.234,1300.375,-367.413
!k,66,1255.726,1318.500,-449.852

!k,67,1182.401,1290.375,-177.966
k,68,105.154,1236.875,102.817
k,69,224.435,1236.875,164.922
k,70,405.511,1236.875,186.110
k,71,633.028,1236.875,184.156
k,72,814.057,1236.875,184.079
k,73,978.101,1236.875,67.067
k,74,1081.623,1300.375,-20.48
k,75,1190.531,1300.375,-172.154

!k,101,10,1226.875,0
!k,102,0,1236.875,0
!k,103,0,1226.875,10

!k,591,1345.328,1318.5,-425.693
!k,592,1355.328,1328.5,-425.693
!k,593,1355.328,1318.5,-415.693

k,601,93.495,1226.9,94.879

k,701,90.618,1226.9,92.207
k,702,91.180,1226.9,92.757
k,703,91.748,1226.9,93.298
k,704,92.324,1226.9,93.833
k,705,92.906,1226.9,94.360

k,711,94.091,1226.9,95.390
k,712,94.694,1226.9,95.894
k,713,95.304,1226.9,96.390
k,714,95.919,1226.9,96.877
k,715,96.542,1226.9,97.357

k,602,97.170,1226.9,97.828

k,721,97.804,1226.9,98.291
k,722,98.443,1226.9,98.746
k,723,99.089,1226.9,99.192
k,724,99.740,1226.9,99.630
```

```
k,725,100.40,1226.9,100.06

k,731,101.73,1226.9,100.89
k,732,102.40,1226.9,101.29
k,733,103.08,1226.9,101.69
k,734,103.77,1226.9,102.07
k,735,104.46,1226.9,102.45

k,603,101.06,1226.9,100.48

k,741,267.08,1226.9,186.85
k,742,272.03,1226.9,188.65
k,743,277.11,1226.9,190.00
k,744,282.29,1226.9,190.91
k,745,287.54,1226.9,191.36

k,751,572.35,1226.9,178.38
k,752,573.84,1226.9,178.37
k,753,575.32,1226.9,178.39
k,754,576.81,1226.9,178.45
k,755,578.29,1226.9,178.55

k,761,775.83,1226.9,198.40
k,762,783.03,1226.9,197.84
k,763,790.10,1226.9,196.41
k,764,796.95,1226.9,194.15
k,765,803.49,1226.9,191.09

k,771,1199.7,1290.4,-186.18
k,772,1202.1,1290.4,-190.55
k,773,1204.1,1290.4,-195.11
k,774,1205.7,1290.4,-199.81
k,775,1206.9,1290.4,-204.63

k,781,1050.9,1227.5,15.088
k,782,1054.4,1229.3,12.567
k,783,1057.5,1232.1,10.402
k,784,1059.8,1235.9,8.7405
k,785,1061.3,1240.2,7.6962

k,791,1062.1,1277.0,6.8409
k,792,1063.2,1281.4,5.3777
k,793,1064.8,1285.1,3.0499
k,794,1067.0,1288.0,0.16395E-01
k,795,1069.5,1289.8,-3.5163

k,801,1232.4,1290.5,-409.45
k,802,1232.7,1291.0,-411.75
k,803,1233.0,1291.7,-413.97
k,804,1233.2,1292.8,-416.08
k,805,1233.5,1294.1,-418.02

k,811,1236.0,1309.0,-432.99
k,812,1238.2,1312.1,-435.76
k,813,1241.3,1314.7,-437.97
k,814,1245.3,1316.7,-439.46
k,815,1249.7,1318.0,-440.13

/com,-------------------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,**********************************

mat,1      ! Material ID 1
type,1      ! Element Type 1
secnum,1     ! Section 1

l,1,2                       ! line number 1
l,2,3
l,3,4
```

```
l,5,6
l,6,7
l,7,8

l,8,9
l,9,10

l,11,12
l,12,13
l,13,14
l,14,140
l,140,15
l,15,16

l,17,18

l,18,20
l,20,21
l,21,22
l,22,23

l,24,25
l,25,26
l,26,27
l,27,28
l,28,29
l,29,290
l,290,31
l,31,32

l,34,35

l,36,37
l,37,38
l,38,39
l,39,40
l,40,41
l,41,43

l,44,45
l,45,46
l,46,47
l,47,48
l,48,49
l,49,51

l,52,53

l,55,56
l,56,57
l,57,58
l,58,59             ! line number 45

lesize,all,,,1
lmesh,all
allsel,all

/com,
/com, Pipe Bend Elements
/com,********************

type,2
secnum,1
mat,1

larc,4,702,701, radcur1         ! line number 46
larc,702,704,703, radcur1
larc,704,601,705, radcur1
larc,601,712,711, radcur1
larc,712,714,713, radcur1
larc,714,602,715, radcur1
larc,602,722,721, radcur1
```

```
larc,722,724,723, radcur1
larc,724,603,725, radcur1
larc,603,732,731, radcur1
larc,732,734,733, radcur1
larc,734,5,735, radcur1
larc,10,742,741, radcur1
larc,742,744,743, radcur1
larc,744,11,745, radcur1
larc,16,752,751, radcur1
larc,752,754,753, radcur1
larc,754,17,755, radcur1
larc,23,762,761, radcur1
larc,762,764,763, radcur1
larc,764,24,765, radcur1
larc,43,772,771, radcur1
larc,772,774,773, radcur1
larc,774,44,775, radcur1            ! line number 69

lsel,s,line,,46,69,1
lesize,all,,,1
lmesh,all
allsel,all


type,3
secnum,1
mat,1

larc,32,782,781, radcur2            ! line number 70
larc,782,784,783, radcur2
larc,784,34,785, radcur2
larc,35,792,791, radcur2
larc,792,794,793, radcur2
larc,794,36,795, radcur2
larc,51,802,801, radcur2
larc,802,804,803, radcur2
larc,804,52,805, radcur2
larc,53,812,811, radcur2
larc,812,814,813, radcur2
larc,814,55,815, radcur2            ! line number 81


lsel,s,line,,70,81,1
lesize,all,,,1
lmesh,all
allsel,all
/com,

/com, Spring Elements
/com,*****************

type,4
real,4
l,49,65                         ! line number 82

lesize,82,,,1
lmesh,all
allsel,all

type,6
real,6
l,5,68                          ! line number 83
l,8,69
l,14,70
l,20,71
l,25,72
l,290,73
l,37,74
l,410,75                        ! line number 90

lsel,s,line,,83,90,1
lesize,all,,,1
```

```
lmesh,all
allsel,all


n1 = node(1254.329,1318.500,-439.952)

n,66000,1255.726,1318.500,-449.852

n3 = node(1279.579,1318.500,-436.387)
n4 = node(1190.531,1290.375,-172.154)

n, 67000,1182.401,1290.375,-177.966

n6 = node(1163.304,1290.375,-134.236)
n7 = node(375.543,1226.875,187.500)

n, 120000,334.171,1226.875,189.421

n9 = node(1355.328,1318.500,-425.693)
n10 = node(431.483,1226.875,184.904)

n,61000,431.943,1226.875,194.899

n12 = node(501.172,1226.875,181.669)
n13 = node(615.118,1226.875,182.316)

n,62000,616.14,1226.875,172.368

n15 = node(579.777,1226.875,178.683)
n16 = node(968.332,1226.875,74.036)

n,63000,974.139,1226.875,82.176

n18 = node(929.764,1226.875,101.547)
n19 = node(1047.098,1226.875,17.793)

n,310000,1012.600,1226.875,42.430

n21 = node(1061.752,1244.875,7.340)
n22 = node(1190.531,1290.375,-172.154)

!n,410000,1190.531,1290.375,-172.154

n,61000,431.943,1226.875,194.899

n,62000,616.14,1226.875,172.368

n,63000,974.139,1226.875,82.176

n27 = node(1227.234,1300.375,-367.413)

n,66000,1255.726,1318.500,-449.852

n,67000,1182.401,1290.375,-177.966


n30 = node(105.154,1236.875,102.817)
n31 = node(224.435,1236.875,164.922)
n32 = node(405.511,1236.875,186.110)
n33 = node(633.028,1236.875,184.156)
n34 = node(814.057,1236.875,184.079)
n35 = node(978.101,1236.875,67.067)
n36 = node(1081.623,1300.375,-20.48)
n37 = node(1190.531,1300.375,-172.154)

n,101000,10,1226.875,0

n,102000,0,1236.875,0

n,103000,0,1226.875,10

n,120000,334.171,1226.875,189.421
```

```
n,310000,1012.600,1226.875,42.430

n,591000,1345.328,1318.5,-425.693

n,592000,1355.328,1328.5,-425.693

n,593000,1355.328,1318.5,-415.693

n46 = node(0,1226.875,0)


type,5
real,5
n1 = 92
n2 = 66000
n3 = 93

ics = 11
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 72
n2 = 67000
n3 = 70

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

/com,
/com, Snubber Elements
/com,******************

n1 = 22
n2 = 120000
n3 = 99

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 26
n2 = 61000
n3 = 28

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 33
n2 = 62000
n3 = 32

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
```

```
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 52
n2 = 63000
n3 = 50

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 58
n2 = 310000
n3 = 60
!n3 = 59

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

/com,
/com, 3D Support at both ends
/com,*************************

type,5
real,5
e,1,101000
e,99,591000

type,6
real,6
e,1,102000
e,99,592000

type,7
real,7
e,1,103000
e,99,593000

type,8
real,8
e,1,101000
e,99,591000

type,9
real,9
e,1,102000
e,99,592000

type,10
real,10
e,1,103000
e,99,593000

/com,-------------------------------------------------------------------------------------

/com,
/com, Model Rigid Region
/com,*******************

cerig,72,172,uy
```

```
/com,------------------------------------------------------------------------------------

/com,
/com, Convert some PIPE289 into ELBOW290 using ELBOW command
/com,

elbow,on,,,sect
allsel,all


/com,
/com, Constraints
/com,*************

nsel,s,node,,61000,63000
nsel,a,node,,164
nsel,a,node,,66000,67000,1
nsel,a,node,,165,173,1
nsel,a,node,,101000,103000
nsel,a,node,,120000
nsel,a,node,,310000
nsel,a,node,,591000,593000
d,all,all,0

nsel,all

/com,------------------------------------------------------------------------------------

/com,
/com, Loads
/com,*******

/com, Temperature Input
/com,*******************

bf,all,temp,Temperature

esel,r,type,,1
esel,a,type,,2
esel,a,type,,3

/com, Pressure Input
/com,****************

sfe,all,1,pres,,Pressue,,,

allsel,all,all
finish

/com,------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal       ! Perform modal solve
modopt,lanb,maxm
lump,on        ! Lumped mass formulation
mxpand,maxm,,,yes       ! Expand the modes with stress calculation
solve
save,
finish


/post1
/out,
/com, ********************************************
/com,  Frequencies obtained from modal solution
```

```
/com, ********************************************
set,list
finish

/com,-------------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/out,scratch
/solution
sfedele,all,1,pres,,,
bfdele,all,temp,,,

antype,spectrum
spopt,mprs,maxm      ! Multi-point response spectrum analysis

gval = 386.4

/com,-------------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 1 (Group 1 - X - Direction Excitation)
/com,************************************************

spunit,1,accg, gval

spfrq,1, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,1,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,1, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,1,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,1, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,1,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,1, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,1,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,1, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,1,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,1, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,1,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,1, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,1,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,1, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,1,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,1, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,1,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,1, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,1,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,1, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,1,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,1, 1000.0
spval,1,, 0.771

/com,
/com, Spectrum 2 (Group 1 - Y - Direction Excitation)
/com,************************************************

spunit,2,accg, gval
```

```
spfrq,2, 0.5,1.4993,1.6207,1.9011,2.0704,3.8023,4.2553,
spval,2,,  0.35,1.45,1.8,1.8,2.61,2.61,2.78,

spfrq,2, 5.1813,5.4054,7.8125,8.1301,9.901,11.5207,14.1044,
spval,2,,  2.78,2.58,2.58,3.25,3.25,3.62,3.62,

spfrq,2, 14.4928,17.6991,23.9981,59.988
spval,2,,  3.05,3.05,1.20,0.75

/com,
/com, Spectrum 3 (Group 1 - Z - Direction Excitation)
/com,*************************************************

spunit,3,accg, gval

spfrq,3, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,3,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,3, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,3,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,3, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,3,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782,

spfrq,3, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
spval,3,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,3, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
spval,3,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,3, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,3,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,3, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,3,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,3, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,3,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,3, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,3,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,3, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,3,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,3, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,3,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,3, 1000.0
spval,3,, 0.771


/com,-----------------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 4 (Group 2 - X - Direction Excitation)
/com,*************************************************

spunit,4,accg, gval

spfrq,4, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,4,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,4, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,4,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,4, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,4,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,4, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
```

```
spval,4,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,4, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
spval,4,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,4, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,4,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,4, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,4,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,4, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,4,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,4, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,4,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,4, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,4,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,4, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,4,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,4, 1000.0
spval,4,, 0.771

/com,
/com, Spectrum 5 (Group 2 - Y - Direction Excitation)
/com,*************************************************

spunit,5,accg, gval

spfrq,5, 0.50,1.4556,1.9011,2.0704,2.907,4.065,4.9603
spval,5,,  1.45,1.8,1.8,2.68,2.68,3.17,3.17

spfrq,5, 5.0,7.5988,8.5034,10.9051,11.5207,14.0845,16.0
spval,5,,  3.03,3.03,4.82,4.82,5.95,5.95,4.49

spfrq,5, 19.1205,21.0084,50.0
spval,5,,  4.49,1.85,1.05

/com,
/com, Spectrum 6 (Group 2 - Z - Direction Excitation)
/com,*************************************************

spunit,6,accg, gval

spfrq,6, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,6,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,6, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,6,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,6, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,6,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,6, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
spval,6,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,6, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
spval,6,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,6, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,6,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,6, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,6,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,6, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,6,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,6, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
```

```
spval,6,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,6, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,6,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,6, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,6,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,6, 1000.0
spval,6,, 0.771

/com,-----------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 7 (Group 3 - X - Direction Excitation)
/com,*************************************************

spunit,7,accg, gval

spfrq,7, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,7,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,7, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,7,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,7, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,7,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,7, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
spval,7,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,7, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
spval,7,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,7, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,7,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,7, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,7,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,7, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,7,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,7, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,7,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,7, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,7,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,7, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,7,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,7, 1000.0
spval,7,, 0.771

/com,
/com, Spectrum 8 (Group 3 - Y - Direction Excitation)
/com,*************************************************

spunit,8,accg, gval

spfrq,8, 0.5,1.9011,2.0704,3.003,4.0486,4.9505,7.1942
spval,8,,  0.4,1.88,2.72,2.72,3.42,3.42,3.82

spfrq,8, 8.1301,9.5238,10.352,12.6422,13.5135,15.4083,15.7978
spval,8,,  7.21,7.21,8.18,8.18,6.39,6.39,5.92

spfrq,8, 17.6991,21.0084,50.0
spval,8,,  5.92,2.25,1.55

/com,
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```
/com, Spectrum 9 (Group 3 - Z - Direction Excitation)
/com,*************************************************

spunit,9,accg, gval

spfrq,9, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,9,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,9, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,9,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,9, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,9,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,9, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
spval,9,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,9, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
spval,9,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,9, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,9,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,9, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,9,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,9, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,9,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,9, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,9,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,9, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,9,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,9, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,9,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,9, 1000.0
spval,9,, 0.771

/com,-------------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 10 (Group 4 - X - Direction Excitation)
/com,*************************************************

spunit,10,accg, gval

spfrq,10, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,10,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,10, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,10,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,10, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,10,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,10, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
spval,10,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,10, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
spval,10,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,10, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,10,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,10, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,10,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,10, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
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spval,10,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,10, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,10,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,10, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,10,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,10, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,10,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,10, 1000.0
spval,10,, 0.771


/com,
/com, Spectrum 11 (Group 4 - Y - Direction Excitation)
/com,**************************************************

spunit,11,accg, gval

spfrq,11, 0.5,1.3004,2.0,3.003,4.0486,4.9505,6.993
spval,11,,  0.5,1.4,2.75,2.75,3.5,3.5,4.5

spfrq,11, 8.1301,10.4167,11.4943,14.845,17.5439,22.2222,50.0
spval,11,,  12.1,12.1,10.7,10.7,2.7,1.8,1.5


/com,
/com, Spectrum 12 (Group 4 - Z - Direction Excitation)
/com,**************************************************

spunit,12,accg, gval

spfrq,12, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,12,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,12, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6778,1.7825
spval,12,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,12, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,12,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,12, 3.2362,3.3898,3.4722,3.5714,3.6101,3.663,3.7313
spval,12,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,12, 3.8168,3.8911,3.9216,4.2918,4.6948,4.7847,5.0505
spval,12,,  4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,12, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,12,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,12, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,12,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,12, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,12,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,12, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,12,,  3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,12, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,12,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,12, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,12,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,12, 1000.0
spval,12,, 0.771

/com,-------------------------------------------------------------------------------------
/com,
```

```
/com,
/com, Nodal Components for Excitation Points (non rotated)
/com,*****************************************************

allsel,all

nsel,s,node,,165
nsel,a,node,,168
nsel,a,node,,170
nsel,a,node,,591000,593000
cm,group_1,node

allsel,all,all

nsel,s,node,,167
nsel,a,node,,173
nsel,a,node,,164
cm,group_2,node

allsel,all,all
nsel,s,node,,166
nsel,a,node,,169
nsel,a,node,,171
cm,group_3,node

allsel,all,all
nsel,s,node,,101000,103000
cm,group_4,node

allsel,all,


/com,-----------------------------------------------------------------------------------
/com,

/com,
/com, -- Support Group 1 - spectrum 1 (Along X - Direction)(68,61,71,63,73,310,591,592,593)
/com,*****************************************************************************************

d,591000,ux,1.0
d,61000,ux,4.5974e-2
d,63000,ux,0.58075
d,310000,ux,-0.81378

pfact,1

d,591000,ux,0.0
d,61000,ux,0
d,63000,ux,0
d,310000,ux,0

/com,
/com, -- Support Group 1 - spectrum 2 (Along Y - Direction)
/com,******************************************************

d,165,uy,1
d,168,uy,1
d,170,uy,1
d,592000,uy,1
d,61000,ux,-0.5842e-16
d,63000,ux,0.2567e-16
d,310000,ux,-0.2074e-15

pfact,2

d,165,uy,0
d,168,uy,0
d,170,uy,0
d,592000,uy,0
d,61000,ux,0
```

```
d,63000,ux,0
d,310000,ux,0

/com,
/com, -- Support Group 1 - spectrum 3 (Along Z - Direction)
/com,*******************************************************

d,593000,uz,1.0
d,61000,ux,0.9989
d,63000,ux,0.8141
d,310000,ux,0.5812

pfact,3

d,593000,uz,0.0
d,61000,ux,0
d,63000,ux,0
d,310000,ux,0

/com,--------------------------------------------------------------------------------
/com,

/com,
/com, -- Support Group 2 - spectrum 4 (Along X - Direction)(120,70,62,65,75,67)
/com,***********************************************************************


d,120000,ux,-0.998923
d,62000,ux,0.1021963
d,67000,ux,-0.8135

pfact,4

d,120000,ux,0
d,62000,ux,0
d,67000,ux,0

/com,
/com, -- Support Group 2 - spectrum 5 (Along Y - Direction)
/com,*******************************************************

d,167,uy,1
d,164,uy,1
d,173,uy,1
d,120000,ux,0.1299e-13
d,62000,ux,0.5497e-16
d,67000,ux,0.1110e-15

pfact,5

d,167,uy,0
d,164,uy,0
d,173,uy,0
d,120000,ux,0
d,62000,ux,0
d,67000,ux,0

/com,
/com, -- Support Group 2 - spectrum 6 (Along Z - Direction)
/com,*******************************************************

d,120000,ux,0.4638e-01
d,62000,ux,-0.9948
d,67000,ux,-0.5816

pfact,6

d,120000,ux,0
d,62000,ux,0
d,67000,ux,0

/com,--------------------------------------------------------------------------------
```

```
/com,

/com,
/com, -- Support Group 3 - spectrum 7 (Along X - Direction)(69,72,74)
/com,*****************************************************************

pfact,7

/com,
/com, -- Support Group 3 - spectrum 8 (Along Y - Direction)
/com,*******************************************************

d,166,uy,1
d,169,uy,1
d,171,uy,1

pfact,8

d,166,uy,0
d,169,uy,0
d,171,uy,0

/com,
/com, -- Support Group 3 - spectrum 9 (Along Z - Direction)
/com,*******************************************************

pfact,9

/com,------------------------------------------------------------------------------------
/com,

/com,
/com, -- Support Group 4 - spectrum 10 (Along X - Direction)(101,102,103,55)
/com,************************************************************************

d,101000,ux,1.0
d,66000,ux,0.1397268

pfact,10

d,101000,ux,0
d,66000,ux,0

/com,
/com, -- Support Group 4 - spectrum 11 (Along Y - Direction)
/com,********************************************************

d,102000,uy,1
d,66000,ux,-0.5268e-16

pfact,11

d,102000,uy,0
d,66000,ux,0

/com,
/com, -- Support Group 4 - spectrum 12 (Along Z - Direction)
/com,********************************************************

d,103000,uz,1
d,66000,ux,-0.9902

pfact,12

d,103000,uz,0
d,66000,ux,0

srss,0.0      ! take all modes (Mode combination method)
solve

/com,------------------------------------------------------------------------------------
/com,
```

```
finish

/com,--------------------------------------------------------------------------------
/com,

/post1
/input,vm-nr1677-02-3b,mcom

/out,

/com,
/com,==============================================================
/com, Maximum nodal displacements and rotations from spectrum solution
/com,==============================================================
/com,

/out,scratch

*GET,AdisX,NODE,63,U,X
*GET,AdisY,NODE,87,U,Y
*GET,AdisZ,NODE,63,U,Z
*GET,ArotX,NODE,58,ROT,X
*GET,ArotY,NODE,72,ROT,Y
*GET,ArotZ,NODE,61,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com,=============================================================
/com, Element Forces and Moments obtained from spectrum solution
/com,=============================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #1 (Pipe289 element)
/com,***********************


esel,s,elem,,1
etable,pxi_1,smisc,1
etable,vyi_1,smisc,6
etable,vzi_1,smisc,5
etable,txi_1,smisc,4
etable,myi_1,smisc,2
etable,mzi_1,smisc,3
esel,all

/out,
/com, ************************************************
/com,  Element forces and moments at element1, node i
/com, ************************************************

pretab,pxi_1,vyi_1,vzi_1,txi_1,myi_1,mzi_1


/out,scratch
/com,==========
/com,  Node J
/com,==========

/com, Element #1 (Pipe289 element)
/com,***********************
```

```
esel,s,elem,,1
etable,pxj_1,smisc,14
etable,vyj_1,smisc,19
etable,vzj_1,smisc,18
etable,txj_1,smisc,17
etable,myj_1,smisc,15
etable,mzj_1,smisc,16
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element1, node j
/com, ************************************************

pretab,pxj_1,vyj_1,vzj_1,txj_1,myj_1,mzj_1



/out,scratch


/com,==========
/com,  Node I
/com,==========

/com, Element #50 (Elbow 290 element)
/com,************************

esel,s,elem,,50
etable,pxi_50,smisc,1
etable,vyi_50,smisc,6
etable,vzi_50,smisc,5
etable,txi_50,smisc,4
etable,myi_50,smisc,2
etable,mzi_50,smisc,3
esel,all

/out,
/com, *************************************************
/com,  Element forces and moments at element 50, node i
/com, ************************************************

pretab,pxi_50,vyi_50,vzi_50,txi_50,myi_50,mzi_50


/out,scratch
/com,==========
/com,  Node J
/com,==========



/com, Element #50 (Elbow290 element)
/com,*******************************
esel,s,elem,,50

etable,pxj_50,smisc,36
etable,vyj_50,smisc,41
etable,vzj_50,smisc,40
etable,txj_50,smisc,39
etable,myj_50,smisc,37
etable,mzj_50,smisc,38
esel,all

allsel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element 50, node j
/com, ************************************************

pretab,pxj_50,vyj_50,vzj_50,txj_50,myj_50,mzj_50
```

```
/com,----------------------------------------------------------------------------

/com, ***************************************
/com,  Reaction forces from spectrum solution
/com, ****************************************

prrsol

finish
```

vm-nr1677-02-3c Input Listing

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/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-02-3c
/title,vm-nr1677-02-3c,NRC piping benchmarks problems,Volume II,Problem 3c

/com, ******************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com, Elements used: PIPE289, ELBOW290, COMBIN14
/com,
/com, Results:
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, ******************************************************************************

/out,scratch

/prep7

YoungModulus1 = 0.277e+08   ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu)) ! Shear Modulus
WMass = 1.546e-03     ! Density
WTick=0.3750     ! Wall Thickness
OD=12.750      ! Outer Diameter

Temperature = 400
Pressue = 615
maxm=15      ! No. of Modes to Extract

radcur1 = -60              ! radius of curvature for bend pipes
radcur2 = -18              ! radius of curvature for bend pipes


/com,------------------------------------------------------------------------------------

et, 1,pipe289,,,    ! Element 1 - PIPE289
et, 2,elbow290,,6    ! Element 2 - ELBOW290
et, 3,elbow290,,6    ! Element 3 - ELBOW290

et, 4,combin14     ! Element 4 - COMBIN14
keyopt,4,2,2     ! Y Degree of Freedom
et, 5,combin14     ! Element 5 - COMBIN14
keyopt,5,2,1     ! X Degree of Freedom
et, 6,combin14     ! Element 6 - COMBIN14
keyopt,6,2,2     ! Y Degree of Freedom
et, 7,combin14     ! Element 7 - COMBIN14
keyopt,7,2,3     ! Z Degree of Freedom
```

```
et, 8,combin14     ! Element 8 - COMBIN14
keyopt,8,2,4     ! ROT-X Degree of Freedom
et, 9,combin14     ! Element 9 - COMBIN14
keyopt,9,2,5     ! ROT-Y Degree of Freedom
et,10,combin14     ! Element 10 - COMBIN14
keyopt,10,2,6     ! ROT-Z Degree of Freedom

/com,------------------------------------------------------------------------------------------

/com, Real Constants
/com,****************

sectype,1,pipe
secdata,OD,WTick,24

r, 4, 0.1e+2
r, 5, 0.1e+13
r, 6, 0.1e+13
r, 7, 0.1e+13
r, 8, 0.1e+13
r, 9, 0.1e+13
r,10, 0.1e+13

/com, ------------------------------------------------------------------------------------------

/com, Material Properties
/com,*********************

mp,ex,  1, YoungModulus1
mp,nuxy,1, Nu
mp,gxy ,1, ShearModulus1
mp,dens,1, WMass



/com,------------------------------------------------------------------------------------------

/com, key points
/com,*******

k,1,0,1226.875,0
k,2,30.021,1226.875,30.550
k,3,60.042,1226.875,61.100
k,4,90.064,1226.875,91.651
k,5,105.154,1226.875,102.817
k,6,139.302,1226.875,120.593
k,7,181.878,1226.875,142.757
k,8,224.435,1226.875,164.922
k,9,243.383,1226.875,174.774
k,10,262.311,1226.875,184.628
k,11,292.798,1226.875,191.342

k,12,334.171,1226.875,189.421
!k,120,334.171,1226.875,189.421

k,13,375.543,1226.875,187.500

k,14,405.511,1226.875,186.110
k,140,431.483,1226.875,184.904

k,15,501.172,1226.875,181.669
k,16,570.860,1226.875,178.433
k,17,579.777,1226.875,178.683
k,18,615.118,1226.875,182.316
k,20,633.028,1226.875,184.156

k,21,678.227,1226.875,188.802
k,22,723.426,1226.875,193.448
k,23,768.625,1226.875,198.095
k,24,809.602,1226.875,187.256
k,25,814.057,1226.875,184.079
k,26,852.626,1226.875,156.568
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k,27,891.195,1226.875,129.058
k,28,929.764,1226.875,101.547

k,29,968.332,1226.875,74.036
k,290,978.101,1226.875,67.067

k,31,1012.600,1226.875,42.430
!k,310,1012.600,1226.875,42.430

k,32,1047.098,1226.875,17.793
k,34,1061.752,1244.875,7.340
k,35,1061.752,1272.375,7.340
k,36,1072.214,1290.375,-7.307
k,37,1081.623,1290.375,-20.48
k,38,1108.85,1290.375,-58.399
k,39,1136.077,1290.375,-96.317
k,40,1163.304,1290.375,-134.236
k,41,1190.531,1290.375,-172.154

/com,
/com, Elastic Support
/com,***********************

k,410,1190.531,1290.375,-172.154

k,43,1197.006,1290.375,-182.019
k,44,1207.729,1290.375,-209.536
k,45,1211.63,1290.375,-241.111
k,46,1215.531,1290.375,-272.687
k,47,1219.432,1290.375,-304.262
k,48,1223.333,1290.375,-335.873
k,49,1227.234,1290.375,-367.413

k,51,1232.114,1290.375,-407.115
k,52,1233.704,1295.647,-419.787
k,53,1234.945,1305.772,-429.836

k,55,1254.329,1318.500,-439.952
k,56,1279.579,1318.500,-436.387
k,57,1304.829,1318.500,-432.823
k,58,1330.078,1318.500,-429.258
k,59,1355.328,1318.500,-425.693

!k,61,431.943,1226.875,194.899
!k,62,616.14,1226.875,172.368
!k,63,974.139,1226.875,82.176
k,65,1227.234,1300.375,-367.413
!k,66,1255.726,1318.500,-449.852

!k,67,1182.401,1290.375,-177.966
k,68,105.154,1236.875,102.817
k,69,224.435,1236.875,164.922
k,70,405.511,1236.875,186.110
k,71,633.028,1236.875,184.156
k,72,814.057,1236.875,184.079
k,73,978.101,1236.875,67.067
k,74,1081.623,1300.375,-20.48
k,75,1190.531,1300.375,-172.154

!k,101,10,1226.875,0
!k,102,0,1236.875,0
!k,103,0,1226.875,10

!k,591,1345.328,1318.5,-425.693
!k,592,1355.328,1328.5,-425.693
!k,593,1355.328,1318.5,-415.693

k,601,93.495,1226.9,94.879

k,701,90.618,1226.9,92.207
k,702,91.180,1226.9,92.757
k,703,91.748,1226.9,93.298
```

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k,704,92.324,1226.9,93.833
k,705,92.906,1226.9,94.360

k,711,94.091,1226.9,95.390
k,712,94.694,1226.9,95.894
k,713,95.304,1226.9,96.390
k,714,95.919,1226.9,96.877
k,715,96.542,1226.9,97.357

k,602,97.170,1226.9,97.828

k,721,97.804,1226.9,98.291
k,722,98.443,1226.9,98.746
k,723,99.089,1226.9,99.192
k,724,99.740,1226.9,99.630
k,725,100.40,1226.9,100.06

k,731,101.73,1226.9,100.89
k,732,102.40,1226.9,101.29
k,733,103.08,1226.9,101.69
k,734,103.77,1226.9,102.07
k,735,104.46,1226.9,102.45

k,603,101.06,1226.9,100.48

k,741,267.08,1226.9,186.85
k,742,272.03,1226.9,188.65
k,743,277.11,1226.9,190.00
k,744,282.29,1226.9,190.91
k,745,287.54,1226.9,191.36

k,751,572.35,1226.9,178.38
k,752,573.84,1226.9,178.37
k,753,575.32,1226.9,178.39
k,754,576.81,1226.9,178.45
k,755,578.29,1226.9,178.55

k,761,775.83,1226.9,198.40
k,762,783.03,1226.9,197.84
k,763,790.10,1226.9,196.41
k,764,796.95,1226.9,194.15
k,765,803.49,1226.9,191.09

k,771,1199.7,1290.4,-186.18
k,772,1202.1,1290.4,-190.55
k,773,1204.1,1290.4,-195.11
k,774,1205.7,1290.4,-199.81
k,775,1206.9,1290.4,-204.63

k,781,1050.9,1227.5,15.088
k,782,1054.4,1229.3,12.567
k,783,1057.5,1232.1,10.402
k,784,1059.8,1235.9,8.7405
k,785,1061.3,1240.2,7.6962

k,791,1062.1,1277.0,6.8409
k,792,1063.2,1281.4,5.3777
k,793,1064.8,1285.1,3.0499
k,794,1067.0,1288.0,0.16395E-01
k,795,1069.5,1289.8,-3.5163

k,801,1232.4,1290.5,-409.45
k,802,1232.7,1291.0,-411.75
k,803,1233.0,1291.7,-413.97
k,804,1233.2,1292.8,-416.08
k,805,1233.5,1294.1,-418.02

k,811,1236.0,1309.0,-432.99
k,812,1238.2,1312.1,-435.76
k,813,1241.3,1314.7,-437.97
k,814,1245.3,1316.7,-439.46
k,815,1249.7,1318.0,-440.13
```

```
/com,-------------------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,**********************************

mat,1      ! Material ID 1
type,1      ! Element Type 1
secnum,1     ! Section 1

l,1,2                       ! line number 1
l,2,3
l,3,4

l,5,6
l,6,7
l,7,8

l,8,9
l,9,10

l,11,12
l,12,13
l,13,14
l,14,140
l,140,15
l,15,16

l,17,18

l,18,20
l,20,21
l,21,22
l,22,23

l,24,25
l,25,26
l,26,27
l,27,28
l,28,29
l,29,290
l,290,31
l,31,32

l,34,35

l,36,37
l,37,38
l,38,39
l,39,40
l,40,41
l,41,43

l,44,45
l,45,46
l,46,47
l,47,48
l,48,49
l,49,51

l,52,53

l,55,56
l,56,57
l,57,58
l,58,59             ! line number 45

lesize,all,,,1
lmesh,all
allsel,all
```

```
/com,
/com, Pipe Bend Elements
/com,********************

type,2
secnum,1
mat,1

larc,4,702,701, radcur1         ! line number 46
larc,702,704,703, radcur1
larc,704,601,705, radcur1
larc,601,712,711, radcur1
larc,712,714,713, radcur1
larc,714,602,715, radcur1
larc,602,722,721, radcur1
larc,722,724,723, radcur1
larc,724,603,725, radcur1
larc,603,732,731, radcur1
larc,732,734,733, radcur1
larc,734,5,735, radcur1
larc,10,742,741, radcur1
larc,742,744,743, radcur1
larc,744,11,745, radcur1
larc,16,752,751, radcur1
larc,752,754,753, radcur1
larc,754,17,755, radcur1
larc,23,762,761, radcur1
larc,762,764,763, radcur1
larc,764,24,765, radcur1
larc,43,772,771, radcur1
larc,772,774,773, radcur1
larc,774,44,775, radcur1            ! line number 69

lsel,s,line,,46,69,1
lesize,all,,,1
lmesh,all
allsel,all


type,3
secnum,1
mat,1

larc,32,782,781, radcur2            ! line number 70
larc,782,784,783, radcur2
larc,784,34,785, radcur2
larc,35,792,791, radcur2
larc,792,794,793, radcur2
larc,794,36,795, radcur2
larc,51,802,801, radcur2
larc,802,804,803, radcur2
larc,804,52,805, radcur2
larc,53,812,811, radcur2
larc,812,814,813, radcur2
larc,814,55,815, radcur2            ! line number 81


lsel,s,line,,70,81,1
lesize,all,,,1
lmesh,all
allsel,all
/com,

/com, Spring Elements
/com,*****************

type,4
real,4
l,49,65                         ! line number 82

lesize,82,,,1
lmesh,all
```

```
allsel,all

type,6
real,6
l,5,68                        ! line number 83
l,8,69
l,14,70
l,20,71
l,25,72
l,290,73
l,37,74
l,410,75                      ! line number 90

lsel,s,line,,83,90,1
lesize,all,,,1
lmesh,all
allsel,all


n1 = node(1254.329,1318.500,-439.952)

n,66000,1255.726,1318.500,-449.852

n3 = node(1279.579,1318.500,-436.387)
n4 = node(1190.531,1290.375,-172.154)

n, 67000,1182.401,1290.375,-177.966

n6 = node(1163.304,1290.375,-134.236)
n7 = node(375.543,1226.875,187.500)

n, 120000,334.171,1226.875,189.421

n9 = node(1355.328,1318.500,-425.693)
n10 = node(431.483,1226.875,184.904)

n,61000,431.943,1226.875,194.899

n12 = node(501.172,1226.875,181.669)
n13 = node(615.118,1226.875,182.316)

n,62000,616.14,1226.875,172.368

n15 = node(579.777,1226.875,178.683)
n16 = node(968.332,1226.875,74.036)

n,63000,974.139,1226.875,82.176

n18 = node(929.764,1226.875,101.547)
n19 = node(1047.098,1226.875,17.793)

n,310000,1012.600,1226.875,42.430

n21 = node(1061.752,1244.875,7.340)
n22 = node(1190.531,1290.375,-172.154)

!n,410000,1190.531,1290.375,-172.154

n,61000,431.943,1226.875,194.899

n,62000,616.14,1226.875,172.368

n,63000,974.139,1226.875,82.176

n27 = node(1227.234,1300.375,-367.413)

n,66000,1255.726,1318.500,-449.852

n,67000,1182.401,1290.375,-177.966


n30 = node(105.154,1236.875,102.817)
```

```
n31 = node(224.435,1236.875,164.922)
n32 = node(405.511,1236.875,186.110)
n33 = node(633.028,1236.875,184.156)
n34 = node(814.057,1236.875,184.079)
n35 = node(978.101,1236.875,67.067)
n36 = node(1081.623,1300.375,-20.48)
n37 = node(1190.531,1300.375,-172.154)

n,101000,10,1226.875,0

n,102000,0,1236.875,0

n,103000,0,1226.875,10

n,120000,334.171,1226.875,189.421

n,310000,1012.600,1226.875,42.430

n,591000,1345.328,1318.5,-425.693

n,592000,1355.328,1328.5,-425.693

n,593000,1355.328,1318.5,-415.693

n46 = node(0,1226.875,0)


type,5
real,5
n1 = 92
n2 = 66000
n3 = 93

ics = 11
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 72
n2 = 67000
n3 = 70

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

/com,
/com, Snubber Elements
/com,******************

n1 = 22
n2 = 120000
n3 = 99

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 26
n2 = 61000
n3 = 28
```

```
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 33
n2 = 62000
n3 = 32

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 52
n2 = 63000
n3 = 50

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

n1 = 58
n2 = 310000
n3 = 60
!n3 = 59

ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0
e,n1,n2

/com,
/com, 3D Support at both ends
/com,*************************

type,5
real,5
e,1,101000
e,99,591000

type,6
real,6
e,1,102000
e,99,592000

type,7
real,7
e,1,103000
e,99,593000

type,8
real,8
e,1,101000
e,99,591000

type,9
real,9
```

```
e,1,102000
e,99,592000

type,10
real,10
e,1,103000
e,99,593000

/com,------------------------------------------------------------------------------------

/com,
/com, Model Rigid Region
/com,********************

cerig,72,172,uy

/com,------------------------------------------------------------------------------------

/com,
/com, Convert some PIPE289 into ELBOW290 using ELBOW command
/com,

elbow,on,,,sect
allsel,all


/com,
/com, Constraints
/com,*************

nsel,s,node,,61000,63000
nsel,a,node,,164
nsel,a,node,,66000,67000,1
nsel,a,node,,165,173,1
nsel,a,node,,101000,103000
nsel,a,node,,120000
nsel,a,node,,310000
nsel,a,node,,591000,593000
d,all,all,0

nsel,all

/com,------------------------------------------------------------------------------------

/com,
/com, Loads
/com,*******

/com, Temperature Input
/com,*******************

bf,all,temp,Temperature

esel,r,type,,1
esel,a,type,,2
esel,a,type,,3

/com, Pressure Input
/com,****************

sfe,all,1,pres,,Pressue,,,

allsel,all,all
finish

/com,------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,
```

```
/solution
antype,modal       ! Perform modal solve
modopt,lanb,maxm
lump,on        ! Lumped mass formulation
mxpand,maxm,,,yes       ! Expand the modes with stress calculation
solve
save,
finish


/post1
/out,
/com, ********************************************
/com,  Frequencies obtained from modal solution
/com, *********************************************
set,list
finish

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,
/out,scratch

/solution
sfedele,all,1,pres,,,
bfdele,all,temp,,,

antype,spectrum
spopt,mprs,maxm     ! Multi-point response spectrum analysis

srss,,,
gval = 386.4

/com,-----------------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 1 (Group 1 - X - Direction Excitation)
/com,*************************************************

id = 1
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855
```

```
spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771

/com,
/com, Spectrum 2 (Group 1 - Y - Direction Excitation)
/com,*************************************************

id = 2
spunit, id,accg, gval

spfrq,id, 0.5,1.4993,1.6207,1.9011,2.0704,3.8023,4.2553
spval,id,,  0.35,1.45,1.8,1.8,2.61,2.61,2.78

spfrq,id, 5.1813,5.4054,7.8125,8.1301,9.901,11.5207,14.1044
spval,id,,  2.78,2.58,2.58,3.25,3.25,3.62,3.62

spfrq,id, 14.4928,17.6991,23.9981,59.988
spval,id,,  3.05,3.05,1.20,0.75

/com,
/com, Spectrum 3 (Group 1 - Z - Direction Excitation)
/com,*************************************************

id = 3
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771

/com,-----------------------------------------------------------------------------------
/com,
```

```
/com,
/com, Spectrum 4 (Group 2 - X - Direction Excitation)
/com,**************************************************

id = 4
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771

/com,
/com, Spectrum 5 (Group 2 - Y - Direction Excitation)
/com,**************************************************

id = 5
spunit, id,accg, gval

spfrq,id, 0.50,1.4556,1.9011,2.0704,2.907,4.065,4.9603
spval,id,,  1.45,1.8,1.8,2.68,2.68,3.17,3.17

spfrq,id, 5.0,7.5988,8.5034,10.9051,11.5207,14.0845,16.0
spval,id,,  3.03,3.03,4.82,4.82,5.95,5.95,4.49

spfrq,id, 19.1205,21.0084,50.0
spval,id,,  4.49,1.85,1.05

/com,
/com, Spectrum 6 (Group 2 - Z - Direction Excitation)
/com,**************************************************

id = 6
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304
```

```
spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771

/com,-----------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 7 (Group 3 - X - Direction Excitation)
/com,*************************************************

id = 7
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83
```

```
spfrq,id, 1000.0
spval,id,, 0.771

/com,
/com, Spectrum 8 (Group 3 - Y - Direction Excitation)
/com,*************************************************

id = 8
spunit, id,accg, gval

spfrq,id, 0.5,1.9011,2.0704,3.003,4.0486,4.9505,7.1942
spval,id,,  0.4,1.88,2.72,2.72,3.42,3.42,3.82

spfrq,id, 8.1301,9.5238,10.352,12.6422,13.5135,15.4083,15.7978
spval,id,, 7.21,7.21,8.18,8.18,6.39,6.39,5.92

spfrq,id, 17.6991,21.0084,50.0
spval,id,,  5.92,2.25,1.55

/com,
/com, Spectrum 9 (Group 3 - Z - Direction Excitation)
/com,*************************************************

id = 9
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771

/com,------------------------------------------------------------------------------------
/com,

/com,
/com, Spectrum 10 (Group 4 - X - Direction Excitation)
/com,*************************************************

id = 10
spunit, id,accg, gval
```

```
spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002

spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771

/com,
/com, Spectrum 11 (Group 4 - Y - Direction Excitation)
/com,**************************************************

id = 11
spunit, id,accg, gval

spfrq,id, 0.5,1.3004,2.0,3.003,4.0486,4.9505,6.993
spval,id,,  0.5,1.4,2.75,2.75,3.5,3.5,4.5

spfrq,id, 8.1301,10.4167,11.4943,14.845,17.5439,22.2222,50.0
spval,id,,  12.1,12.1,10.7,10.7,2.7,1.8,1.5

/com,
/com, Spectrum 12 (Group 4 - Z - Direction Excitation)
/com,**************************************************

id = 12
spunit, id,accg, gval

spfrq,id, 1.0,1.0428,1.1025,1.1905,1.2270,1.2739,1.2937
spval,id,,  1.162,1.282,1.399,1.549,1.606,1.676,1.704

spfrq,id, 1.3423,1.3889,1.4104,1.4347,1.5552,1.6949,1.7825
spval,id,,  1.774,1.839,1.869,1.904,2.084,2.246,2.304

spfrq,id, 1.9305,2.0747,2.2779,2.4752,2.6042,2.6596,2.9499
spval,id,,  2.382,2.479,2.592,2.644,2.64,2.639,2.782

spfrq,id, 3.2362,3.3898,3.4965,3.5714,3.6101,3.663,3.7313
spval,id,,  2.951,3.066,3.215,3.384,3.532,3.766,4.189

spfrq,id, 3.8168,3.8911,3.9216,4.218,4.6948,4.7847,5.0505
spval,id,, 4.793,5.189,5.224,5.232,5.227,5.152,3.002
```

```
spfrq,id, 5.0761,5.3476,5.7471,5.9524,5.9880,6.6225,7.4627
spval,id,,  2.923,2.90,2.873,2.849,2.844,2.761,2.667

spfrq,id, 7.8125,7.874,7.9365,8.3333,8.9286,9.5238,9.6154
spval,id,,  2.635,2.685,2.755,2.087,2.797,2.744,2.674

spfrq,id, 9.7087,10.4167,10.8696,11.6279,11.7647,12.1951,12.50
spval,id,,  2.627,2.781,2.931,3.077,3.112,3.134,3.134

spfrq,id, 12.8205,13.1579,13.3333,13.4953,13.5135,13.8889,14.2857
spval,id,, 3.116,2.975,2.687,2.56,2.399,2.064,1.855

spfrq,id, 15.3846,15.625,17.8571,18.8679,22.7273,23.8095,24.3902
spval,id,,  1.524,1.512,1.472,1.335,1.09,1.073,1.07

spfrq,id, 25.641,26.3158,27.027,27.7778,28.5714,40.0,76.9231
spval,id,,  1.049,1.004,0.9823,0.9669,0.956,0.893,0.83

spfrq,id, 1000.0
spval,id,, 0.771

/com,-----------------------------------------------------------------------------------------
/com,
/com,
/com, Nodal Components for Excitation Points (non rotated)
/com,*****************************************************

allsel,all,all

nsel,s,node,,165
nsel,a,node,,61000
nsel,a,node,,168
nsel,a,node,,63000
nsel,a,node,,170
nsel,a,node,,310000
nsel,a,node,,591000,593000
cm,group_1,node

allsel,all,all

nsel,s,node,,167
nsel,a,node,,120000
nsel,a,node,,62000
nsel,a,node,,67000
nsel,a,node,,173
nsel,a,node,,164
cm,group_2,node

allsel,all,all
nsel,s,node,,166
nsel,a,node,,169
nsel,a,node,,171
cm,group_3,node

allsel,all,all
nsel,s,node,,101000,103000
nsel,a,node,,66000
cm,group_4,node

allsel,all,all
eplo

/com,
/com, ****************************************************
! -- Support Group 1 - spectrum 1 (Along X - Direction)

sed,1,,,group_1
pfact,1
sed,0,,,group_1

! -- Support Group 1 - spectrum 2 (Along Y - Direction)
```

```
sed,,1,,group_1
pfact,2
sed,,0,,group_1

! -- Support Group 1 - spectrum 3 (Along Z - Direction)

sed,,,1,group_1
pfact,3
sed,,,0,group_1

! -- Support Group 2 - spectrum 4 (Along X - Direction)

sed,1,,,group_2
pfact,4
sed,0,,,group_2

! -- Support Group 2 - spectrum 5 (Along Y - Direction)

sed,,1,,group_2
pfact,5
sed,,0,,group_2

! -- Support Group 2 - spectrum 6 (Along Z - Direction)

sed,,,1,group_2
pfact,6
sed,,,0,group_2


! -- Support Group 3 - spectrum 8 (Along Y - Direction)

sed,,1,,group_3
pfact,8
sed,,0,,group_3


! -- Support Group 4 - spectrum 10 (Along X - Direction)

sed,1,,,group_4
pfact,10
sed,0,,,group_4

! -- Support Group 4 - spectrum 11 (Along Y - Direction)

sed,,1,,group_4
pfact,11
sed,,0,,group_4

! -- Support Group 4 - spectrum 12 (Along Z - Direction)

sed,,,1,group_4
pfact,12
sed,,,0,group_4


srss,0,,YES   ! activate Absolute Sum for MPRS

solve

fini
/com, ****************************************************
/post1
/input,,mcom

/out,

/com,
/com,=============================================================
/com, Maximum nodal displacements and rotations from spectrum solution
/com,=============================================================
/com,
```

```
/out,scratch

*GET,AdisX,NODE,63,U,X
*GET,AdisY,NODE,87,U,Y
*GET,AdisZ,NODE,63,U,Z
*GET,ArotX,NODE,58,ROT,X
*GET,ArotY,NODE,52,ROT,Y
*GET,ArotZ,NODE,61,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com,=================================================================
/com, Element Forces and Moments obtained from spectrum solution
/com,=================================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************


esel,s,elem,,1
etable,pxi_1,smisc,1
etable,vyi_1,smisc,6
etable,vzi_1,smisc,5
etable,txi_1,smisc,4
etable,myi_1,smisc,2
etable,mzi_1,smisc,3
esel,all

/out,
/com, ************************************************
/com,  Element forces and moments at element1, node i
/com, ************************************************

pretab,pxi_1,vyi_1,vzi_1,txi_1,myi_1,mzi_1


/out,scratch
/com,==========
/com,  Node J
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************

esel,s,elem,,1
etable,pxj_1,smisc,14
etable,vyj_1,smisc,19
etable,vzj_1,smisc,18
etable,txj_1,smisc,17
etable,myj_1,smisc,15
etable,mzj_1,smisc,16
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element1, node j
/com, ************************************************

pretab,pxj_1,vyj_1,vzj_1,txj_1,myj_1,mzj_1
```

```
/out,scratch


/com,==========
/com,  Node I
/com,==========

/com, Element #50 (Elbow 290 element)
/com,************************

esel,s,elem,,50
etable,pxi_50,smisc,1
etable,vyi_50,smisc,6
etable,vzi_50,smisc,5
etable,txi_50,smisc,4
etable,myi_50,smisc,2
etable,mzi_50,smisc,3
esel,all

/out,
/com, ************************************************
/com,  Element forces and moments at element 50, node i
/com, ***********************************************

pretab,pxi_50,vyi_50,vzi_50,txi_50,myi_50,mzi_50


/out,scratch
/com,==========
/com,  Node J
/com,==========



/com, Element #50 (Elbow290 element)
/com,*******************************
esel,s,elem,,50

etable,pxj_50,smisc,36
etable,vyj_50,smisc,41
etable,vzj_50,smisc,40
etable,txj_50,smisc,39
etable,myj_50,smisc,37
etable,mzj_50,smisc,38
esel,all

allsel,all

/out,
/com, *********************************************
/com,  Element forces and moments at element 50, node j
/com, ***********************************************

pretab,pxj_50,vyj_50,vzj_50,txj_50,myj_50,mzj_50



/com,----------------------------------------------------------------------------

/com, **************************************
/com,  Reaction forces from spectrum solution
/com, ***************************************

prrsol

finish
```

vm-nr6645-01-1a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr6645-01-1a
/title,vm-nr6645-01-1a,NRC Piping Benchmark Problems,Volume 1,Method 1
/com,*************************************************************************
/com,
/com, Reference: Reevaluation of Regulatory Guidance
/com,            on modal response combination methods
/com,            for seismic response spectrum analysis
/com,           NUREG/CR-6645
/com,    R.Morante, Y.Wang
/com,    December 1999.
/com,
/com, Description:
/com, Response spectrum analysis on BM3 piping model using 14 modes + missing mass
/com,
/com,
/com, Elements used: PIPE289, ELBOW290, COMBIN14
/com,
/com, Results :
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum displacements and rotations obtained from spectrum solution
/com, 3. Element forces and moments obtained from spectrum solution
/com, 4. Reaction forces obtained from spectrum solution. SRSS, 1% damping
/com,
/com,
/com,*************************************************************************

/out,scratch
/prep7

youngmodulus = 2.9e+7     ! Young's modulus
nu = 0.3      ! Poisson ratio
shearmodulus = youngmodulus/(2*(1+nu))   ! Shear modulus

et,1,pipe289,,,

sectype,1,pipe
secdata,3.5,0.216,24

mp,ex,1,youngmodulus     ! Material properties
mp,nuxy,1,nu
mp,gxy,1,shearmodulus
mp,dens,1,1.043e-3

et,2,pipe289,,,

sectype,2,pipe
secdata,4.5,0.237,24

mp,ex,2,youngmodulus     ! Material properties
mp,nuxy,2,nu
mp,gxy,2,shearmodulus
mp,dens,2,1.107e-03

et,3,pipe289,,,

sectype,3,pipe
secdata,8.625,0.322,24

mp,ex,3,youngmodulus     ! Material properties
mp,nuxy,3,nu
mp,gxy,3,shearmodulus
mp,dens,3,1.253e-3

et,4,elbow290,,6
```

```
sectype,4,pipe
secdata,3.5,0.216,24

mp,ex,4,youngmodulus     ! Material properties
mp,nuxy,4,nu
mp,gxy,4,shearmodulus
mp,dens,4,1.043e-3

et,5,elbow290,,6

sectype,5,pipe
secdata,4.5,0.237,24

mp,ex,5,youngmodulus     ! Material properties
mp,nuxy,5,nu
mp,gxy,5,shearmodulus
mp,dens,5,1.107e-3

et,6,elbow290,,6

sectype,6,pipe
secdata,8.625,0.322,24

mp,ex,6,youngmodulus     ! Material properties
mp,nuxy,6,nu
mp,gxy,6,shearmodulus
mp,dens,6,1.253e-3

et,7,combin14      ! COMBIN14 spring-damper element
keyopt,7,2,1      ! Longitudinal spring damper element (UX DOF)
r,7,1.0e+5      ! Spring constant

et,8,combin14      ! COMBIN14 spring-damper element
keyopt,8,2,2      ! Longitudinal spring damper element (UY DOF)
r,8,1.0e+8      ! Spring constant

et,9,combin14      ! COMBIN14 spring-damper element
keyopt,9,2,3      ! Longitudinal spring damper element (Uz DOF)
r,9,1.0e+11      ! Spring constant

et,10,combin14      ! COMBIN14 spring-damper element
keyopt,10,2,4      ! Torsional spring damper element (ROTX DOF)
r,10,1.0e+20      ! Spring constant

et,11,combin14      ! COMBIN14 spring-damper element
keyopt,11,2,5      ! Torsional spring damper element (ROTY DOF)
r,11,1.0e+20      ! Spring constant

et,12,combin14      ! COMBIN14 spring-damper element
keyopt,12,2,6      ! Torsional spring damper element (ROTZ DOF)
r,12,1.0e+20      ! Spring constant


/com, ********************
/com, Key points
/com, ********************


k,  1,
k,  2,  15.000,
k,  3,  19.500,   -4.500
k,  4,  19.500, -180.000
k,  5,  19.500, -199.500
k,  6,  19.500, -204.000,   4.500
k,  7,  19.500, -204.000, 139.500
k,  8,  24.000, -204.000, 144.000
k,  9,  96.000, -204.000, 144.000
k, 10, 254.000, -204.000, 144.000
k, 11, 333.000, -204.000, 144.000
k, 12, 411.000, -204.000, 144.000
k, 13, 483.000, -204.000, 144.000
k, 14, 487.500, -204.000, 148.500
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k, 15, 487.500, -204.000, 192.000
k, 16, 487.500, -204.000, 235.500
k, 17, 492.000, -204.000, 240.000
k, 18, 575.000, -204.000, 240.000
k, 19, 723.000, -204.000, 240.000
k, 20, 727.500, -208.500, 240.000
k, 21, 727.500, -264.000, 240.000
k, 22, 727.500, -264.000, 205.000
k, 23, 727.500, -264.000, 190.000
k, 24, 733.500, -264.000, 184.000
k, 25, 753.500, -264.000, 184.000
k, 26, 845.500, -264.000, 184.000
k, 27, 851.500, -264.000, 178.000
k, 28, 851.500, -264.000, 160.000
k, 29, 851.500, -264.000, 142.000
k, 30, 851.500, -270.000, 136.000
k, 31, 851.500, -360.000, 136.000
k, 32, 727.500, -264.000, 255.000
k, 33, 727.500, -264.000, 270.000
k, 34, 727.500, -264.000, 306.000
k, 35, 727.500, -264.000, 414.000
k, 36, 739.500, -264.000, 426.000
k, 37, 847.500, -264.000, 426.000
k, 38, 955.500, -264.000, 426.000

k,101,16.165,-0.15333,0
k,102,17.25,-0.60289,0
k,103,18.182,-1.318,0
k,104,18.897,-2.25,0
k,105,19.347,-3.3353,0
k,501,19.5,-200.66,0.15333
k,502,19.5,-201.75,0.60289
k,503,19.5,-202.68,1.318
k,504,19.5,-203.4,2.25
k,505,19.5,-203.85,3.3353
k,701,19.653,-204,140.66
k,702,20.103,-204,141.75
k,703,20.818,-204,142.68
k,704,21.75,-204,143.4
k,705,22.835,-204,143.85
k,131,484.16,-204,144.15
k,132,485.25,-204,144.6
k,133,486.18,-204,145.32
k,134,486.9,-204,146.25
k,135,487.35,-204,147.34
k,161,487.65,-204,236.66
k,162,488.1,-204,237.75
k,163,488.82,-204,238.68
k,164,489.75,-204,239.4
k,165,490.84,-204,239.85
k,191,724.16,-204.15,240
k,192,725.25,-204.6,240
k,193,726.18,-205.32,240
k,194,726.9,-206.25,240
k,195,727.35,-207.34,240
k,231,727.7,-264,188.45
k,232,728.3,-264,187
k,233,729.26,-264,185.76
k,234,730.5,-264,184.8
k,235,731.95,-264,184.2
k,261,847.05,-264,183.8
k,262,848.5,-264,183.2
k,263,849.74,-264,182.24
k,264,850.7,-264,181
k,265,851.3,-264,179.55

k,291,851.5,-264.204,140.4471
k,292,851.5,-264.804,139
k,293,851.5,-265.757,137.7574
k,294,851.5,-267,136.8038
k,295,851.5,-268.447,136.2044
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k,351,727.91,-264,417.11
k,352,729.11,-264,420
k,353,731.01,-264,422.49
k,354,733.5,-264,424.39
k,355,736.39,-264,425.59

/com, ************************
/com,  Straight pipe elements
/com, ************************

type,1
secnum,1
mat,1

l, 1, 2                     ! line number 1
l, 3, 4
l, 4, 5
l, 6, 7
l, 8, 9
l, 9,10
l,10,11
l,11,12
l,12,13
l,14,15
l,15,16
l,17,18
l,18,19
l,20,21                     ! line number 14
lsel,s,line,,1,14,1
lesize,all,,,4
lmesh,all
allsel,all

type,2
secnum,2
mat,2

l,21,22                     ! line number 15
l,22,23
l,24,25
l,25,26
l,27,28
l,28,29
l,30,31                     ! line number 21
lsel,s,line,,15,21,1
lesize,all,,,4
lmesh,all
allsel,all

type,3
secnum,3
mat,3

l,21,32                     ! line number 22
l,32,33
l,33,34
l,34,35
l,36,37
l,37,38                     ! line number 27

lsel,s,line,,22,27,1
lesize,all,,,4
lmesh,all
allsel,all

/com, ********************
/com, Curved pipe elements
/com, *********************

type,4
secnum,1
mat,4
```

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larc,2,102,101                  ! line number 28
larc,102,104,103
larc,104,3,105
larc,5,502,501
larc,502,504,503
larc,504,6,505
larc,7,702,701
larc,702,704,703
larc,704,8,705
larc,13,132,131
larc,132,134,133
larc,134,14,135
larc,16,162,161
larc,162,164,163
larc,164,17,165
larc,19,192,191
larc,192,194,193
larc,194,20,195             ! line number 45

lsel,s,line,,28,45,1
lesize,all,,,4
lmesh,all
allsel,all


type,5
secnum,2
mat,5

larc,23,232,231             ! line number 46
larc,232,234,233
larc,234,24,235
larc,26,262,261
larc,262,264,263
larc,264,27,265
larc,29,292,291
larc,292,294,293
larc,294,30,295             ! line number 54

lsel,s,line,,46,54,1
lesize,all,,,4
lmesh,all
allsel,all

type,6
secnum,3
mat,6

larc,35,352,351             ! line number 55
larc,352,354,353
larc,354,36,355             ! line number 57


lsel,s,line,,55,57,1
lesize,all,,,4
lmesh,all
allsel,all


/com, ***************************
/com, nodes for elastic support
/com, ****************************

dist = 50.0       ! Visualization

n,10001,        -dist
n,20001,             ,          dist
n,30001,             ,              , -dist
n,10004,  19.500+dist, -180.000
n,30004,  19.500     , -180.000     , -dist
n,20007,  19.500     , -204.000+dist, 139.500
```

```
n,20011, 333.000     , -204.000+dist, 144.000
n,30011, 333.000     , -204.000     , 144.000-dist
n,10015, 487.500-dist, -204.000     , 192.000
n,20017, 492.000     , -204.000-dist, 240.000
n,30017, 492.000     , -204.000     , 240.000-dist
n,10023, 727.500-dist, -264.000     , 190.000
n,20023, 727.500     , -264.000+dist, 190.000
n,10031, 851.500+dist, -360.000     , 136.000
n,20031, 851.500     , -360.000-dist, 136.000
n,30031, 851.500     , -360.000     , 136.000-dist
n,20036, 739.500     , -264.000-dist, 426.000
n,30036, 739.500     , -264.000     , 426.000-dist
n,10038, 955.500+dist, -264.000     , 426.000
n,20038, 955.500     , -264.000-dist, 426.000
n,30038, 955.500     , -264.000     , 426.000-dist


/com, ****************************
/com, Elastic supports and anchors
/com, ****************************

type,7
real,8
e, node(19.5,-180.00,0),10004

real,7
e,node(487.50,-204.00,192.00),10015
e,node(727.50,-264.00,190.00),10023

real,9
e, node(0,0,0),10001
e,node(851.50,-360.00,136.00),10031
e,node(955.50,-264.00,426.00),10038

type,8
real,8
e, node(19.50,-204.00,139.50),20007
e,node(333.00,-204.00,144.00),20011
e,node(492.00,-204.00,240.00),20017
e,node(727.50,-264.00,190.00),20023
e,node(739.50,-264.00,426.00),20036

real,9
e, node(0,0,0),20001
e,node(851.50,-360.00,136.00),20031
e,node(955.500,-264.000,426.000),20038

type,9
real,8
e, node(19.50,-180.00,0),30004

real,7
e,node(333.00,-204.00,144.00),30011
e,node(492.00,-204.00,240.00),30017
e,node(739.500,-264.00,426.00),30036

real,9
e, node(0,0,0),30001
e,node(851.500,-360.00,136.00),30031
e,node(955.500,-264.000,426.000),30038

type,10
real,10
e, node(0,0,0),10001
e,node(851.500,-360.000,136.000),10031
e,node(955.500,-264.000,426.000),10038

type,11
real,10

e, node(0,0,0),20001
e,node(851.500,-360.000,136.000),20031
```

```
e,node(955.500,-264.000,426.000),20038

type,12
real,10

e, node(0,0,0),30001
e,node(851.50,-360.00,136.00),30031
e,node(955.50,-264.00,426.00),30038
allsel,all

/com, ************************************************************
/com,  Converting some PIPE289 into ELBOW290 using ELBOW command
/com,  near the pipe bends
/com, ************************************************************

elbow,on,,,sect

allsel,all

/com, ***************
/com, Constraints
/com, ***************

nsel,s,node,,10000,40000
d,all,all,0
allsel,all
fini

/com, ****************
/com, Modal analysis
/com, ****************

/solu
antype,modal
modopt,lanb,14
lumpm,on
mxpand,14,,,yes
solve
fini

/post1
/out,
/com, ******************************************
/com, Frequencies obtained from modal solution
/com, ******************************************
set,list
finish

/com, **********************
/com,  Spectrum analysis
/com, **********************

/out,scratch
/solu
antype,spectrum
spopt,sprs,,     ! Single point response spectrum solve
svtype,2,386.4     ! Seismic acceleration response
srss,0.001,disp     ! SRSS mode combination, displacement solution

sed,1,0,0     ! Excitation in X direction

freq    , 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.00
sv, 0.01, 0.06, 0.13, 0.13, 0.20, 0.35, 0.39, 0.37, 0.41, 0.76

freq    , 1.10, 1.20, 1.30, 1.40, 1.50, 1.60, 1.70, 1.80, 1.90
sv, 0.01, 0.64, 0.59, 0.91, 1.03, 1.46, 0.95, 0.91, 1.61, 1.92

freq    , 2.00, 2.10, 2.20, 2.30, 2.40, 2.50, 2.60, 2.70, 2.80
sv, 0.01, 1.57, 1.18, 2.65, 2.85, 3.26, 4.47, 4.75, 5.29, 7.44

freq    , 2.90, 3.00, 3.15, 3.30, 3.45, 3.60, 3.80, 4.00, 4.20
sv, 0.01, 4.27, 4.61, 4.13, 3.96, 4.05, 2.44, 2.09, 2.29, 1.52
```

```
freq    , 4.40, 4.60, 4.80, 5.00, 5.25, 5.50, 5.75, 6.00, 6.25
sv, 0.01, 1.34, 1.37, 1.36, 1.31, 1.69, 1.27, 1.04, 0.76, 0.76

freq    , 6.50, 6.75, 7.00, 7.25, 7.50, 7.75, 8.00, 8.50, 9.00
sv, 0.01, 0.69, 0.70, 0.74, 0.70, 0.67, 0.66, 0.61, 0.75, 0.60

freq    , 9.50,10.00,10.50,11.00,11.50,12.00,12.50,13.00,13.50
sv, 0.01, 0.69, 0.61, 0.70, 0.59, 0.61, 0.56, 0.59, 0.59, 0.59

freq    ,14.00,14.50,15.00,16.00,17.00,18.00,20.00,22.00,25.00
sv, 0.01, 0.58, 0.59, 0.58, 0.55, 0.56, 0.55, 0.55, 0.55, 0.54

freq    ,28.00,31.00,34.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
sv, 0.01, 0.54, 0.54, 0.54, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00


mmass,on,0.54     ! Missing mass with ZPA = 0.54
solve
save
finish

/post1
/input,,mcom

/out,

/com,
/com,==================================================================
/com, Maximum nodal displacements and rotations from spectrum solution
/com,==================================================================
/com,

/out,scratch

*GET,AdisX,NODE,279,U,X
*GET,AdisY,NODE,105,U,Y
*GET,AdisZ,NODE,50,U,Z
*GET,ArotX,NODE,78,ROT,X
*GET,ArotY,NODE,82,ROT,Y
*GET,ArotZ,NODE,113,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com,=================================================================
/com, Element Forces and Moments obtained from spectrum solution
/com,=================================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #1 (Pipe289 element)
/com,***********************


esel,s,elem,,1
etable,pxi_1,smisc,1
etable,vyi_1,smisc,6
etable,vzi_1,smisc,5
etable,txi_1,smisc,4
etable,myi_1,smisc,2
etable,mzi_1,smisc,3
esel,all
```

```
/out,
/com, ************************************************
/com,  Element forces and moments at element1, node i
/com, ************************************************

pretab,pxi_1,vyi_1,vzi_1,txi_1,myi_1,mzi_1


/out,scratch
/com,==========
/com,  Node J
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************

esel,s,elem,,1
etable,pxj_1,smisc,14
etable,vyj_1,smisc,19
etable,vzj_1,smisc,18
etable,txj_1,smisc,17
etable,myj_1,smisc,15
etable,mzj_1,smisc,16
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element1, node j
/com, ************************************************

pretab,pxj_1,vyj_1,vzj_1,txj_1,myj_1,mzj_1



/out,scratch


/com,==========
/com,  Node I
/com,==========

/com, Element #28 (Elbow 290 element)
/com,*************************

esel,s,elem,,28
etable,pxi_28,smisc,1
etable,vyi_28,smisc,6
etable,vzi_28,smisc,5
etable,txi_28,smisc,4
etable,myi_28,smisc,2
etable,mzi_28,smisc,3
esel,all

/out,
/com, *************************************************
/com,  Element forces and moments at element 28, node i
/com, ************************************************

pretab,pxi_28,vyi_28,vzi_28,txi_28,myi_28,mzi_28


/out,scratch
/com,==========
/com,  Node J
/com,==========



/com, Element #28 (Elbow290 element)
/com,********************************
esel,s,elem,,28
```

```
etable,pxj_28,smisc,36
etable,vyj_28,smisc,41
etable,vzj_28,smisc,40
etable,txj_28,smisc,39
etable,myj_28,smisc,37
etable,mzj_28,smisc,38
esel,all

allsel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element 28, node j
/com, ************************************************

pretab,pxj_28,vyj_28,vzj_28,txj_28,myj_28,mzj_28



/com,----------------------------------------------------------------------------

/com, ***************************************
/com,  Reaction forces from spectrum solution
/com, ****************************************

prrsol

finish
```

vm-nr6645-01-2a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr6645-01-2a
/title,vm-nr6645-01-2a,NRC Piping Benchmark Problems,Volume 1,Method 2
/com,*****************************************************************************
/com,
/com, Reference: Reevaluation of Regulatory Guidance
/com,            on modal response combination methods
/com,            for seismic response spectrum analysis
/com,           NUREG/CR-6645
/com,    R.Morante, Y.Wang
/com,    December 1999.
/com,
/com, Description:
/com, Response spectrum analysis on BM3 piping model using 14 modes + missing mass
/com,
/com, Lindley Yow rigid resonse calculation
/com,
/com, Elements used: PIPE289, ELBOW290, COMBIN14
/com,
/com, Results :
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum displacements and rotations obtained from spectrum solution
/com, 3. Element forces and moments obtained from spectrum solution
/com, 4. Reaction forces obtained from spectrum solution. SRSS, 1% damping
/com,
/com,
/com,*****************************************************************************

/out,scratch
/prep7

youngmodulus = 2.9e+7     ! Young's modulus
nu = 0.3      ! Poisson ratio
shearmodulus = youngmodulus/(2*(1+nu))   ! Shear modulus
```

```
et,1,pipe289,,,

sectype,1,pipe
secdata,3.5,0.216,24

mp,ex,1,youngmodulus     ! Material properties
mp,nuxy,1,nu
mp,gxy,1,shearmodulus
mp,dens,1,1.043e-3

et,2,pipe289,,,

sectype,2,pipe
secdata,4.5,0.237,24

mp,ex,2,youngmodulus     ! Material properties
mp,nuxy,2,nu
mp,gxy,2,shearmodulus
mp,dens,2,1.107e-03

et,3,pipe289,,,

sectype,3,pipe
secdata,8.625,0.322,24

mp,ex,3,youngmodulus     ! Material properties
mp,nuxy,3,nu
mp,gxy,3,shearmodulus
mp,dens,3,1.253e-3

et,4,elbow290,,6

sectype,4,pipe
secdata,3.5,0.216,24

mp,ex,4,youngmodulus     ! Material properties
mp,nuxy,4,nu
mp,gxy,4,shearmodulus
mp,dens,4,1.043e-3

et,5,elbow290,,6

sectype,5,pipe
secdata,4.5,0.237,24

mp,ex,5,youngmodulus     ! Material properties
mp,nuxy,5,nu
mp,gxy,5,shearmodulus
mp,dens,5,1.107e-3

et,6,elbow290,,6

sectype,6,pipe
secdata,8.625,0.322,24

mp,ex,6,youngmodulus     ! Material properties
mp,nuxy,6,nu
mp,gxy,6,shearmodulus
mp,dens,6,1.253e-3

et,7,combin14      ! COMBIN14 spring-damper element
keyopt,7,2,1      ! Longitudinal spring damper element (UX DOF)
r,7,1.0e+5      ! Spring constant

et,8,combin14      ! COMBIN14 spring-damper element
keyopt,8,2,2      ! Longitudinal spring damper element (UY DOF)
r,8,1.0e+8      ! Spring constant

et,9,combin14      ! COMBIN14 spring-damper element
keyopt,9,2,3      ! Longitudinal spring damper element (Uz DOF)
r,9,1.0e+11      ! Spring constant
```

```
et,10,combin14      ! COMBIN14 spring-damper element
keyopt,10,2,4      ! Torsional spring damper element (ROTX DOF)
r,10,1.0e+20      ! Spring constant

et,11,combin14      ! COMBIN14 spring-damper element
keyopt,11,2,5      ! Torsional spring damper element (ROTY DOF)
r,11,1.0e+20      ! Spring constant

et,12,combin14      ! COMBIN14 spring-damper element
keyopt,12,2,6      ! Torsional spring damper element (ROTZ DOF)
r,12,1.0e+20      ! Spring constant


/com, *******************
/com, Key points
/com, *******************


k,  1,
k,  2,  15.000,
k,  3,  19.500,   -4.500
k,  4,  19.500, -180.000
k,  5,  19.500, -199.500
k,  6,  19.500, -204.000,   4.500
k,  7,  19.500, -204.000, 139.500
k,  8,  24.000, -204.000, 144.000
k,  9,  96.000, -204.000, 144.000
k, 10, 254.000, -204.000, 144.000
k, 11, 333.000, -204.000, 144.000
k, 12, 411.000, -204.000, 144.000
k, 13, 483.000, -204.000, 144.000
k, 14, 487.500, -204.000, 148.500
k, 15, 487.500, -204.000, 192.000
k, 16, 487.500, -204.000, 235.500
k, 17, 492.000, -204.000, 240.000
k, 18, 575.000, -204.000, 240.000
k, 19, 723.000, -204.000, 240.000
k, 20, 727.500, -208.500, 240.000
k, 21, 727.500, -264.000, 240.000
k, 22, 727.500, -264.000, 205.000
k, 23, 727.500, -264.000, 190.000
k, 24, 733.500, -264.000, 184.000
k, 25, 753.500, -264.000, 184.000
k, 26, 845.500, -264.000, 184.000
k, 27, 851.500, -264.000, 178.000
k, 28, 851.500, -264.000, 160.000
k, 29, 851.500, -264.000, 142.000
k, 30, 851.500, -270.000, 136.000
k, 31, 851.500, -360.000, 136.000
k, 32, 727.500, -264.000, 255.000
k, 33, 727.500, -264.000, 270.000
k, 34, 727.500, -264.000, 306.000
k, 35, 727.500, -264.000, 414.000
k, 36, 739.500, -264.000, 426.000
k, 37, 847.500, -264.000, 426.000
k, 38, 955.500, -264.000, 426.000

k,101,16.165,-0.15333,0
k,102,17.25,-0.60289,0
k,103,18.182,-1.318,0
k,104,18.897,-2.25,0
k,105,19.347,-3.3353,0
k,501,19.5,-200.66,0.15333
k,502,19.5,-201.75,0.60289
k,503,19.5,-202.68,1.318
k,504,19.5,-203.4,2.25
k,505,19.5,-203.85,3.3353
k,701,19.653,-204,140.66
k,702,20.103,-204,141.75
k,703,20.818,-204,142.68
k,704,21.75,-204,143.4
k,705,22.835,-204,143.85
```

```
k,131,484.16,-204,144.15
k,132,485.25,-204,144.6
k,133,486.18,-204,145.32
k,134,486.9,-204,146.25
k,135,487.35,-204,147.34
k,161,487.65,-204,236.66
k,162,488.1,-204,237.75
k,163,488.82,-204,238.68
k,164,489.75,-204,239.4
k,165,490.84,-204,239.85
k,191,724.16,-204.15,240
k,192,725.25,-204.6,240
k,193,726.18,-205.32,240
k,194,726.9,-206.25,240
k,195,727.35,-207.34,240
k,231,727.7,-264,188.45
k,232,728.3,-264,187
k,233,729.26,-264,185.76
k,234,730.5,-264,184.8
k,235,731.95,-264,184.2
k,261,847.05,-264,183.8
k,262,848.5,-264,183.2
k,263,849.74,-264,182.24
k,264,850.7,-264,181
k,265,851.3,-264,179.55

k,291,851.5,-264.204,140.4471
k,292,851.5,-264.804,139
k,293,851.5,-265.757,137.7574
k,294,851.5,-267,136.8038
k,295,851.5,-268.447,136.2044

k,351,727.91,-264,417.11
k,352,729.11,-264,420
k,353,731.01,-264,422.49
k,354,733.5,-264,424.39
k,355,736.39,-264,425.59

/com, *************************
/com,  Straight pipe elements
/com, *************************

type,1
secnum,1
mat,1

l, 1, 2                    ! line number 1
l, 3, 4
l, 4, 5
l, 6, 7
l, 8, 9
l, 9,10
l,10,11
l,11,12
l,12,13
l,14,15
l,15,16
l,17,18
l,18,19
l,20,21                    ! line number 14
lsel,s,line,,1,14,1
lesize,all,,,4
lmesh,all
allsel,all

type,2
secnum,2
mat,2

l,21,22                    ! line number 15
l,22,23
l,24,25
```

```
l,25,26
l,27,28
l,28,29
l,30,31                    ! line number 21
lsel,s,line,,15,21,1
lesize,all,,,4
lmesh,all
allsel,all

type,3
secnum,3
mat,3

l,21,32                    ! line number 22
l,32,33
l,33,34
l,34,35
l,36,37
l,37,38                    ! line number 27

lsel,s,line,,22,27,1
lesize,all,,,4
lmesh,all
allsel,all

/com, *******************
/com, Curved pipe elements
/com, ********************

type,4
secnum,1
mat,4

larc,2,102,101                 ! line number 28
larc,102,104,103
larc,104,3,105
larc,5,502,501
larc,502,504,503
larc,504,6,505
larc,7,702,701
larc,702,704,703
larc,704,8,705
larc,13,132,131
larc,132,134,133
larc,134,14,135
larc,16,162,161
larc,162,164,163
larc,164,17,165
larc,19,192,191
larc,192,194,193
larc,194,20,195            ! line number 45

lsel,s,line,,28,45,1
lesize,all,,,4
lmesh,all
allsel,all


type,5
secnum,2
mat,5

larc,23,232,231            ! line number 46
larc,232,234,233
larc,234,24,235
larc,26,262,261
larc,262,264,263
larc,264,27,265
larc,29,292,291
larc,292,294,293
larc,294,30,295            ! line number 54
```

```
lsel,s,line,,46,54,1
lesize,all,,,4
lmesh,all
allsel,all

type,6
secnum,3
mat,6

larc,35,352,351             ! line number 55
larc,352,354,353
larc,354,36,355             ! line number 57


lsel,s,line,,55,57,1
lesize,all,,,4
lmesh,all
allsel,all


/com, ***************************
/com, nodes for elastic support
/com, ****************************

dist = 50.0       ! Visualization

n,10001,        -dist
n,20001,             ,          dist
n,30001,             ,              , -dist
n,10004,  19.500+dist, -180.000
n,30004,  19.500     , -180.000     , -dist
n,20007,  19.500     , -204.000+dist, 139.500
n,20011, 333.000     , -204.000+dist, 144.000
n,30011, 333.000     , -204.000     , 144.000-dist
n,10015, 487.500-dist, -204.000     , 192.000
n,20017, 492.000     , -204.000-dist, 240.000
n,30017, 492.000     , -204.000     , 240.000-dist
n,10023, 727.500-dist, -264.000     , 190.000
n,20023, 727.500     , -264.000+dist, 190.000
n,10031, 851.500+dist, -360.000     , 136.000
n,20031, 851.500     , -360.000-dist, 136.000
n,30031, 851.500     , -360.000     , 136.000-dist
n,20036, 739.500     , -264.000-dist, 426.000
n,30036, 739.500     , -264.000     , 426.000-dist
n,10038, 955.500+dist, -264.000     , 426.000
n,20038, 955.500     , -264.000-dist, 426.000
n,30038, 955.500     , -264.000     , 426.000-dist


/com, ****************************
/com, Elastic supports and anchors
/com, ****************************

type,7
real,8
e, node(19.5,-180.00,0),10004

real,7
e,node(487.50,-204.00,192.00),10015
e,node(727.50,-264.00,190.00),10023

real,9
e, node(0,0,0),10001
e,node(851.50,-360.00,136.00),10031
e,node(955.50,-264.00,426.00),10038

type,8
real,8
e, node(19.50,-204.00,139.50),20007
e,node(333.00,-204.00,144.00),20011
e,node(492.00,-204.00,240.00),20017
e,node(727.50,-264.00,190.00),20023
```

```
e,node(739.50,-264.00,426.00),20036

real,9
e, node(0,0,0),20001
e,node(851.50,-360.00,136.00),20031
e,node(955.500,-264.000,426.000),20038

type,9
real,8
e, node(19.50,-180.00,0),30004

real,7
e,node(333.00,-204.00,144.00),30011
e,node(492.00,-204.00,240.00),30017
e,node(739.500,-264.00,426.00),30036

real,9
e, node(0,0,0),30001
e,node(851.500,-360.00,136.00),30031
e,node(955.500,-264.000,426.000),30038

type,10
real,10
e, node(0,0,0),10001
e,node(851.500,-360.000,136.000),10031
e,node(955.500,-264.000,426.000),10038

type,11
real,10

e, node(0,0,0),20001
e,node(851.500,-360.000,136.000),20031
e,node(955.500,-264.000,426.000),20038

type,12
real,10

e, node(0,0,0),30001
e,node(851.50,-360.00,136.00),30031
e,node(955.50,-264.00,426.00),30038
allsel,all

/com, ************************************************************
/com,  Converting some PIPE289 into ELBOW290 using ELBOW command
/com,  near the pipe bends
/com, ************************************************************

elbow,on,,,sect

allsel,all

/com, ***************
/com, Constraints
/com, ***************

nsel,s,node,,10000,40000
d,all,all,0
allsel,all
fini

/com, ****************
/com, Modal analysis
/com, ****************

/solu
antype,modal
modopt,lanb,14
lumpm,on
mxpand,14,,,yes
solve
fini
```

```
/post1
/out,
/com, ******************************************
/com, Frequencies obtained from modal solution
/com, ******************************************
set,list
finish

/com, **********************
/com,  Spectrum analysis
/com, **********************

/out,scratch
/solu
antype,spectrum
spopt,sprs,,     ! Single point response spectrum solve
svtype,2,386.4     ! Seismic acceleration response
srss,0.001,disp     ! SRSS mode combination, displacement solution

sed,1,0,0     ! Excitation in X direction

freq    , 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.00
sv, 0.01, 0.06, 0.13, 0.13, 0.20, 0.35, 0.39, 0.37, 0.41, 0.76

freq    , 1.10, 1.20, 1.30, 1.40, 1.50, 1.60, 1.70, 1.80, 1.90
sv, 0.01, 0.64, 0.59, 0.91, 1.03, 1.46, 0.95, 0.91, 1.61, 1.92

freq    , 2.00, 2.10, 2.20, 2.30, 2.40, 2.50, 2.60, 2.70, 2.80
sv, 0.01, 1.57, 1.18, 2.65, 2.85, 3.26, 4.47, 4.75, 5.29, 7.44

freq    , 2.90, 3.00, 3.15, 3.30, 3.45, 3.60, 3.80, 4.00, 4.20
sv, 0.01, 4.27, 4.61, 4.13, 3.96, 4.05, 2.44, 2.09, 2.29, 1.52

freq    , 4.40, 4.60, 4.80, 5.00, 5.25, 5.50, 5.75, 6.00, 6.25
sv, 0.01, 1.34, 1.37, 1.36, 1.31, 1.69, 1.27, 1.04, 0.76, 0.76

freq    , 6.50, 6.75, 7.00, 7.25, 7.50, 7.75, 8.00, 8.50, 9.00
sv, 0.01, 0.69, 0.70, 0.74, 0.70, 0.67, 0.66, 0.61, 0.75, 0.60

freq    , 9.50,10.00,10.50,11.00,11.50,12.00,12.50,13.00,13.50
sv, 0.01, 0.69, 0.61, 0.70, 0.59, 0.61, 0.56, 0.59, 0.59, 0.59

freq    ,14.00,14.50,15.00,16.00,17.00,18.00,20.00,22.00,25.00
sv, 0.01, 0.58, 0.59, 0.58, 0.55, 0.56, 0.55, 0.55, 0.55, 0.54

freq    ,28.00,31.00,34.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
sv, 0.01, 0.54, 0.54, 0.54, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00


mmass,on,0.54     ! Missing mass with ZPA = 0.54
rigresp,on,lindley,0.54    ! Rigid response using Lindley approach
solve
save
fini


/post1
/input,,mcom

/out,

/com,
/com,============================================================
/com, Maximum nodal displacements and rotations from spectrum solution
/com,============================================================
/com,

/out,scratch

*GET,AdisX,NODE,274,U,X
*GET,AdisY,NODE,105,U,Y
*GET,AdisZ,NODE,50,U,Z
```

```
*GET,ArotX,NODE,78,ROT,X
*GET,ArotY,NODE,81,ROT,Y
*GET,ArotZ,NODE,113,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com,==============================================================
/com, Element Forces and Moments obtained from spectrum solution
/com,==============================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************


esel,s,elem,,1
etable,pxi_1,smisc,1
etable,vyi_1,smisc,6
etable,vzi_1,smisc,5
etable,txi_1,smisc,4
etable,myi_1,smisc,2
etable,mzi_1,smisc,3
esel,all

/out,
/com, ************************************************
/com,  Element forces and moments at element1, node i
/com, ************************************************

pretab,pxi_1,vyi_1,vzi_1,txi_1,myi_1,mzi_1


/out,scratch
/com,==========
/com,  Node J
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************

esel,s,elem,,1
etable,pxj_1,smisc,14
etable,vyj_1,smisc,19
etable,vzj_1,smisc,18
etable,txj_1,smisc,17
etable,myj_1,smisc,15
etable,mzj_1,smisc,16
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element1, node j
/com, ************************************************

pretab,pxj_1,vyj_1,vzj_1,txj_1,myj_1,mzj_1



/out,scratch
```

```
/com,==========
/com,  Node I
/com,==========

/com, Element #28 (Elbow 290 element)
/com,*************************

esel,s,elem,,28
etable,pxi_28,smisc,1
etable,vyi_28,smisc,6
etable,vzi_28,smisc,5
etable,txi_28,smisc,4
etable,myi_28,smisc,2
etable,mzi_28,smisc,3
esel,all

/out,
/com, *************************************************
/com,  Element forces and moments at element 28, node i
/com, ************************************************

pretab,pxi_28,vyi_28,vzi_28,txi_28,myi_28,mzi_28


/out,scratch
/com,==========
/com,  Node J
/com,==========



/com, Element #28 (Elbow290 element)
/com,*******************************
esel,s,elem,,28

etable,pxj_28,smisc,36
etable,vyj_28,smisc,41
etable,vzj_28,smisc,40
etable,txj_28,smisc,39
etable,myj_28,smisc,37
etable,mzj_28,smisc,38
esel,all

allsel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element 28, node j
/com, ************************************************

pretab,pxj_28,vyj_28,vzj_28,txj_28,myj_28,mzj_28



/com,----------------------------------------------------------------------------

/com, ***************************************
/com,  Reaction forces from spectrum solution
/com, ****************************************

prrsol

finish
```

vm-nr1677-02-4a Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-02-4a
```

```
/title,vm-nr1677-02-4a,NRC piping benchmarks problems,Volume II,Problem 4a

/com, *************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com,
/com, Elements used: PIPE289, ELBOW290, MASS21 and COMBIN14
/com,
/com, Results :
/com, The following results are outputted:
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com, *****************************************************************************

/out,scratch

/prep7

YoungModulus = 0.283e+8    ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus = YoungModulus/(2*(1+Nu)) ! Shear Modulus
K = 0.911e-5     ! Thermal Expansion
maxm = 50      ! No. of Modes Extracted

/com,
/com, Section Property
/com,*****************

/com,
/com, Wall Thickness
/com,----------------

WTick_1 = 2.25
WTick_2 = 3.44
WTick_3 = 1.0
WTick_4 = 2.64
WTick_5 = 74.775

WTick_6 = 1.0
WTick_7 = 2.64
WTick_8 = 0.7180
WTick_9 = 1.62
WTick_10 = 46.035

WTick_11 = 0.7180
WTick_12 = 0.906
WTick_13 = 0.365

/com,
/com, Outer Diameter
/com,----------------

OD_1 = 32.25
OD_2 = 15.625
OD_3 = 10.75
OD_4 = 16.03
OD_5 = 160.3

OD_6 = 10.75
OD_7 = 16.03
OD_8 = 6.625
OD_9 = 9.87
OD_10 = 98.7

OD_11 = 6.625
OD_12 = 8.625
OD_13 = 10.75
```

```
/com,--------------------------------------------------------------------------------

/com,
/com, Element Types
/com,***************

et,1,pipe289,,,
et,2,pipe289,,,
et,3,pipe289,,,
et,4,pipe289,,,
et,5,pipe289,,,
et,6,pipe289,,,
et,7,pipe289,,,
et,8,pipe289,,,
et,9,pipe289,,,
et,10,pipe289,,,
et,11,pipe289,,,
et,12,pipe289,,,
et,13,pipe289,,,

et,14,elbow290,,
et,15,elbow290,,
et,16,elbow290,,
et,17,elbow290,,
et,18,elbow290,,
et,19,elbow290,,
et,20,elbow290,,
et,21,elbow290,,
et,22,elbow290,,

et,23,mass21      ! 3D Mass without rotatary inertia
keyopt,23,3,2

et,24,mass21
keyopt,24,3,2

et,25,mass21
keyopt,25,3,2

et,26,mass21
keyopt,26,3,2

et,27,mass21
keyopt,27,3,2

et,28,mass21
keyopt,28,3,2

et,29,mass21
keyopt,29,3,2

et,30,mass21
keyopt,30,3,2

et,31,mass21
keyopt,31,3,2

et,32,mass21
keyopt,32,3,2

et,33,mass21
keyopt,33,3,2

et,34,mass21
keyopt,34,3,2

et,35,mass21
keyopt,35,3,2

et,36,mass21
```

```
keyopt,36,3,2

et,37,mass21
keyopt,37,3,2

et,38,mass21
keyopt,38,3,2

et,39,mass21
keyopt,39,3,2

et,40,mass21
keyopt,40,3,2

et,41,mass21
keyopt,41,3,2

et,42,mass21
keyopt,42,3,2

et,43,mass21
keyopt,43,3,2

et,44,mass21
keyopt,44,3,2

et,45,mass21
keyopt,45,3,2

et,46,mass21
keyopt,46,3,2

et,47,mass21
keyopt,47,3,2

et,48,combin14,,1      ! Spring Elements Types and Real constants
keyopt,48,2,1      ! X Degree of Freedom

et,49,combin14,,2
keyopt,49,2,2      ! Y Degree of Freedom

et,50,combin14,,3
keyopt,50,2,3      ! Z Degree of Freedom

et,51,combin14,,2
keyopt,51,2,2      ! Y Degree of Freedom

et,52,combin14,,2
keyopt,52,2,2      ! Y Degree of Freedom

et,53,combin14,,3
keyopt,53,2,3      ! Z Degree of Freedom

et,54,combin14,,1
keyopt,54,2,1      ! X Degree of Freedom

et,55,combin14,,2
keyopt,55,2,2      ! Y Degree of Freedom

et,56,combin14,,1
keyopt,56,2,1      ! X Degree of Freedom

et,57,combin14,,1
keyopt,57,2,1      ! X Degree of Freedom

et,58,combin14,,2
keyopt,58,2,2      ! Y Degree of Freedom

et,59,combin14,,1
keyopt,59,2,1      ! X Degree of Freedom

et,60,combin14,,2
```

```
keyopt,60,2,2      ! Y Degree of Freedom

et,61,combin14,,1
keyopt,61,2,1      ! X Degree of Freedom

et,62,combin14,,2
keyopt,62,2,2      ! Y Degree of Freedom

et,63,combin14,,2
keyopt,63,2,2      ! Y Degree of Freedom

et,64,combin14,,1
keyopt,64,2,1      ! X Degree of Freedom

et,65,combin14,,2
keyopt,65,2,2      ! Y Degree of Freedom

et,66,combin14,,3
keyopt,66,2,3      ! Z Degree of Freedom

et,67,combin14,,2
keyopt,67,2,2      ! Y Degree of Freedom

et,68,combin14,,1
keyopt,68,2,1      ! X Degree of Freedom

et,69,combin14,,1
keyopt,69,2,1      ! X Degree of Freedom

et,70,combin14,,2
keyopt,70,2,2      ! Y Degree of Freedom

et,71,combin14,,1
keyopt,71,2,1      ! X Degree of Freedom

et,72,combin14,,2
keyopt,72,2,2      ! Y Degree of Freedom

et,73,combin14,,1
keyopt,73,2,1      ! X Degree of Freedom

et,74,combin14,,1
keyopt,74,2,1      ! X Degree of Freedom

et,75,combin14,,3
keyopt,75,2,3      ! Z Degree of Freedom

et,76,combin14,,2
keyopt,76,2,2      ! Y Degree of Freedom

et,77,combin14,,2
keyopt,77,2,2      ! Y Degree of Freedom

et,78,combin14,,1
keyopt,78,2,1      ! X Degree of Freedom

et,79,combin14,,2
keyopt,79,2,2      ! Y Degree of Freedom

et,80,combin14,,2
keyopt,80,2,2      ! Y Degree of Freedom

et,81,combin14,,1
keyopt,81,2,1      ! X Degree of Freedom

et,82,combin14,,2
keyopt,82,2,2      ! Y Degree of Freedom

et,83,combin14,,3
keyopt,83,2,3      ! Z Degree of Freedom

/com,-----------------------------------------------------------------------------------
```

```
/com

/com, Real Constants
/com,****************

sectype,1,pipe
secdata,OD_1,WTick_1,

sectype,2,pipe
secdata,OD_2,WTick_2,

sectype,3,pipe
secdata,OD_3,WTick_3,

sectype,4,pipe
secdata,OD_4,WTick_4,

sectype,5,pipe
secdata,OD_5,WTick_5,

sectype,6,pipe
secdata,OD_6,WTick_6,

sectype,7,pipe
secdata,OD_7,WTick_7,

sectype,8,pipe
secdata,OD_8,WTick_8,

sectype,9,pipe
secdata,OD_9,WTick_9,

sectype,10,pipe
secdata,OD_10,WTick_10,

sectype,11,pipe
secdata,OD_11,WTick_11,

sectype,12,pipe
secdata,OD_12,WTick_12,

sectype,13,pipe
secdata,OD_13,WTick_13,

sectype,14,pipe
secdata,OD_3,WTick_3,

sectype,15,pipe
secdata,OD_6,WTick_6,

sectype,16,pipe
secdata,OD_6,WTick_6,

sectype,17,pipe
secdata,OD_13,WTick_13,

sectype,18,pipe
secdata,OD_13,WTick_13,

sectype,19,pipe
secdata,OD_8,WTick_8,

sectype,20,pipe
secdata,OD_12,WTick_12,

sectype,21,pipe
secdata,OD_12,WTick_12,

sectype,22,pipe
secdata,OD_12,WTick_12,

r,23,1.69306
```

```
r,24,5.07505
r,25,4.96894
r,26,1.20212
r,27,1.42495
r,28,1.88768
r,29,2.18323
r,30,2.4397
r,31,2.98188
r,32,1.41874
r,33,1.04943e+1
r,34,9.30124e-1
r,35,1.6118
r,36,6.74431e-1
r,37,6.43116e-1
r,38,1.06962
r,39,1.20549
r,40,1.05642
r,41,1.25388
r,42,1.3543
r,43,6.66149e-1
r,44,2.27769
r,45,1.15217
r,46,1.23214
r,47,1.52976

r,48, 0.1e+9
r,49, 0.1e+9
r,50, 0.1e+9
r,51, 0.1080e+4
r,52, 0.6001e+5
r,53, 0.6001e+5
r,54, 0.6001e+5
r,55, 0.7541e+6
r,56, 0.7541e+6
r,57, 0.6001e+5
r,58, 0.6000e+3
r,59, 0.6001e+5
r,60, 0.7601e+5
r,61, 0.6001e+5
r,62, 0.8000e+3
r,63, 0.6001e+5
r,64, 0.1000e+9
r,65, 0.1000e+9
r,66, 0.1000e+9
r,67, 0.2600e+3
r,68, 0.5901e+5
r,69, 0.2400e+5
r,70, 0.7601e+5
r,71, 0.2801e+5
r,72, 0.2460e+6
r,73, 0.6001e+5
r,74, 0.6001e+5
r,75, 0.7501e+5
r,76, 0.4660e+6
r,77, 0.3400e+3
r,78, 0.6001e+5
r,79, 0.5000e+6
r,80, 0.5000e+6
r,81, 0.1000e+9
r,82, 0.1000e+9
r,83, 0.1000e+9

/com,------------------------------------------------------------------------------------

/com, Material Properties
/com,*********************

MP,EX,  1, YoungModulus
MP,NUXY,1, Nu
MP,GXY ,1, ShearModulus
MP,ALPX,1, K
```

```
/com,-------------------------------------------------------------------------------------

/com, Nodes
/com,*******

k,1,-203.808,4715.952,139.224
k,2,-215.808,4715.952,139.224
k,3,-203.808,4703.952,139.224
k,4,-203.808,4715.952,127.224
k,5,-203.268,4719.852,154.860
k,6,-202.308,4726.800,182.748
k,7,-202.008,4728.948,191.340
k,8,-201.876,4729.392,194.916
k,9,-201.888,4729.392,194.988
k,10,-205.908,4729.392,205.740
k,11,-210.036,4729.392,210.168
k,12,-212.160,4729.392,212.436
k,13,-213.324,4729.392,213.684
k,14,-220.968,4729.392,221.868
k,15,-220.968,4734.492,221.868
k,16,-231.888,4729.392,233.568
k,17,-233.952,4729.392,235.776
k,18,-233.952,4741.392,235.776
k,19,-235.980,4729.392,237.936
k,20,-246.204,4714.392,248.904

k,21,-246.204,4705.860,248.904
k,22,-246.204,4686.792,248.904
k,23,-246.204,4676.952,248.904
k,24,-246.204,4665.900,248.904
k,25,-246.204,4638.876,248.904
k,26,-246.204,4631.628,248.904
k,27,-246.204,4628.952,248.904
k,28,-256.812,4613.952,238.296
k,29,-263.004,4613.952,232.104
k,30,-263.004,4625.952,232.104
k,31,-264.048,4613.952,231.060
k,32,-275.352,4613.952,219.744
k,33,-275.352,4619.052,219.744
k,34,-286.668,4613.952,208.440
k,35,-291.996,4613.952,203.112
k,36,-302.604,4613.952,198.720
k,37,-314.988,4613.952,198.720
k,38,-314.988,4613.952,186.720
k,39,-340.380,4613.952,198.720
k,40,-366.000,4613.952,198.720

k,41,-381.000,4628.952,198.720
k,42,-381.000,4630.560,198.720
k,43,-381.000,4655.952,198.720
k,44,-369.035,4655.952,197.800
k,45,-381.000,4689.588,198.720
k,46,-381.000,4756.872,198.720
k,47,-381.000,4760.952,198.720
k,48,-396.000,4775.952,198.720
k,49,-399.000,4775.952,198.720
k,50,-399.000,4787.952,198.720
k,51,-402.600,4775.952,198.720
k,52,-402.600,4775.872,210.685
k,53,-440.904,4775.952,198.720
k,54,-450.612,4775.952,198.720
k,55,-465.612,4790.952,198.720
k,56,-465.612,4796.592,198.720
k,57,-453.643,4796.592,197.860
k,58,-465.612,4840.068,198.720
k,59,-465.612,4927.032,198.720
k,60,-465.612,4943.952,198.720

k,61,-459.864,4958.952,212.568
k,62,-458.712,4958.952,215.340
k,63,-458.712,4970.952,215.340
k,64,-455.748,4958.952,222.480
```

```
k,65,-463.860,4958.952,242.076
k,66,-484.044,4958.952,250.452
k,67,-533.124,4958.952,270.828
k,68,-537.724,4958.952,259.745
k,69,-552.516,4958.952,278.880
k,70,-552.600,4958.952,278.916
k,71,-560.652,4958.952,298.392
k,72,-559.464,4958.952,301.248
k,73,-559.464,4970.952,301.248
k,74,-558.312,4958.952,304.020
k,75,-553.866,4961.957,293.286
k,76,-554.868,4958.952,312.324
k,77,-548.736,4958.952,327.108
k,78,-548.736,4981.752,327.108
k,79,-546.708,4958.952,331.992
k,80,-542.604,4958.952,341.880

k,81,-538.152,4958.952,352.620
k,82,-532.404,4973.952,366.468
k,83,-532.404,4988.628,366.468
k,84,-532.404,5039.952,366.468
k,85,-532.404,5040.048,366.468
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/com, Straight Pipe (Tangent) Elements
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/com,
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larc,462,464,463,
larc,464,274,465,
larc,274,472,471,
larc,472,474,473,
larc,474,86,475,        ! 181

lsel,s,line,,176,181,1
lesize,all,,,1
```

```
lmesh,all
allsel,all


type,19
secnum,8
larc,100,482,481,          ! 182
larc,482,484,483,
larc,484,275,485,
larc,275,492,491,
larc,492,494,493,
larc,494,101,495,
larc,103,502,501,
larc,502,504,503,
larc,504,104,505,
larc,105,512,511,
larc,512,514,513,
larc,514,106,515,
larc,115,522,521,
larc,522,524,523,
larc,524,116,525,
larc,121,532,531,
larc,532,534,533,
larc,534,122,535,
larc,125,542,541,
larc,542,544,543,
larc,544,126,545,
larc,131,552,551,
larc,552,554,553,
larc,554,132,555,
larc,139,562,561,
larc,562,564,563,
larc,564,140,565,
larc,147,572,571,
larc,572,574,573,
larc,574,276,575,
larc,276,582,581,
larc,582,584,583,
larc,584,148,585,
larc,152,592,591,
larc,592,594,593,
larc,594,277,595,
larc,277,602,601,
larc,602,604,603,
larc,604,153,605,
larc,155,612,611,
larc,612,614,613,
larc,614,156,615,          ! 223

lsel,s,line,,182,223,1
lesize,all,,,1
lmesh,all
allsel,all

type,20
secnum,12
larc,171,622,621,         ! 224
larc,622,624,623,
larc,624,172,625,
larc,174,632,631,
larc,632,634,633,
larc,634,175,635,
larc,181,642,641,
larc,642,644,643,
larc,644,278,645,
larc,278,652,651,
larc,652,654,653,
larc,654,182,655,
larc,183,662,661,
larc,662,664,663,
larc,664,279,665,
larc,279,672,671,
```

```
larc,672,674,673,
larc,674,184,675,     ! 241

lsel,s,line,,224,241,
lesize,all,,,1
lmesh,all
allsel,all


type,21
secnum,12
larc,186,682,681,     ! 242
larc,682,684,683,
larc,684,187,685,     ! 244

lsel,s,line,,242,244
lesize,all,,,1
lmesh,all
allsel,all


type,22
secnum,12
larc,179,692,691,      ! 245
larc,692,694,693,
larc,694,180,695,      ! 247


lsel,s,line,,245,247
lesize,all,,,1
lmesh,all
allsel,all



/com, Convert some PIPE289 into ELBOW290 using ELBOW command


elbow,on,,,sect






/com, Point Mass without considering rotatary inertia
/com,*************************************************

type,23
real,23
e,node(-212.160,4729.392,212.436)
e,node(-246.204,4705.860,248.904)
e,node(-246.204,4638.876,248.904)

type,24
real,24
e,node(-220.968,4734.492,221.868)

type,25
real,25
e,node(-275.352,4619.052,219.744)

type,26
real,26
e,node(-286.668,4613.952,208.440)

type,27
real,27
e,node(-340.380,4613.952,198.720)
e,node(-381.000,4630.560,198.720)
```

```
type,28
real,28
e,node(-381.000,4689.588,198.720)
e,node(-381.000,4756.872,198.720)

type,29
real,29
e,node(-440.904,4775.952,198.720)

type,30
real,30
e,node(-465.612,4840.068,198.720)
e,node(-465.612,4927.032,198.720)

type,31
real,31
e,node(-484.044,4958.952,250.452)

type,32
real,32
e,node(-552.516,4958.952,278.880)

type,33
real,33
e,node(-548.736,4981.752,327.108)

type,34
real,34
e,node(-546.708,4958.952,331.992)
e,node(-532.404,4988.628,366.468)
e,node(-532.404,5039.952,366.468)

type,35
real,35
e,node(-578.988,5091.924,385.812)

type,36
real,36
e,node(-232.056,4665.936,263.052)
e,node(-225.696,4613.952,256.692)
e,node(-216.048,4613.952,208.800)

type,37
real,37
e,node(-216.048,4613.952,155.748)
e,node(-216.048,4613.952,103.944)

type,38
real,38
e,node(-216.048,4613.952,34.980)

type,39
real,39
e,node(-276.048,4613.952,40.452)
e,node(-276.048,4613.952,137.544)

type,40
real,40
e,node(-276.048,4668.492,177.948)
e,node(-276.048,4753.560,177.948)

type,41
real,41
e,node(-350.532,4775.952,177.948)
e,node(-451.512,4775.952,177.948)

type,42
real,42
e,node(-481.020,4855.320,177.948)
e,node(-481.020,4964.388,177.948)

type,43
```

```
real,43
e,node(-520.044,5009.952,194.148)
e,node(-566.916,5021.892,213.600)
e,node(-556.716,5057.952,238.188)

type,44
real,44
e,node(-553.884,5062.044,245.004)

type,45
real,45
e,node(-534.588,5057.952,291.528)
e,node(-512.880,5057.952,343.824)

type,46
real,46
e,node(-496.392,5037.192,383.544)
e,node(-539.784,5021.952,409.358)
e,node(-588.540,5021.952,438.372)
e,node(-613.716,5047.452,470.388)

type,47
real,47
e,node(-570.048,5047.452,521.736)
e,node(-516.180,5047.452,574.200)
e,node(-462.312,5047.452,626.676)

/com,
/com, Elastic supports and anchors
/com,******************************

type,48
real,48
l,1,2           ! 248
lesize,248,,,1
lmesh,248
allsel,all


type,49
real,49
l,1,3           ! 249
lesize,249,,,1
lmesh,249
allsel,all

type,50
real,50
l,1,4
lesize,250,,,1
lmesh,250
allsel,all

id = 51
type,51
real,51
l,17,18
lesize,251,,,1
lmesh,251
allsel,all


type,52
real,52
l,29,30
lesize,252,,,1
lmesh,252
allsel,all

type,53
real,53
l,37,38
```

```
lesize,253,,,1
lmesh,253
allsel,all

type,55
real,55
l,49,50
lesize,254,,,1
lmesh,254
allsel,all

type,58
real,58
l,62,63
lesize,255,,,1
lmesh,255
allsel,all

type,60
real,60
l,72,73
lesize,256,,,1
lmesh,256
allsel,all

type,62
real,62
l,87,88
lesize,257,,,1
lmesh,257
allsel,all

type,63
real,63
l,89,90
lesize,258,,,1
lmesh,258
allsel,all

type,64
real,64
l,94,95
lesize,259,,,1
lmesh,259
allsel,all

type,65
real,65
l,94,96
lesize,260,,,1
lmesh,260
allsel,all

type,66
real,66
l,94,97
lesize,261,,,1
lmesh,261
allsel,all

type,67
real,67
l,108,109
lesize,262,,,1
lmesh,262
allsel,all

type,68
real,68
l,112,113
lesize,263,,,1
lmesh,263
```

```
allsel,all

type,70
real,70
l,119,120
lesize,264,,,1
lmesh,264
allsel,all

type,72
real,72
l,133,134
lesize,265,,,1
lmesh,265
allsel,all

type,75
real,75
l,145,146
lesize,266,,,1
lmesh,266
allsel,all

type,76
real,76
l,149,150
lesize,267,,,1
lmesh,267
allsel,all

type,77
real,77
l,157,158
lesize,268,,,1
lmesh,268
allsel,all

id = 79
type,79
real,79
l,169,170
lesize,269,,,1
lmesh,269
allsel,all

type,80
real,80
l,188,177
lesize,270,,,1
lmesh,270
allsel,all

type,81
real,81
l,192,193
lesize,271,,,1
lmesh,271
allsel,all

type,82
real,82
l,192,194
lesize,272,,,1
lmesh,272
allsel,all

type,83
real,83
l,192,195
lesize,273,,,1
lmesh,273
allsel,all
```

```
n,44000,-369.035,4655.952,197.800

n,52000,-402.600,4775.872,210.685

n,57000,-453.643,4796.592,197.860

n,49000,-399.00,4775.952,198.720

n,68000,-537.724,4958.952,259.745

n,75000,-553.866,4961.957,293.286

n,72000,-559.464,4958.952,301.248

n,118000,-231.048,4616.447,29.785

n,128000,-274.814,4625.952,189.884

n,136000,-300.048,4781.441,188.620

n,142000,-469.580,4800.792,181.571

n,166000,-556.148,5060.878,260.821





/com,
/com, rotate nodes with less than 3 supports
/com,***************************************

wplane,,nx(69),ny(69),nz(69),nx(44000),ny(44000),nz(44000),nx(71),ny(71),nz(71)
cswplane,11,0
nrotat,69
nrotat,44000
csys,0

real,54
type,54
e,69,44000

wplane,,nx(80),ny(80),nz(80),nx(52000),ny(52000),nz(52000),nx(78),ny(78),nz(78)
cswplane,12,0
nrotat,80
nrotat,52000
csys,0

real,56
type,56
e,80,52000

wplane,,nx(87),ny(87),nz(87),nx(57000),ny(57000),nz(57000),nx(86),ny(86),nz(86)
cswplane,13,0
nrotat,87
nrotat,57000
csys,0

real,57
type,57
e,87,57000

wplane,,nx(103),ny(103),nz(103),nx(68000),ny(68000),nz(68000),nx(101),ny(101),nz(101)
cswplane,14,0
nrotat,103
nrotat,68000
csys,0
```

```
real,59
type,59
e,103,68000

wplane,,nx(112),ny(112),nz(112),nx(75000),ny(75000),nz(75000),nx(110),ny(110),nz(110)
cswplane,15,0
nrotat,112
nrotat,75000
csys,0

real,61
type,61
e,112,75000

wplane,,nx(172),ny(172),nz(172),nx(118000),ny(118000),nz(118000),nx(171),ny(171),nz(171)
cswplane,16,0
nrotat,172
nrotat,118000
csys,0

real,69
type,69
e,172,118000

wplane,,nx(186),ny(186),nz(186),nx(128000),ny(128000),nz(128000),nx(185),ny(185),nz(185)
cswplane,17,0
nrotat,186
nrotat,128000
csys,0

real,71
type,71
e,186,128000

wplane,,nx(197),ny(197),nz(197),nx(136000),ny(136000),nz(136000),nx(195),ny(195),nz(195)
cswplane,18,0
nrotat,197
nrotat,136000
csys,0

real,73
type,73
e,197,136000

wplane,,nx(206),ny(206),nz(206),nx(142000),ny(142000),nz(142000),nx(205),ny(205),nz(205)
cswplane,19,0
nrotat,206
nrotat,142000
csys,0

real,74
type,74
e,206,142000

wplane,,nx(243),ny(243),nz(243),nx(166000),ny(166000),nz(166000),nx(234),ny(234),nz(234)
cswplane,20,0
nrotat,243
nrotat,166000
csys,0

real,78
type,78
e,243,166000

/com,-------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

ksel,s,,,2,4
ksel,a,,,18
```

```
ksel,a,,,30
ksel,a,,,38
!ksel,a,,,44
ksel,a,,,50
!ksel,a,,,52
!ksel,a,,,57
ksel,a,,,63
!ksel,a,,,68
ksel,a,,,73
!ksel,a,,,75
ksel,a,,,88
ksel,a,,,90
ksel,a,,,95,97
ksel,a,,,109
ksel,a,,,113
!ksel,a,,,118
ksel,a,,,120
!ksel,a,,,128
ksel,a,,,134
!ksel,a,,,136
!ksel,a,,,142
ksel,a,,,146
ksel,a,,,150
ksel,a,,,158
!ksel,a,,,166
ksel,a,,,170
ksel,a,,,177
ksel,a,,,193,195
nslk,s
d,all,all
allsel,all,all


nsel,s,node,,44000
nsel,a,node,,52000
nsel,a,node,,57000
nsel,a,node,,68000
nsel,a,node,,75000
nsel,a,node,,118000
nsel,a,node,,128000
nsel,a,node,,136000
nsel,a,node,,142000
nsel,a,node,,166000
d,all,all,0
allsel,all


ksel,s,,,1
nslk,s
d,all,rotx,,,,,roty,rotz
allsel,all

ksel,s,,,94
nslk,s
d,all,rotx,,,,,roty,rotz
allsel,all

ksel,s,,,192
nslk,s
d,all,rotx,,,,,roty,rotz
allsel,all
finish

/com,--------------------------------------------------------------------------------

/com,
/com,============
/com, Modal Solve
/com,============
/com,

/solution
```

```
antype,modal     ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on      ! Use Lumped Mass Matrix Approximation
mxpand,maxm,,,yes     ! Expand solutions with Element Calculations turned ON
solve
finish

/post1
/out,
/com, ******************************************
/com,  Frequencies obtained from modal solution
/com, *******************************************
set,list
finish

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/out,scratch
/solution
antype,spectr      ! Perform Spectrum Analysis
spopt,sprs,maxm      ! Single Point Response Spectrum
SRSS,0.0       ! Combine modes using SRSS mode combination

/com,--------------------------------------------------------------------------------
/com,

/com,
/com, spectrum 1 (X - Direction)
/com,****************************

svtyp, 2, 386.20

freq,0.2,0.5,0.5263,0.578,0.7752,1.7241,2.0,2.1978,2.2472,
SV,,0.16,0.16,0.16,0.23,0.339,0.55,0.555,0.555,0.65,

freq,2.9851,3.125,4.1667,5.0,5.7143,7.6923,9.0909,9.5238,10.4167
sv,,0.65,1.5,1.5,1.36,0.45,0.935,0.935,0.995,1.31,

freq,14.0845,17.8571,19.6078,27.027,33.3333,50.0,100.0
sv,,1.31,1.0,1.222,1.222,0.5,0.252,0.252,

sed,1,0,0
solve

/com,
/com, spectrum 2 (Y - Direction)
/com,****************************

svtyp, 2, 386.20
freq,,

FREQ,0.2,0.6061,0.667,1.9231,2.439,3.7037,4.0,5.3476,5.5866,
SV,,0.085,0.115,0.125,0.36,0.40,0.525,0.54,0.54,0.506,

FREQ,8.333,10.989,12.5,14.7059,20.0,21.2766,22.2222,27.7778,28.5714,
SV,,2.6,2.6,0.9,0.875,0.875,0.76,0.85,0.85,0.522,

FREQ,30.303,33.3333,50.0,100.0
SV,,0.255,0.295,0.194,0.194

sed,0,1,0
solve

/com,
/com, spectrum 3 (Z - Direction)
/com,***************************

svtyp, 2, 386.20
```

```
freq,,,

FREQ,0.2,0.5,0.5814,1.7544,2.1739,2.8571,3.0303,4.1667,5.0,
SV,,0.16,0.16,0.23,0.56,0.56,0.80,1.5,1.5,1.15,

FREQ,5.2632,5.7143,5.8824,6.2893,6.5789,7.4074,9.6154,10.4167,14.0845,
SV,,0.64,0.64,0.7,0.7,0.875,1.05,1.05,1.31,1.31,

FREQ,15.873,17.2414,25.0,27.027,32.2581,50.0,100.0
SV,,0.85,1.15,1.15,1.1,0.5,0.225,0.225,

sed,0,0,1
solve

finish

/com,------------------------------------------------------------------------------------------
/com,

/com,------------------------------------------------------------------------------------------

/post1
/input,,mcom

/out,
/com,
/com,===================================================================
/com, Maximum nodal displacements and rotations from spectrum solution
/com,===================================================================
/com,

/out,scratch

*GET,AdisX,NODE,470,U,X
*GET,AdisY,NODE,243,U,Y
*GET,AdisZ,NODE,425,U,Z
*GET,ArotX,NODE,172,ROT,X
*GET,ArotY,NODE,217,ROT,Y
*GET,ArotZ,NODE,127,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com,==================================================================
/com, Element Forces and Moments obtained from spectrum solution
/com,==================================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************


esel,s,elem,,1
etable,pxi_1,smisc,1
etable,vyi_1,smisc,6
etable,vzi_1,smisc,5
etable,txi_1,smisc,4
etable,myi_1,smisc,2
etable,mzi_1,smisc,3
esel,all

/out,
```

```
/com, ************************************************
/com,  Element forces and moments at element1, node i
/com, ************************************************

pretab,pxi_1,vyi_1,vzi_1,txi_1,myi_1,mzi_1


/out,scratch
/com,==========
/com,  Node J
/com,==========

/com, Element #1 (Pipe289 element)
/com,***********************

esel,s,elem,,1
etable,pxj_1,smisc,14
etable,vyj_1,smisc,19
etable,vzj_1,smisc,18
etable,txj_1,smisc,17
etable,myj_1,smisc,15
etable,mzj_1,smisc,16
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element1, node j
/com, ************************************************

pretab,pxj_1,vyj_1,vzj_1,txj_1,myj_1,mzj_1



/out,scratch


/com,==========
/com,  Node I
/com,==========

/com, Element #240 (Elbow 290 element)
/com,************************

esel,s,elem,,240
etable,pxi_240,smisc,1
etable,vyi_240,smisc,6
etable,vzi_240,smisc,5
etable,txi_240,smisc,4
etable,myi_240,smisc,2
etable,mzi_240,smisc,3
esel,all

/out,
/com, *************************************************
/com,  Element forces and moments at element 240, node i
/com, ************************************************

pretab,pxi_240,vyi_240,vzi_240,txi_240,myi_240,mzi_240


/out,scratch
/com,==========
/com,  Node J
/com,==========



/com, Element #240 (Elbow290 element)
/com,******************************
esel,s,elem,,240

etable,pxj_240,smisc,36
```

```
etable,vyj_240,smisc,41
etable,vzj_240,smisc,40
etable,txj_240,smisc,39
etable,myj_240,smisc,37
etable,mzj_240,smisc,38
esel,all

allsel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element 240, node j
/com, ************************************************

pretab,pxj_240,vyj_240,vzj_240,txj_240,myj_240,mzj_240



/com,--------------------------------------------------------------------------------

/com, ***************************************
/com,  Reaction forces from spectrum solution
/com, ****************************************

prrsol

finish
```

vm-nr1677-02-4c Input Listing

```
/COM,ANSYS MEDIA REL. 150 (11/8/2013) REF. VERIF. MANUAL: REL. 150
/verify,vm-nr1677-02-4c
/title,vm-nr1677-02-4c,NRC piping benchmarks problems,Volume II,Problem 4c
/com, *******************************************************************************
/com, Reference: Piping benchmark problems,Dynamic analysis independant support
/com,            motion response spectrum method, P. Bezler, M. Subudhi and
/com,            M.Hartzman, NUREG/CR--1677-Vol.2, August 1985.
/com,
/com, Elements used: PIPE289, ELBOW290, COMBIN14 and MASS21
/com,
/com,
/com, Results :
/com, The following results are outputted
/com, 1. Frequencies obtained from modal solution.
/com, 2. Maximum nodal displacements and rotations obtained from spectrum solution.
/com, 3. Element forces/moments obtained from spectrum solution.
/com, 4. Reaction forces obtained from spectrum solution.
/com,
/com,
/com, *******************************************************************************

/out,scratch

/prep7

YoungModulus = 0.283e+8    ! Young's Modulus
Nu = 0.3      ! Minor Poisson's Ratio
ShearModulus = YoungModulus/(2*(1+Nu)) ! Shear Modulus
K = 0.911e-5     ! Thermal Expansion
maxm = 50      ! No. of Modes Extracted

/com,
/com, Section Property
/com,*****************

/com,
/com, Wall Thickness
/com,----------------
```

```
WTick_1 = 2.25
WTick_2 = 3.44
WTick_3 = 1.0
WTick_4 = 2.64
WTick_5 = 74.775

WTick_6 = 1.0
WTick_7 = 2.64
WTick_8 = 0.7180
WTick_9 = 1.62
WTick_10 = 46.035

WTick_11 = 0.7180
WTick_12 = 0.906
WTick_13 = 0.365

/com,
/com, Outer Diameter
/com,----------------

OD_1 = 32.25
OD_2 = 15.625
OD_3 = 10.75
OD_4 = 16.03
OD_5 = 160.3

OD_6 = 10.75
OD_7 = 16.03
OD_8 = 6.625
OD_9 = 9.87
OD_10 = 98.7

OD_11 = 6.625
OD_12 = 8.625
OD_13 = 10.75


/com,------------------------------------------------------------------------------------

/com,
/com, Element Types
/com,***************

et,1,pipe289,,,
et,2,pipe289,,,
et,3,pipe289,,,
et,4,pipe289,,,
et,5,pipe289,,,
et,6,pipe289,,,
et,7,pipe289,,,
et,8,pipe289,,,
et,9,pipe289,,,
et,10,pipe289,,,
et,11,pipe289,,,
et,12,pipe289,,,
et,13,pipe289,,,

et,14,elbow290,,
et,15,elbow290,,
et,16,elbow290,,
et,17,elbow290,,
et,18,elbow290,,
et,19,elbow290,,
et,20,elbow290,,
et,21,elbow290,,
et,22,elbow290,,

et,23,mass21      ! 3D Mass without rotatary inertia
keyopt,23,3,2

et,24,mass21
```

```
keyopt,24,3,2

et,25,mass21
keyopt,25,3,2

et,26,mass21
keyopt,26,3,2

et,27,mass21
keyopt,27,3,2

et,28,mass21
keyopt,28,3,2

et,29,mass21
keyopt,29,3,2

et,30,mass21
keyopt,30,3,2

et,31,mass21
keyopt,31,3,2

et,32,mass21
keyopt,32,3,2

et,33,mass21
keyopt,33,3,2

et,34,mass21
keyopt,34,3,2

et,35,mass21
keyopt,35,3,2

et,36,mass21
keyopt,36,3,2

et,37,mass21
keyopt,37,3,2

et,38,mass21
keyopt,38,3,2

et,39,mass21
keyopt,39,3,2

et,40,mass21
keyopt,40,3,2

et,41,mass21
keyopt,41,3,2

et,42,mass21
keyopt,42,3,2

et,43,mass21
keyopt,43,3,2

et,44,mass21
keyopt,44,3,2

et,45,mass21
keyopt,45,3,2

et,46,mass21
keyopt,46,3,2

et,47,mass21
keyopt,47,3,2

et,48,combin14,,1      ! Spring Elements Types and Real constants
```

```
keyopt,48,2,1      ! X Degree of Freedom

et,49,combin14,,2
keyopt,49,2,2      ! Y Degree of Freedom

et,50,combin14,,3
keyopt,50,2,3      ! Z Degree of Freedom

et,51,combin14,,2
keyopt,51,2,2      ! Y Degree of Freedom

et,52,combin14,,2
keyopt,52,2,2      ! Y Degree of Freedom

et,53,combin14,,3
keyopt,53,2,3      ! Z Degree of Freedom

et,54,combin14,,1
keyopt,54,2,1      ! X Degree of Freedom

et,55,combin14,,2
keyopt,55,2,2      ! Y Degree of Freedom

et,56,combin14,,1
keyopt,56,2,1      ! X Degree of Freedom

et,57,combin14,,1
keyopt,57,2,1      ! X Degree of Freedom

et,58,combin14,,2
keyopt,58,2,2      ! Y Degree of Freedom

et,59,combin14,,1
keyopt,59,2,1      ! X Degree of Freedom

et,60,combin14,,2
keyopt,60,2,2      ! Y Degree of Freedom

et,61,combin14,,1
keyopt,61,2,1      ! X Degree of Freedom

et,62,combin14,,2
keyopt,62,2,2      ! Y Degree of Freedom

et,63,combin14,,2
keyopt,63,2,2      ! Y Degree of Freedom

et,64,combin14,,1
keyopt,64,2,1      ! X Degree of Freedom

et,65,combin14,,2
keyopt,65,2,2      ! Y Degree of Freedom

et,66,combin14,,3
keyopt,66,2,3      ! Z Degree of Freedom

et,67,combin14,,2
keyopt,67,2,2      ! Y Degree of Freedom

et,68,combin14,,1
keyopt,68,2,1      ! X Degree of Freedom

et,69,combin14,,1
keyopt,69,2,1      ! X Degree of Freedom

et,70,combin14,,2
keyopt,70,2,2      ! Y Degree of Freedom

et,71,combin14,,1
keyopt,71,2,1      ! X Degree of Freedom

et,72,combin14,,2
```

```
keyopt,72,2,2      ! Y Degree of Freedom

et,73,combin14,,1
keyopt,73,2,1      ! X Degree of Freedom

et,74,combin14,,1
keyopt,74,2,1      ! X Degree of Freedom

et,75,combin14,,3
keyopt,75,2,3      ! Z Degree of Freedom

et,76,combin14,,2
keyopt,76,2,2      ! Y Degree of Freedom

et,77,combin14,,2
keyopt,77,2,2      ! Y Degree of Freedom

et,78,combin14,,1
keyopt,78,2,1      ! X Degree of Freedom

et,79,combin14,,2
keyopt,79,2,2      ! Y Degree of Freedom

et,80,combin14,,2
keyopt,80,2,2      ! Y Degree of Freedom

et,81,combin14,,1
keyopt,81,2,1      ! X Degree of Freedom

et,82,combin14,,2
keyopt,82,2,2      ! Y Degree of Freedom

et,83,combin14,,3
keyopt,83,2,3      ! Z Degree of Freedom

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secdata,OD_1,WTick_1,

sectype,2,pipe
secdata,OD_2,WTick_2,

sectype,3,pipe
secdata,OD_3,WTick_3,

sectype,4,pipe
secdata,OD_4,WTick_4,

sectype,5,pipe
secdata,OD_5,WTick_5,

sectype,6,pipe
secdata,OD_6,WTick_6,

sectype,7,pipe
secdata,OD_7,WTick_7,

sectype,8,pipe
secdata,OD_8,WTick_8,

sectype,9,pipe
secdata,OD_9,WTick_9,

sectype,10,pipe
secdata,OD_10,WTick_10,

sectype,11,pipe
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secdata,OD_11,WTick_11,

sectype,12,pipe
secdata,OD_12,WTick_12,

sectype,13,pipe
secdata,OD_13,WTick_13,

sectype,14,pipe
secdata,OD_3,WTick_3,

sectype,15,pipe
secdata,OD_6,WTick_6,

sectype,16,pipe
secdata,OD_6,WTick_6,

sectype,17,pipe
secdata,OD_13,WTick_13,

sectype,18,pipe
secdata,OD_13,WTick_13,

sectype,19,pipe
secdata,OD_8,WTick_8,

sectype,20,pipe
secdata,OD_12,WTick_12,

sectype,21,pipe
secdata,OD_12,WTick_12,

sectype,22,pipe
secdata,OD_12,WTick_12,

r,23,1.69306
r,24,5.07505
r,25,4.96894
r,26,1.20212
r,27,1.42495
r,28,1.88768
r,29,2.18323
r,30,2.4397
r,31,2.98188
r,32,1.41874
r,33,1.04943e+1
r,34,9.30124e-1
r,35,1.6118
r,36,6.74431e-1
r,37,6.43116e-1
r,38,1.06962
r,39,1.20549
r,40,1.05642
r,41,1.25388
r,42,1.3543
r,43,6.66149e-1
r,44,2.27769
r,45,1.15217
r,46,1.23214
r,47,1.52976

r,48, 0.1e+9
r,49, 0.1e+9
r,50, 0.1e+9
r,51, 0.1080e+4
r,52, 0.6001e+5
r,53, 0.6001e+5
r,54, 0.6001e+5
r,55, 0.7541e+6
r,56, 0.7541e+6
r,57, 0.6001e+5
r,58, 0.6000e+3
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r,59, 0.6001e+5
r,60, 0.7601e+5
r,61, 0.6001e+5
r,62, 0.8000e+3
r,63, 0.6001e+5
r,64, 0.1000e+9
r,65, 0.1000e+9
r,66, 0.1000e+9
r,67, 0.2600e+3
r,68, 0.5901e+5
r,69, 0.2400e+5
r,70, 0.7601e+5
r,71, 0.2801e+5
r,72, 0.2460e+6
r,73, 0.6001e+5
r,74, 0.6001e+5
r,75, 0.7501e+5
r,76, 0.4660e+6
r,77, 0.3400e+3
r,78, 0.6001e+5
r,79, 0.5000e+6
r,80, 0.5000e+6
r,81, 0.1000e+9
r,82, 0.1000e+9
r,83, 0.1000e+9

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/com, Material Properties
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MP,EX,  1, YoungModulus
MP,NUXY,1, Nu
MP,GXY ,1, ShearModulus
MP,ALPX,1, K

/com,-------------------------------------------------------------------------------------

/com, Nodes
/com,*******

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k,2,-215.808,4715.952,139.224
k,3,-203.808,4703.952,139.224
k,4,-203.808,4715.952,127.224
k,5,-203.268,4719.852,154.860
k,6,-202.308,4726.800,182.748
k,7,-202.008,4728.948,191.340
k,8,-201.876,4729.392,194.916
k,9,-201.888,4729.392,194.988
k,10,-205.908,4729.392,205.740
k,11,-210.036,4729.392,210.168
k,12,-212.160,4729.392,212.436
k,13,-213.324,4729.392,213.684
k,14,-220.968,4729.392,221.868
k,15,-220.968,4734.492,221.868
k,16,-231.888,4729.392,233.568
k,17,-233.952,4729.392,235.776
k,18,-233.952,4741.392,235.776
k,19,-235.980,4729.392,237.936
k,20,-246.204,4714.392,248.904

k,21,-246.204,4705.860,248.904
k,22,-246.204,4686.792,248.904
k,23,-246.204,4676.952,248.904
k,24,-246.204,4665.900,248.904
k,25,-246.204,4638.876,248.904
k,26,-246.204,4631.628,248.904
k,27,-246.204,4628.952,248.904
k,28,-256.812,4613.952,238.296
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k,30,-263.004,4625.952,232.104
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k,36,-302.604,4613.952,198.720
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k,38,-314.988,4613.952,186.720
k,39,-340.380,4613.952,198.720
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k,45,-381.000,4689.588,198.720
k,46,-381.000,4756.872,198.720
k,47,-381.000,4760.952,198.720
k,48,-396.000,4775.952,198.720
k,49,-399.000,4775.952,198.720
k,50,-399.000,4787.952,198.720
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k,52,-402.600,4775.872,210.685
k,53,-440.904,4775.952,198.720
k,54,-450.612,4775.952,198.720
k,55,-465.612,4790.952,198.720
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k,60,-465.612,4943.952,198.720

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k,63,-458.712,4970.952,215.340
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k,66,-484.044,4958.952,250.452
k,67,-533.124,4958.952,270.828
k,68,-537.724,4958.952,259.745
k,69,-552.516,4958.952,278.880
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k,71,-560.652,4958.952,298.392
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k,73,-559.464,4970.952,301.248
k,74,-558.312,4958.952,304.020
k,75,-553.866,4961.957,293.286
k,76,-554.868,4958.952,312.324
k,77,-548.736,4958.952,327.108
k,78,-548.736,4981.752,327.108
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k,94,-578.988,5141.940,385.812
k,95,-590.988,5141.940,385.812
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k,384,-463.60,4783.5,198.72
k,385,-465.10,4787.1,198.72

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k,392,-464.84,4951.5,200.58
k,393,-463.93,4954.6,202.78
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k,412,-555.97,4959.0,280.86
k,413,-557.43,4959.0,282.15
k,414,-558.72,4959.0,283.62
k,415,-559.80,4959.0,285.24

k,421,-561.28,4959.0,288.84
k,422,-561.66,4959.0,290.75
k,423,-561.79,4959.0,292.69
k,424,-561.66,4959.0,294.64
k,425,-561.28,4959.0,296.55

k,431,-536.66,4959.5,356.20
k,432,-535.28,4961.0,359.54
k,433,-534.09,4963.3,362.41
k,434,-533.17,4966.5,364.61
k,435,-532.60,4970.1,366.00

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k,442,-568.72,5055.5,381.54
k,443,-570.44,5056.1,382.25
k,444,-572.07,5057.0,382.93
k,445,-573.58,5058.1,383.55

k,451,-576.13,5060.9,384.61
k,452,-577.13,5062.5,385.03
k,453,-577.93,5064.2,385.37
k,454,-578.51,5066.1,385.61
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k,462,-532.86,5043.9,366.66
k,463,-533.44,5045.8,366.89
k,464,-534.23,5047.5,367.22
k,465,-535.23,5049.1,367.63

k,471,-537.77,5051.9,368.68
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k,472,-539.27,5053.0,369.31
k,473,-540.89,5053.8,369.98
k,474,-542.60,5054.5,370.69
k,475,-544.37,5054.8,371.43

k,481,-237.61,4676.9,257.51
k,482,-236.79,4676.7,258.32
k,483,-236.01,4676.3,259.11
k,484,-235.26,4675.8,259.86
k,485,-234.56,4675.2,260.55

k,491,-233.37,4673.5,261.74
k,492,-232.90,4672.5,262.20
k,493,-232.53,4671.4,262.58
k,494,-232.27,4670.3,262.84
k,495,-232.11,4669.1,263.00

k,501,-231.84,4620.6,262.84
k,502,-231.20,4618.5,262.20
k,503,-230.19,4616.6,261.19
k,504,-228.88,4615.2,259.87
k,505,-227.34,4614.3,258.34

k,511,-217.91,4614.0,248.80
k,512,-217.25,4614.0,247.82
k,513,-216.73,4614.0,246.76
k,514,-216.35,4614.0,245.64
k,515,-216.12,4614.0,244.49

k,521,-216.35,4614.0,24.719
k,522,-217.25,4614.0,22.548
k,523,-218.68,4614.0,20.684
k,524,-220.55,4614.0,19.254
k,525,-222.72,4614.0,18.355

k,531,-269.38,4614.0,18.355
k,532,-271.55,4614.0,19.254
k,533,-273.41,4614.0,20.684
k,534,-274.84,4614.0,22.548
k,535,-275.74,4614.0,24.719

k,541,-276.05,4614.3,171.28
k,542,-276.05,4615.2,173.45
k,543,-276.05,4616.6,175.31
k,544,-276.05,4618.5,176.74
k,545,-276.05,4620.6,177.64

k,551,-276.35,4769.3,177.95
k,552,-277.25,4771.5,177.95
k,553,-278.68,4773.3,177.95
k,554,-280.55,4774.7,177.95
k,555,-282.72,4775.6,177.95

k,561,-474.35,4776.3,177.95
k,562,-476.52,4777.2,177.95
k,563,-478.38,4778.6,177.95
k,564,-479.81,4780.5,177.95
k,565,-480.71,4782.6,177.95

k,571,-481.05,5001.8,177.96
k,572,-481.23,5003.0,178.03
k,573,-481.55,5004.2,178.16
k,574,-482.01,5005.3,178.35
k,575,-482.61,5006.3,178.60

k,581,-484.16,5008.0,179.23
k,582,-485.08,5008.7,179.62
k,583,-486.07,5009.2,180.03
k,584,-487.13,5009.6,180.47
k,585,-488.22,5009.9,180.93

k,591,-559.69,5010.0,210.61
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k,592,-560.75,5010.3,211.05
k,593,-561.78,5010.6,211.48
k,594,-562.76,5011.2,211.88
k,595,-563.66,5011.8,212.25

k,601,-565.20,5013.5,212.89
k,602,-565.80,5014.5,213.14
k,603,-566.28,5015.5,213.34
k,604,-566.63,5016.6,213.48
k,605,-566.84,5017.8,213.57

k,611,-566.80,5051.3,213.88
k,612,-566.46,5053.5,214.71
k,613,-565.91,5055.3,216.04
k,614,-565.20,5056.7,217.76
k,615,-564.36,5057.6,219.76

k,621,-499.80,5057.5,375.34
k,622,-498.69,5056.3,378.01
k,623,-497.74,5054.4,380.30
k,624,-497.01,5051.9,382.06
k,625,-496.55,5049.1,383.17

k,631,-496.74,5030.8,383.75
k,632,-497.77,5028.0,384.37
k,633,-499.41,5025.5,385.34
k,634,-501.55,5023.6,386.61
k,635,-504.03,5022.4,388.09

k,641,-595.50,5037.0,442.51
k,642,-595.76,5038.6,442.67
k,643,-596.20,5040.1,442.92
k,644,-596.80,5041.5,443.28
k,645,-597.55,5042.8,443.72

k,651,-599.47,5045.0,444.86
k,652,-600.59,5045.9,445.52
k,653,-601.81,5046.6,446.25
k,654,-603.08,5047.1,447.01
k,655,-604.40,5047.4,447.79

k,661,-612.19,5047.5,452.56
k,662,-613.36,5047.5,453.61
k,663,-614.38,5047.5,454.80
k,664,-615.23,5047.5,456.12
k,665,-615.91,5047.5,457.54

k,671,-616.68,5047.5,460.57
k,672,-616.76,5047.5,462.14
k,673,-616.64,5047.5,463.71
k,674,-616.31,5047.5,465.24
k,675,-615.78,5047.5,466.72

k,681,-603.04,5047.5,488.27
k,682,-602.05,5047.5,489.71
k,683,-601.00,5047.5,491.10
k,684,-599.89,5047.5,492.45
k,685,-598.73,5047.5,493.74

k,691,-590.37,5022.2,439.46
k,692,-592.00,5023.0,440.43
k,693,-593.40,5024.3,441.26
k,694,-594.48,5025.9,441.91
k,695,-595.17,5027.8,442.32

/com,------------------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,**********************************

mat,1
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```
type,1
secnum,1
l,1,5                       ! 1
lesize,1,,,1
lmesh,1

type,2
secnum,2
l,5,6                       ! 2
lesize,2,,,1
lmesh,2


type,3
secnum,3
l,6,7                       ! 3
l,8,9
l,10,11                     ! 5
lsel,s,line,,3,5,1
lesize,all,,,1
lmesh,all
allsel,all

type,4
secnum,4
l,11,12                     ! 6
l,12,13
l,13,14
l,14,16
l,31,32
l,32,34                     ! 11
lsel,s,line,,6,11,1
lesize,all,,,1
lmesh,all
allsel,all


type,5
secnum,5
l,14,15                     ! 12
l,32,33
l,77,78                     ! 14

lsel,s,line,,12,14,1
lesize,all,,,1
lmesh,all
allsel,all


type,6
secnum,6
l,16,17                     ! 15
l,17,19
l,20,21
l,21,22
l,22,23
l,23,24
l,24,25
l,25,26
l,26,27
l,28,29
l,29,31
l,34,35
l,36,37
l,37,39
l,39,40
l,41,42
l,42,43
l,43,45
l,45,46
l,46,47
l,48,49
```

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l,49,51
l,51,53
l,53,54
l,55,56
l,56,58
l,58,59
l,59,60
l,61,62
l,62,64
l,65,66
l,66,67
l,67,69
l,69,70
l,71,72
l,72,74
l,74,76                     ! 51

lsel,s,line,,15,51,1
lesize,all,,,1
lmesh,all
allsel,all


type,7
secnum,7
l,76,77                     ! 52
l,77,79
l,79,80                     ! 54

lsel,s,line,,52,54,1
lesize,all,,,1
lmesh,all
allsel,all

type,13
secnum,13
l,80,81                     ! 55
l,82,83
l,83,84
l,84,85
l,86,87
l,87,89
l,89,91
l,92,93
l,93,94                     ! 63


lsel,s,line,,55,63,1
lesize,all,,,1
lmesh,all
allsel,all

id = 8
type,8
secnum,8
l,23,98                     ! 64
l,98,99
l,99,100
l,101,102
l,102,103
l,104,105
l,106,107
l,107,108
l,108,110
l,110,111
l,111,112
l,112,114
l,114,115
l,116,117
l,117,119
l,119,121
l,122,123
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l,123,124
l,124,125
l,126,127
l,127,129
l,129,130
l,130,131
l,132,133
l,133,135
l,135,137
l,137,138
l,138,139
l,140,141
l,141,143
l,143,144
l,144,145
l,145,147
l,148,149
l,149,151
l,151,152
l,153,154
l,154,155
l,156,157
l,157,159
l,163,164                    ! 104


lsel,s,line,,64,104,1
lesize,all,,,1
lmesh,all
allsel,all

type,9
secnum,9
l,159,160                    ! 105
l,160,161
l,161,163                    !107


lsel,s,line,,105,107,1
lesize,all,,,1
lmesh,all
allsel,all

type,10
secnum,10
l,161,162                    ! 108
lesize,108,,,1
lmesh,108
allsel,all


type,12
secnum,12
l,164,165                    ! 109
l,165,167
l,167,168
l,168,169
l,169,171
l,172,173
l,173,174
l,175,176
l,176,178
l,178,179
l,180,181
l,182,183
l,184,185
l,185,186
l,187,188
l,188,189
l,189,190
l,190,191
l,191,192                    ! 127
```

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lsel,s,line,,109,127,1
lesize,all,,,1
lmesh,all
allsel,all


/com,
/com, Pipe Bend Elements
/com,********************

mat,1

type,14
secnum,3
larc,7,302,301,           ! 128
larc,302,304,303,
larc,304,8,305,
larc,9,312,311,
larc,312,314,313,
larc,314,10,315,          ! 133

lsel,s,line,,128,133
lesize,all,,,1
lmesh,all
allsel,all


type,15
secnum,6
larc,19,322,321,              ! 134
larc,322,324,323,
larc,324,20,325,
larc,27,332,331,
larc,332,334,333,
larc,334,271,335,
larc,271,342,341,
larc,342,344,343,
larc,344,28,345,
larc,35,352,351,
larc,352,354,353,
larc,354,36,355,
larc,40,362,361,
larc,362,364,363,
larc,364,41,365,
larc,47,372,371,
larc,372,374,373,
larc,374,48,375,
larc,54,382,381,
larc,382,384,383,
larc,384,55,385,
larc,60,392,391,
larc,392,394,393,
larc,394,61,395,
larc,64,402,401,
larc,402,404,403,
larc,404,65,405,          ! 160

lsel,s,line,,134,160,1
lesize,all,,,1
lmesh,all
allsel,all


type,16
secnum,6
larc,70,412,411,        ! 161
larc,412,414,413,
larc,414,272,415,
larc,272,422,421,
larc,422,424,423,
larc,424,71,425,        ! 166
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```
lsel,s,line,,161,166
lesize,all,,,1
lmesh,all
allsel,all


type,17
secnum,13
larc,81,432,431,          ! 167
larc,432,434,433,
larc,434,82,435,
larc,91,442,441,
larc,442,444,443
larc,444,273,445,
larc,273,452,451,
larc,452,454,453,
larc,454,92,455,          ! 175

lsel,s,line,,167,175
lesize,all,,,1
lmesh,all
allsel,all


type,18
secnum,13
larc,85,462,461,        ! 176
larc,462,464,463,
larc,464,274,465,
larc,274,472,471,
larc,472,474,473,
larc,474,86,475,        ! 181

lsel,s,line,,176,181,1
lesize,all,,,1
lmesh,all
allsel,all


type,19
secnum,8
larc,100,482,481,          ! 182
larc,482,484,483,
larc,484,275,485,
larc,275,492,491,
larc,492,494,493,
larc,494,101,495,
larc,103,502,501,
larc,502,504,503,
larc,504,104,505,
larc,105,512,511,
larc,512,514,513,
larc,514,106,515,
larc,115,522,521,
larc,522,524,523,
larc,524,116,525,
larc,121,532,531,
larc,532,534,533,
larc,534,122,535,
larc,125,542,541,
larc,542,544,543,
larc,544,126,545,
larc,131,552,551,
larc,552,554,553,
larc,554,132,555,
larc,139,562,561,
larc,562,564,563,
larc,564,140,565,
larc,147,572,571,
larc,572,574,573,
larc,574,276,575,
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larc,276,582,581,
larc,582,584,583,
larc,584,148,585,
larc,152,592,591,
larc,592,594,593,
larc,594,277,595,
larc,277,602,601,
larc,602,604,603,
larc,604,153,605,
larc,155,612,611,
larc,612,614,613,
larc,614,156,615,          ! 223

lsel,s,line,,182,223,1
lesize,all,,,1
lmesh,all
allsel,all

type,20
secnum,12
larc,171,622,621,         ! 224
larc,622,624,623,
larc,624,172,625,
larc,174,632,631,
larc,632,634,633,
larc,634,175,635,
larc,181,642,641,
larc,642,644,643,
larc,644,278,645,
larc,278,652,651,
larc,652,654,653,
larc,654,182,655,
larc,183,662,661,
larc,662,664,663,
larc,664,279,665,
larc,279,672,671,
larc,672,674,673,
larc,674,184,675,     ! 241

lsel,s,line,,224,241,
lesize,all,,,1
lmesh,all
allsel,all


type,21
secnum,12
larc,186,682,681,     ! 242
larc,682,684,683,
larc,684,187,685,     ! 244

lsel,s,line,,242,244
lesize,all,,,1
lmesh,all
allsel,all


type,22
secnum,12
larc,179,692,691,      ! 245
larc,692,694,693,
larc,694,180,695,      ! 247


lsel,s,line,,245,247
lesize,all,,,1
lmesh,all
allsel,all


/com, Convert some PIPE289 into ELBOW290 using ELBOW command
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elbow,on,,,sect





/com, Point Mass without considering rotatary inertia
/com,*************************************************

type,23
real,23
e,node(-212.160,4729.392,212.436)
e,node(-246.204,4705.860,248.904)
e,node(-246.204,4638.876,248.904)

type,24
real,24
e,node(-220.968,4734.492,221.868)

type,25
real,25
e,node(-275.352,4619.052,219.744)

type,26
real,26
e,node(-286.668,4613.952,208.440)

type,27
real,27
e,node(-340.380,4613.952,198.720)
e,node(-381.000,4630.560,198.720)

type,28
real,28
e,node(-381.000,4689.588,198.720)
e,node(-381.000,4756.872,198.720)

type,29
real,29
e,node(-440.904,4775.952,198.720)

type,30
real,30
e,node(-465.612,4840.068,198.720)
e,node(-465.612,4927.032,198.720)

type,31
real,31
e,node(-484.044,4958.952,250.452)

type,32
real,32
e,node(-552.516,4958.952,278.880)

type,33
real,33
e,node(-548.736,4981.752,327.108)

type,34
real,34
e,node(-546.708,4958.952,331.992)
e,node(-532.404,4988.628,366.468)
e,node(-532.404,5039.952,366.468)

type,35
real,35
e,node(-578.988,5091.924,385.812)
```

```
type,36
real,36
e,node(-232.056,4665.936,263.052)
e,node(-225.696,4613.952,256.692)
e,node(-216.048,4613.952,208.800)

type,37
real,37
e,node(-216.048,4613.952,155.748)
e,node(-216.048,4613.952,103.944)

type,38
real,38
e,node(-216.048,4613.952,34.980)

type,39
real,39
e,node(-276.048,4613.952,40.452)
e,node(-276.048,4613.952,137.544)

type,40
real,40
e,node(-276.048,4668.492,177.948)
e,node(-276.048,4753.560,177.948)

type,41
real,41
e,node(-350.532,4775.952,177.948)
e,node(-451.512,4775.952,177.948)

type,42
real,42
e,node(-481.020,4855.320,177.948)
e,node(-481.020,4964.388,177.948)

type,43
real,43
e,node(-520.044,5009.952,194.148)
e,node(-566.916,5021.892,213.600)
e,node(-556.716,5057.952,238.188)

type,44
real,44
e,node(-553.884,5062.044,245.004)

type,45
real,45
e,node(-534.588,5057.952,291.528)
e,node(-512.880,5057.952,343.824)

type,46
real,46
e,node(-496.392,5037.192,383.544)
e,node(-539.784,5021.952,409.358)
e,node(-588.540,5021.952,438.372)
e,node(-613.716,5047.452,470.388)

type,47
real,47
e,node(-570.048,5047.452,521.736)
e,node(-516.180,5047.452,574.200)
e,node(-462.312,5047.452,626.676)

/com,
/com, Elastic supports and anchors
/com,******************************

type,48
real,48
l,1,2          ! 248
lesize,248,,,1
lmesh,248
```

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allsel,all


type,49
real,49
l,1,3           ! 249
lesize,249,,,1
lmesh,249
allsel,all

type,50
real,50
l,1,4
lesize,250,,,1
lmesh,250
allsel,all

id = 51
type,51
real,51
l,17,18
lesize,251,,,1
lmesh,251
allsel,all


type,52
real,52
l,29,30
lesize,252,,,1
lmesh,252
allsel,all

type,53
real,53
l,37,38
lesize,253,,,1
lmesh,253
allsel,all

type,55
real,55
l,49,50
lesize,254,,,1
lmesh,254
allsel,all

type,58
real,58
l,62,63
lesize,255,,,1
lmesh,255
allsel,all

type,60
real,60
l,72,73
lesize,256,,,1
lmesh,256
allsel,all

type,62
real,62
l,87,88
lesize,257,,,1
lmesh,257
allsel,all

type,63
real,63
l,89,90
lesize,258,,,1
```



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lmesh,258
allsel,all

type,64
real,64
l,94,95
lesize,259,,,1
lmesh,259
allsel,all

type,65
real,65
l,94,96
lesize,260,,,1
lmesh,260
allsel,all

type,66
real,66
l,94,97
lesize,261,,,1
lmesh,261
allsel,all

type,67
real,67
l,108,109
lesize,262,,,1
lmesh,262
allsel,all

type,68
real,68
l,112,113
lesize,263,,,1
lmesh,263
allsel,all

type,70
real,70
l,119,120
lesize,264,,,1
lmesh,264
allsel,all

type,72
real,72
l,133,134
lesize,265,,,1
lmesh,265
allsel,all

type,75
real,75
l,145,146
lesize,266,,,1
lmesh,266
allsel,all

type,76
real,76
l,149,150
lesize,267,,,1
lmesh,267
allsel,all

type,77
real,77
l,157,158
lesize,268,,,1
lmesh,268
allsel,all
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id = 79
type,79
real,79
l,169,170
lesize,269,,,1
lmesh,269
allsel,all

type,80
real,80
l,188,177
lesize,270,,,1
lmesh,270
allsel,all

type,81
real,81
l,192,193
lesize,271,,,1
lmesh,271
allsel,all

type,82
real,82
l,192,194
lesize,272,,,1
lmesh,272
allsel,all

type,83
real,83
l,192,195
lesize,273,,,1
lmesh,273
allsel,all


n,44000,-369.035,4655.952,197.800

n,52000,-402.600,4775.872,210.685

n,57000,-453.643,4796.592,197.860

n,49000,-399.00,4775.952,198.720

n,68000,-537.724,4958.952,259.745

n,75000,-553.866,4961.957,293.286

n,72000,-559.464,4958.952,301.248

n,118000,-231.048,4616.447,29.785

n,128000,-274.814,4625.952,189.884

n,136000,-300.048,4781.441,188.620

n,142000,-469.580,4800.792,181.571

n,166000,-556.148,5060.878,260.821




/com,
/com, rotate nodes with less than 3 supports
/com,****************************************
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wplane,,nx(69),ny(69),nz(69),nx(44000),ny(44000),nz(44000),nx(71),ny(71),nz(71)
cswplane,11,0
nrotat,69
nrotat,44000
csys,0

real,54
type,54
e,69,44000

wplane,,nx(80),ny(80),nz(80),nx(52000),ny(52000),nz(52000),nx(78),ny(78),nz(78)
cswplane,12,0
nrotat,80
nrotat,52000
csys,0

real,56
type,56
e,80,52000

wplane,,nx(87),ny(87),nz(87),nx(57000),ny(57000),nz(57000),nx(86),ny(86),nz(86)
cswplane,13,0
nrotat,87
nrotat,57000
csys,0

real,57
type,57
e,87,57000

wplane,,nx(103),ny(103),nz(103),nx(68000),ny(68000),nz(68000),nx(101),ny(101),nz(101)
cswplane,14,0
nrotat,103
nrotat,68000
csys,0

real,59
type,59
e,103,68000

wplane,,nx(112),ny(112),nz(112),nx(75000),ny(75000),nz(75000),nx(110),ny(110),nz(110)
cswplane,15,0
nrotat,112
nrotat,75000
csys,0

real,61
type,61
e,112,75000

wplane,,nx(172),ny(172),nz(172),nx(118000),ny(118000),nz(118000),nx(171),ny(171),nz(171)
cswplane,16,0
nrotat,172
nrotat,118000
csys,0

real,69
type,69
e,172,118000

wplane,,nx(186),ny(186),nz(186),nx(128000),ny(128000),nz(128000),nx(185),ny(185),nz(185)
cswplane,17,0
nrotat,186
nrotat,128000
csys,0

real,71
type,71
e,186,128000

wplane,,nx(197),ny(197),nz(197),nx(136000),ny(136000),nz(136000),nx(195),ny(195),nz(195)
cswplane,18,0
```

```
nrotat,197
nrotat,136000
csys,0

real,73
type,73
e,197,136000

wplane,,nx(206),ny(206),nz(206),nx(142000),ny(142000),nz(142000),nx(205),ny(205),nz(205)
cswplane,19,0
nrotat,206
nrotat,142000
csys,0

real,74
type,74
e,206,142000

wplane,,nx(243),ny(243),nz(243),nx(166000),ny(166000),nz(166000),nx(234),ny(234),nz(234)
cswplane,20,0
nrotat,243
nrotat,166000
csys,0

real,78
type,78
e,243,166000

/com,------------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

ksel,s,,,2,4
ksel,a,,,18
ksel,a,,,30
ksel,a,,,38
!ksel,a,,,44
ksel,a,,,50
!ksel,a,,,52
!ksel,a,,,57
ksel,a,,,63
!ksel,a,,,68
ksel,a,,,73
!ksel,a,,,75
ksel,a,,,88
ksel,a,,,90
ksel,a,,,95,97
ksel,a,,,109
ksel,a,,,113
!ksel,a,,,118
ksel,a,,,120
!ksel,a,,,128
ksel,a,,,134
!ksel,a,,,136
!ksel,a,,,142
ksel,a,,,146
ksel,a,,,150
ksel,a,,,158
!ksel,a,,,166
ksel,a,,,170
ksel,a,,,177
ksel,a,,,193,195
nslk,s
d,all,all
allsel,all,all


nsel,s,node,,44000
nsel,a,node,,52000
nsel,a,node,,57000
```

```
nsel,a,node,,68000
nsel,a,node,,75000
nsel,a,node,,118000
nsel,a,node,,128000
nsel,a,node,,136000
nsel,a,node,,142000
nsel,a,node,,166000
d,all,all,0
allsel,all


ksel,s,,,1
nslk,s
d,all,rotx,,,,,roty,rotz
allsel,all

ksel,s,,,94
nslk,s
d,all,rotx,,,,,roty,rotz
allsel,all

ksel,s,,,192
nslk,s
d,all,rotx,,,,,roty,rotz
allsel,all
finish

/com,-------------------------------------------------------------------------------------

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal     ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on      ! Use Lumped Mass Matrix Approximation
mxpand,maxm,,,yes     ! Expand solutions with Element Calculations turned ON
solve
finish

/post1
/out,
/com, *******************************************
/com,  Frequencies obtained from modal solution
/com, ********************************************
set,list
finish


/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/out,scratch
/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,mprs,maxm     ! Multi Point Response Spectrum

gval = 386.0

/com,
/com, Support Group 1, Spectrum 1X
/com,******************************

id = 1
spunit, id,accg, gval
```

```
spfrq,id, 0.2,0.5,0.5263,0.7018,0.7752,1.0582,1.105
spval,id,,  0.16,0.16,0.195,0.235,0.339,0.339,0.305

spfrq,id, 1.25,1.3889,1.5221,1.7241,1.9231,2.0,2.1978
spval,id,,  0.305,0.395,0.395,0.525,0.525,0.555,0.555

spfrq,id, 2.2472,2.9851,3.3333,5.0,5.7143,7.6923,9.0909
spval,id,,  0.65,0.65,1.36,1.36,0.45,0.935,0.935

spfrq,id, 9.5238,12.8205,13.8889,17.8571,19.6078,27.027,33.3333
spval,id,,  0.995,0.995,1.0,1.0,1.222,1.222,0.5

spfrq,id, 50.0,100.0
spval,id,,  0.252,0.252

/com,
/com, spectrum 1Y (Group 1)
/com,***********************

id = 2
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.6061,0.6086,0.7752,1.5504,1.6667
spval,id,,  8.0e-2,8.0e-2,0.115,0.115,0.141,0.255,0.255

spfrq,id, 1.8349,2.0,2.2727,2.381,2.9762,3.4722,3.9216
spval,id,,  0.265,0.34,0.34,0.36,0.36,0.452,0.452

spfrq,id, 3.9841,5.4054,5.5556,6.3694,7.8125,10.5263,11.236
spval,id,,  0.5,0.5,0.4,0.4,1.4,1.4,1.0

spfrq,id, 11.7647,12.987,14.7059,20.0,22.2222,23.809,26.3158
spval,id,,  1.0,0.625,0.875,0.875,0.6,0.6,0.415

spfrq,id, 28.5714,30.303,33.3333,50.0,100.0
spval,id,,  0.415,0.295,0.295,0.165,0.165

/com,
/com, spectrum 1Z (Group 1)
/com,***********************

id = 3
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.5263,0.9524,1.0417,1.5601,1.5873
spval,id,,  0.15,0.15,0.167,0.24,0.305,0.305,0.28

spfrq,id, 1.7391,1.9048,2.1053,2.5974,3.3333,5.0,5.2632
spval,id,,  0.435,0.435,0.496,0.496,1.15,1.15,0.64

spfrq,id, 5.7143,5.8824,6.2893,6.5789,7.4074,9.6154,11.3636
spval,id,,  0.64,0.7,0.7,0.875,1.05,1.05,0.62

spfrq,id, 12.8205,14.0845,15.873,17.2414,25.0,27.027,32.2581
spval,id,,  0.62,0.755,0.65,1.15,1.15,1.1,0.5

spfrq,id, 50.0,100.0
spval,id,,  0.225,0.225

/com,-----------------------------------------------------------------------------------

/com,
/com, Support Group 2, Spectrum 2X
/com,******************************

id = 4
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.5714,0.9091,0.9524,1.25,1.7544
spval,id,,  0.15,0.15,0.22,0.25,0.31,0.31,0.47

spfrq,id, 2.3256,3.2258,4.5455,5.1282,5.5556,7.6923,10.0
```

```
spval,id,,  0.47,0.39,0.35,0.29,0.35,0.35,0.23

spfrq,id, 12.5,16.6667,19.2308,33.3333,100.0
spval,id,,  0.3,0.3,0.25,0.09,0.09

/com,
/com, spectrum 2Y (Group 2)
/com,***********************

id = 5
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.6667,3.7037,4.3478,4.5455,5.5556
spval,id,,  0.085,0.085,0.125,0.525,0.525,0.47,0.47

spfrq,id, 8.3333,10.989,13.3333,16.667,17.2414,21.2766,22.2222
spval,id,,  2.6,2.6,0.5,0.5,0.76,0.76,0.85

spfrq,id, 27.7778,29.4118,100.0
spval,id,,  0.85,0.194,0.194

/com,
/com, spectrum 2Z (Group 2)
/com,***********************

id = 6
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.5714,0.9091,0.9524,1.25,1.7544
spval,id,,  0.15,0.15,0.22,0.25,0.31,0.31,0.47

spfrq,id, 2.3256,3.2258,4.5455,5.1282,5.5556,7.6923,10.0
spval,id,,  0.47,0.39,0.35,0.29,0.35,0.35,0.23

spfrq,id, 12.5,16.6667,19.2308,33.3333,100.0
spval,id,,  0.3,0.3,0.25,0.09,0.09

/com,----------------------------------------------------------------------------------

/com,
/com, Support Group 3, Spectrum 3X
/com,******************************

id = 7
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.578,1.7241,2.9412,3.0303,4.1667
spval,id,,  0.16,0.16,0.23,0.52,0.50,0.73,0.73

spfrq,id, 4.7619,5.4054,8.3333,10.5263,14.2857,17.8571,23.8095
spval,id,,  0.28,0.34,0.32,0.8,0.8,0.3,0.3

spfrq,id, 25.0,31.25,38.4615,100.0
spval,id,,  0.27,0.27,0.12,0.11

/com,
/com, spectrum 3Y (Group 3)
/com,***********************

id = 8
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.5814,1.25,1.4286,1.9231,2.3256
spval,id,,  0.08,0.08,0.11,0.19,0.20,0.35,0.35

spfrq,id, 2.439,3.3898,4.0,5.4054,5.8824,6.25,8.3333
spval,id,,  0.40,0.42,0.52,0.52,0.40,0.43,0.43

spfrq,id, 12.5,16.6667,23.2558,100.0
spval,id,,  0.47,0.14,0.14,0.12

/com,
```

```
/com, spectrum 3Z (Group 3)
/com,**********************

id = 9
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.578,1.7241,2.9412,3.0303,4.1667
spval,id,,  0.16,0.16,0.23,0.52,0.50,0.73,0.73

spfrq,id, 4.7619,5.4054,8.3333,10.5263,14.2857,17.8571,23.8095
spval,id,,  0.28,0.34,0.32,0.8,0.8,0.3,0.3

spfrq,id, 25.0,31.25,38.4615,100.0
spval,id,,  0.27,0.27,0.12,0.11

/com,-------------------------------------------------------------------------------

/com,
/com, Support Group 4, Spectrum 4X
/com,*****************************

id = 10
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.578,1.25,1.7241,2.2222,2.9412
spval,id,,  0.16,0.16,0.23,0.32,0.55,0.55,0.81

spfrq,id, 3.125,4.1667,5.1282,7.6923,10.4167,14.0845,16.9492
spval,id,,  1.50,1.50,0.29,0.3,1.31,1.31,0.46

spfrq,id, 23.8095,26.3158,32.2581,38.4615,100.0
spval,id,,  0.46,0.30,0.30,0.17,0.16

/com,
/com, spectrum 4Y (Group 4)
/com,**********************

id = 11
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.5848,1.5625,1.9231,2.3256,2.439
spval,id,,  0.08,0.08,0.11,0.20,0.36,0.36,0.40

spfrq,id, 3.0303,3.4483,4.0,5.3476,5.7143,6.25,8.0
spval,id,,  0.43,0.43,0.54,0.54,0.45,0.52,0.52

spfrq,id, 9.0909,12.5,18.1818,100.0
spval,id,,  0.9,0.9,0.18,0.14

/com,
/com, spectrum 4Z (Group 4)
/com,**********************

id = 12
spunit, id,accg, gval

spfrq,id, 0.2,0.5,0.578,1.25,1.7241,2.2222,2.9412
spval,id,,  0.16,0.16,0.23,0.32,0.55,0.55,0.81

spfrq,id, 3.125,4.1667,5.1282,7.6923,10.4167,14.0845,14.4928
spval,id,,  1.5,1.5,0.29,0.3,1.31,1.31,0.46

spfrq,id, 23.8095,26.3158,32.2581,38.4615,100.0
spval,id,,  0.46,0.3,0.3,0.17,0.16

/com,-------------------------------------------------------------------------------

/com,
/com, Nodal Components for Excitation Points
/com,****************************************

nsel,,node,,496,498
```

```
nsel,a,node,,499
cm,group1,node

allsel,all

nsel,,node,,500
nsel,a,node,,501
nsel,a,node,,510
nsel,a,node,,511
nsel,a,node,,118000
nsel,a,node,,512
nsel,a,node,,128000
nsel,a,node,,513
cm,group2,node

allsel,all

nsel,,node,,44000
nsel,a,node,,502
nsel,a,node,,52000
nsel,a,node,,57000
nsel,a,node,,136000
nsel,a,node,,142000
nsel,a,node,,514
cm,group3,node

allsel,all

nsel,,node,,503
nsel,a,node,,68000
nsel,a,node,,504
nsel,a,node,,75000
nsel,a,node,,505
nsel,a,node,,506
nsel,a,node,,507,509
nsel,a,node,,515
nsel,a,node,,516
nsel,a,node,,166000
nsel,a,node,,517
nsel,a,node,,518
nsel,a,node,,519,521
cm,group4,node

allsel,all,all

/com,-------------------------------------------------------------------------------

! -- Support Group 1 - spectrum 1 (Along X - Direction)
sed,1,,,group1
pfact,1
sed,0,,,group1

! -- Support Group 1 - spectrum 2 (Along Y - Direction)
sed,,1,,group1
pfact,2
sed,,0,,group1

! -- Support Group 1 - spectrum 3 (Along Z - Direction)
sed,,,1,group1
pfact,3
sed,,,0,group1

! -- Support Group 2 - spectrum 4 (Along X - Direction)
sed,1,,,group2
pfact,4
sed,0,,,group2

! -- Support Group 2 - spectrum 5 (Along Y - Direction)
sed,,1,,group2
pfact,5
sed,,0,,group2
```

```
! -- Support Group 2 - spectrum 6 (Along Z - Direction)
sed,,,1,group2
pfact,6
sed,,,0,group2

! -- Support Group 3 - spectrum 7 (Along X - Direction)
sed,1,,,group3
pfact,7
sed,0,,,group3

! -- Support Group 3 - spectrum 8 (Along Y - Direction)
sed,,1,,group3
pfact,8
sed,,0,,group3

! -- Support Group 3 - spectrum 9 (Along Z - Direction)
sed,,,1,group3
pfact,9
sed,,,0,group3

! -- Support Group 4 - spectrum 10 (Along X - Direction)
sed,1,,,group4
pfact,10
sed,0,,,group4

! -- Support Group 4 - spectrum 11 (Along Y - Direction)
sed,,1,,group4
pfact,11
sed,,0,,group4

! -- Support Group 4 - spectrum 12 (Along Z - Direction)
sed,,,1,group4
pfact,12
sed,,,0,group4

srss,0.00010,,yes   ! activate Absolute Sum
solve

finish

/com,------------------------------------------------------------------------------------

/post1
/input,,mcom

/out,

/com,
/com,=============================================================
/com, Maximum nodal displacements and rotations from spectrum solution
/com,=============================================================
/com,

/out,scratch

*GET,AdisX,NODE,470,U,X
*GET,AdisY,NODE,243,U,Y
*GET,AdisZ,NODE,425,U,Z
*GET,ArotX,NODE,208,ROT,X
*GET,ArotY,NODE,217,ROT,Y
*GET,ArotZ,NODE,175,ROT,Z

/out,
*stat,AdisX
*stat,AdisY
*stat,AdisZ
*stat,ArotX
*stat,ArotY
*stat,ArotZ

/com,============================================================
/com, Element Forces and Moments obtained from spectrum solution
```

```
/com,==============================================================

/out,scratch

/com,==========
/com,  Node I
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************


esel,s,elem,,1
etable,pxi_1,smisc,1
etable,vyi_1,smisc,6
etable,vzi_1,smisc,5
etable,txi_1,smisc,4
etable,myi_1,smisc,2
etable,mzi_1,smisc,3
esel,all

/out,
/com, ************************************************
/com,  Element forces and moments at element1, node i
/com, ************************************************

pretab,pxi_1,vyi_1,vzi_1,txi_1,myi_1,mzi_1


/out,scratch
/com,==========
/com,  Node J
/com,==========

/com, Element #1 (Pipe289 element)
/com,************************

esel,s,elem,,1
etable,pxj_1,smisc,14
etable,vyj_1,smisc,19
etable,vzj_1,smisc,18
etable,txj_1,smisc,17
etable,myj_1,smisc,15
etable,mzj_1,smisc,16
esel,all

/out,
/com, **********************************************
/com,  Element forces and moments at element1, node j
/com, ************************************************

pretab,pxj_1,vyj_1,vzj_1,txj_1,myj_1,mzj_1



/out,scratch


/com,==========
/com,  Node I
/com,==========

/com, Element #240 (Elbow 290 element)
/com,*************************

esel,s,elem,,240
etable,pxi_240,smisc,1
etable,vyi_240,smisc,6
etable,vzi_240,smisc,5
etable,txi_240,smisc,4
etable,myi_240,smisc,2
etable,mzi_240,smisc,3
```

```
esel,all

/out,
/com, ************************************************
/com,  Element forces and moments at element 240, node i
/com, ***********************************************

pretab,pxi_240,vyi_240,vzi_240,txi_240,myi_240,mzi_240


/out,scratch
/com,==========
/com,  Node J
/com,==========



/com, Element #240 (Elbow290 element)
/com,********************************
esel,s,elem,,240

etable,pxj_240,smisc,36
etable,vyj_240,smisc,41
etable,vzj_240,smisc,40
etable,txj_240,smisc,39
etable,myj_240,smisc,37
etable,mzj_240,smisc,38
esel,all

allsel,all

/out,
/com, *********************************************
/com,  Element forces and moments at element 240, node j
/com, ***********************************************

pretab,pxj_240,vyj_240,vzj_240,txj_240,myj_240,mzj_240



/com,---------------------------------------------------------------------------

/com, ***************************************
/com,  Reaction forces from spectrum solution
/com, ****************************************

prrsol

finish
```

demonstration-problem1-290 Input Listing

```
/batch,list
/verify,demonstration_problem1_290
JPGPRF,500,100,1
/title,Bend pipe model meshed with ELBOW290 elements

/COM, ELBOW290


/filnam,290

/prep7

et,1,pipe289      ! Element 1 - PIPE289 (Straight Pipe Element)

et,2,elbow290      ! Element 2- ELBOW290 (Bend Pipe Element)
keyopt,2,2,6      ! General section deformation is 6
```

```
/com, Section properties
/com,****************

fact = 1.5

sectype,1,pipe
secdata,7.288*fact,0.1205,24   ! Outer Diameter, Wall Thickness, Radius of Curvature


/com, Material properties
/com, *******************


mp,ex,1,24e6
mp,nuxy,1,0.3
mp,dens,1,0.000125


/com, keypoints
/com,*******

k,1,0.0,0.0,0.0
k,2,0.0,54.45,0.0
k,3,0.0,108.9,0.0
k,4,10.632,134.568,0.0
k,5,36.3,145.2,0.0
k,6,54.15,145.2,0.0
k,7,72.0,145.2,0.0
k,8,97.668,145.2,10.632
k,9,108.3,145.2,36.3
k,10,108.3,145.2,56.80
k,11,108.3,145.2,77.3

k,12,2.7631,122.79,0
k,13,22.408,142.44,0
k,14,85.9,145,2.76
k,15,106,145,22.4


/com, Lines
/com, ************

l,1,2
l,2,3
larc,3,4,12,-36.30
larc,4,5,13,-36.30
l,5,6
l,6,7
larc,7,8,14,-36.30
larc,8,9,15,-36.30
l,9,10
l,10,11


/com, Straight Pipe (Tangent Elements)
/com,**********************************

type,1
mat,1
secnum,1
lsel,s,line,,1
lsel,a,line,,2
lsel,a,line,,5
lsel,a,line,,6
lsel,a,line,,9
lsel,a,line,,10
lesize,all,,,6
lmesh,all
allsel,all

/com, Bend Pipe Elements
```

```
/com,**********************************

type,2
mat,1
secnum,1

lsel,s,line,,3
lsel,a,line,,4
lsel,a,line,,7
lsel,a,line,,8

lesize,all,,,6
lmesh,all
allsel,all

/com, Selecting just portion of bend elements
/com, ******************************************

lsel,u,line,,3,4,1
lclear,all
allsel,all

/com,  Constraints
/com, ******************************

nsel,s,node,,14
d,all,all,0
d,all,sect,0   ! Constraining all the section deformations
allsel,all
finish

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal
outres,all,all
modopt,lanb,15     ! LANB mode extraction method
mxpand,15,,,yes     ! Expand all 15 modes
solve
finish

/post1
set,list      ! Frequencies obtained from Modal Solve
/show,jpeg
/eshape,1
/efacet,2
/view,1,1,1,1
/graphics,power
eplot
/replot
set,1,1
plnsol,u,sum
set,1,2
plnsol,u,sum
set,1,3
plnsol,u,sum
set,1,4
plnsol,u,sum
set,1,5
plnsol,u,sum
set,1,6
plnsol,u,sum
set,1,7
plnsol,u,sum
set,1,8
plnsol,u,sum
set,1,9
plnsol,u,sum
```

```
set,1,10
plnsol,u,sum
set,1,11
plnsol,u,sum
set,1,12
plnsol,u,sum
set,1,13
plnsol,u,sum
set,1,14
plnsol,u,sum
set,1,15
plnsol,u,sum
finish



/com,----------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,sprs      ! Single Point Excitation Response Spectrum
dmprat,0.02      ! Constant Damping Ratio
grp,0.00      ! Group Modes based on significance level
svtyp,2      ! Seismic Acceleration Response Loading

sed,1       ! Excitation in X direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve
sed,0,0,0

sed,,1      ! Excitation in Y direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,266.7,580.7,580.7,466.7,792,792,293.3,516.7,516.7
sv,0.02,355.5,311.5,295.7,253.3,192.7,159.6,128.4,122.7,96.7
solve
sed,0,0,0

sed,,,1      ! Excitation in Z direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve
fini

/com,----------------------------------------------------------------------------

/post1
/input,290,mcom

/com, *========================================================
/com, * Displacement Sum and Equivalent Stress
/com, *==========================================================

plnsol,u,sum
*get,umax,plnsol,0,max
*get,umin,plnsol,0,min
plnsol,s,eqv
*get,smax,plnsol,0,max
```

```
*get,smin,plnsol,0,min
/show,close
*stat,umax
*stat,umin
*stat,smax
*stat,smin
finish
/exit,nosave
```

demonstration-problem1-281 Input Listing

```
/batch,list
/verify,demonstration_problem1_281
JPGPRF,500,100,1
/title,Bend Pipe model meshed with SHELL281 elements

/filnam,281

/prep7

fact = 1.5

out_dia = 7.288*fact   ! Outer Diameter
wall_thk = 0.1205    ! Wall Thickness

out_rad = out_dia/2   ! Outer Radius

in_rad = out_dia/2 - wall_thk  ! Inner Radius

hf_thick = wall_thk/2   ! Half Thickness
midd = in_rad+hf_thick

et,1,shell281    ! SHELL281 element

sectype,1,shell    ! Shell Section Definition
secdata,wall_thk,1,0,3


/com, Material Properties
/com, *********************

mp,ex,1,24e6
mp,nuxy,1,0.3
mp,dens,1,0.000125

/com, keypoints
/com,*******

k,1,0.0,0.0,0.0
k,2,0.0,54.45,0.0
k,3,0.0,108.9,0.0
k,4,10.632,134.568,0.0
k,5,36.3,145.2,0.0
k,6,54.15,145.2,0.0
k,7,72.0,145.2,0.0
k,8,97.668,145.2,10.632
k,9,108.3,145.2,36.3
k,10,108.3,145.2,56.80
k,11,108.3,145.2,77.3


k,12,2.7631,122.79,0
k,13,22.408,142.44,0
k,14,85.9,145,2.76
k,15,106,145,22.4


k,101,midd,0,0
k,102,0,0,midd
```

```
k,103,-midd,0,0
k,104,0,0,-midd

/com,  Lines
/com,*************************

larc,101,102,1,midd
larc,102,103,1,midd
larc,103,104,1,midd
larc,104,101,1,midd

lsel,s,line,,1,4,1

l,1,3,12                     ! form a line between 1 and 3, with no.of.divisions=8

adrag,1,2,3,4,,,5


larc,3,4,12,-36.3

adrag,6,13,11,9,,,14

larc,4,5,13,-36.3,

adrag,18,15,22,20,,,23

l,5,7,12

adrag,31,27,29,24,,,32

larc,7,8,14,-36.3

adrag,33,40,38,36,,,41

larc,8,9,15,-36.3

adrag,42,49,47,45,,,50

l,9,11,12

adrag,51,58,56,54,,,59

lesize,all,,,16


amap,1,16,17,101,102
amap,2,17,18,102,103
amap,3,18,19,103,104
amap,4,16,19,101,104
amap,5,16,17,20,21
amap,6,17,18,21,22
amap,7,18,19,22,23
amap,8,16,19,20,23
amap,9,21,22,24,25
amap,10,22,23,25,26
amap,11,20,23,26,27
amap,12,20,21,24,27
amap,13,24,27,28,29
amap,14,24,25,29,30
amap,15,25,26,30,31
amap,16,26,27,28,31
amap,17,28,29,32,33
amap,18,29,30,33,34
amap,19,30,31,34,35
amap,20,28,31,32,35
amap,21,32,33,36,37
amap,22,33,34,37,38
amap,23,34,35,38,39
amap,24,32,35,36,39
amap,25,36,37,40,41
amap,26,37,38,41,42
amap,27,38,39,42,43
```

```
amap,28,36,39,40,43

allsel,all

asel,s,area,,5,12,1
esla,s
cm,needed,elem
allsel,all

asel,u,area,,5,12,1
aclear,all
allsel,all

/com, Constraints
/com,**********************

nsel,s,loc,y,108.90
d,all,all,0
allsel,all
finish

/com,
/com, =========================
/com,  Modal Solve
/com, =========================
/com,

/solution
antype,modal
outres,all,all
modopt,lanb,15     ! LANB mode extraction method
mxpand,15,,,yes     ! Expand all 15 modes
solve
finish

/post1
set,list      ! Frequencies obtained from Modal solve
/show,jpeg
/eshape,0
/efacet,2
/view,1,1,1,1
/graphics,power
eplot
/replot
set,1,1
plnsol,u,sum
set,1,2
plnsol,u,sum
set,1,3
plnsol,u,sum
set,1,4
plnsol,u,sum
set,1,5
plnsol,u,sum
set,1,6
plnsol,u,sum
set,1,7
plnsol,u,sum
set,1,8
plnsol,u,sum
set,1,9
plnsol,u,sum
set,1,10
plnsol,u,sum
set,1,11
plnsol,u,sum
set,1,12
plnsol,u,sum
set,1,13
plnsol,u,sum
set,1,14
plnsol,u,sum
```

```
set,1,15
plnsol,u,sum
finish



/com,---------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,sprs      ! Single Point Excitation Response Spectrum
dmprat,0.02      ! Constant Damping Ratio
grp,0.0      ! Group Modes based on significance level
svtyp,2      ! Seismic Acceleration Response Loading

sed,1       ! Excitation in X direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve
sed,0,0,0

sed,,1      ! Excitation in Y direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,266.7,580.7,580.7,466.7,792,792,293.3,516.7,516.7
sv,0.02,355.5,311.5,295.7,253.3,192.7,159.6,128.4,122.7,96.7
solve
sed,0,0,0

sed,,,1      ! Excitation in Z direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve
fini

/com,---------------------------------------------------------------------------

/post1
/input,281,mcom

/com, *========================================================
/com, * Displacement Sum and Equivalent Stress
/com, *==========================================================

plnsol,u,sum
*get,umax,plnsol,0,max
*get,umin,plnsol,0,min
plnsol,s,eqv
*get,smax,plnsol,0,max
*get,smin,plnsol,0,min
/show,close
*stat,umax
*stat,umin
*stat,smax
*stat,smin
finish
/exit,nosave
```

demonstration-problem1-18 Input Listing

```
/batch,list
/verify,demonstration_problem1_18
JPGPRF,500,100,1
/title,Bend pipe model meshed with PIPE18 elements

/COM, PIPE18


/filnam,18


/prep7

et,1,pipe18      ! Element 1 - PIPE18 (Pipe Bend Element)


/com, Real Constants
/com,****************

fact=1.5

r,1,7.288*fact,0.1205,36.30,0.0,0.0,0.0 ! Outer Diameter,Wall Thickness,Radius of Curvature


/com, Material properties
/com, ********************


mp,ex,1,24e6
mp,nuxy,1,0.3
mp,dens,1,0.000125


/com, Nodes
/com,*******


  n,    14,     0.0000,      108.90,      0.0000
  n,    26,     36.300,      145.20,      0.0000
  n,    76,     10.632,      134.57,      0.0000
  n,    77,    0.77718E-01,  111.27,      0.0000
  n,    78,    0.31055,      113.64,      0.0000
  n,    79,    0.69749,      115.98,      0.0000
  n,    80,     1.2369,      118.30,      0.0000
  n,    81,     1.9264,      120.57,      0.0000
  n,    82,     2.7632,      122.79,      0.0000
  n,    83,     3.7435,      124.96,      0.0000
  n,    84,     4.8633,      127.05,      0.0000
  n,    85,     6.1176,      129.07,      0.0000
  n,    86,     7.5013,      131.00,      0.0000
  n,    87,     9.0082,      132.83,      0.0000
  n,    88,     12.366,      136.19,      0.0000
  n,    89,     14.202,      137.70,      0.0000
  n,    90,     16.133,      139.08,      0.0000
  n,    91,     18.150,      140.34,      0.0000
  n,    92,     20.245,      141.46,      0.0000
  n,    93,     22.245,      142.44,      0.0000
  n,    94,     24.632,      143.27,      0.0000
  n,    95,     26.905,      143.96,      0.0000
  n,    96,     29.218,      144.50,      0.0000
  n,    97,     31.562,      144.89,      0.0000
  n,    98,     33.926,      145.12,      0.0000

n,100,0,90.750,0
n,101,42.250,145.20,0
```

```
/com, Elements
/com, ********************

type,1
mat,1
real,1

e,     14,    78,    100
e,     78,    80,    14
e,     80,    82,    78
e,     82,    84,    80
e,     84,    86,    82
e,     86,    76,    84
e,     76,    89,    86
e,     89,    91,    93
e,     91,    93,    95
e,     93,    95,    97
e,     95,    97,    26
e,     97,    26,    101



/com, Constraints
/com,*************

d,14,all,0
allsel,all
finish

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal
outres,all,all
modopt,lanb,15     ! LANB mode extraction method
mxpand,15,,,yes     ! Extract all 15 modes
solve
finish

/post1
set,list      ! Frequencies obtained from Modal Solve
/show,jpeg
/eshape,1,1
/efacet,2
/view,1,1,1,1
/graphics,power
eplot
/replot
set,1,1
plnsol,u,sum
set,1,2
plnsol,u,sum
set,1,3
plnsol,u,sum
set,1,4
plnsol,u,sum
set,1,5
plnsol,u,sum
set,1,6
plnsol,u,sum
set,1,7
plnsol,u,sum
set,1,8
plnsol,u,sum
set,1,9
plnsol,u,sum
set,1,10
plnsol,u,sum
```

```
set,1,11
plnsol,u,sum
set,1,12
plnsol,u,sum
set,1,13
plnsol,u,sum
set,1,14
plnsol,u,sum
set,1,15
plnsol,u,sum
finish



/com,-------------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,sprs      ! Single Point Excitation Response Spectrum
dmprat,0.02      ! Constant Damping Ratio
grp,0.00      ! Group Modes based on significance level
svtyp,2      ! Seismic Acceleration Response Loading

sed,1       ! Excitation in X direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve
sed,0,0,0

sed,,1      ! Excitation in Y direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,266.7,580.7,580.7,466.7,792,792,293.3,516.7,516.7
sv,0.02,355.5,311.5,295.7,253.3,192.7,159.6,128.4,122.7,96.7
solve
sed,0,0,0

sed,,,1      ! Excitation in Z direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve
fini

/com,-------------------------------------------------------------------------------

/post1
/input,18,mcom

/com, *========================================================
/com, * Displacement Sum and Equivalent Stress
/com, *==========================================================

plnsol,u,sum
*get,umax,plnsol,0,max
*get,umin,plnsol,0,min
plnsol,s,eqv
*get,smax,plnsol,0,max
*get,smin,plnsol,0,min
/show,close
```

```
*stat,umax
*stat,umin
*stat,smax
*stat,smin
finish
/exit,nosave
```

demonstration-problem2-290 Input Listing

```
/batch,list
/verify,demonstration_problem2_290
JPGPRF,500,100,1
/title,Piping model meshed with ELBOW290 elements

/COM, ELBOW290

/filnam,290

/prep7

et,1,pipe289     ! Element 1 - PIPE289 (Straight Pipe Element)

et,2,elbow290     ! Element 2 - ELBOW290 (Elbow Element)
keyopt,2,2,6     ! General section deformation is 6


/com, Section properties
/com,****************

fact = 1.5

sectype,1,pipe     ! Pipe section definition
secdata,7.288*fact,0.241,24


/com, Material properties
/com, ********************


mp,ex,1,24e6
mp,nuxy,1,0.3
mp,dens,1,0.000125


/com, keypoints
/com,*******

k,1,0.0,0.0,0.0
k,2,0.0,54.45,0.0
k,3,0.0,108.9,0.0
k,4,10.632,134.568,0.0
k,5,36.3,145.2,0.0
k,6,54.15,145.2,0.0
k,7,72.0,145.2,0.0
k,8,97.668,145.2,10.632
k,9,108.3,145.2,36.3
k,10,108.3,145.2,56.80
k,11,108.3,145.2,77.3

k,12,2.7631,122.79,0
k,13,22.408,142.44,0
k,14,85.9,145,2.76
k,15,106,145,22.4


/com, Lines
/com, ************

l,1,2
l,2,3
```

```
larc,3,4,12,-36.30
larc,4,5,13,-36.30
l,5,6
l,6,7
larc,7,8,14,-36.30
larc,8,9,15,-36.30
l,9,10
l,10,11


/com, Straight Pipe (Tangent Elements)
/com,**********************************

type,1
mat,1
secnum,1
lsel,s,line,,1
lsel,a,line,,10
lesize,all,,,12
lmesh,all
lsel,all

lsel,s,line,,2
lsel,a,line,,5
lsel,a,line,,6
lsel,a,line,,9
lesize,all,,,12
lmesh,all
allsel,all

/com, Bend Pipe Elements
/com,**********************************

type,2
mat,1
secnum,1

lsel,s,line,,3
lsel,a,line,,4
lsel,a,line,,7
lsel,a,line,,8

lesize,all,,,12
lmesh,all
allsel,all


/com, Converting all PIPE289 into ELBOW290 elements
/com, *********************************************************

emodif,all,type,2
allsel,all


/com, Constraints
/com,*************


ksel,s,,,1
ksel,a,,,11
nslk,s
d,all,all,0
d,all,sect,0

allsel,all
finish

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,
```

```
/solution
antype,modal
outres,all,all
modopt,lanb,15     ! LANB mode extraction method
mxpand,15,,,yes     ! Expand all 15 modes
solve
finish

/post1
set,list      ! Frequencies obtained from modal solve
/show,jpeg
/eshape,1
/efacet,2
/view,1,1,1,1
/graphics,power
eplot
/replot
set,1,1
plnsol,u,sum
set,1,2
plnsol,u,sum
set,1,3
plnsol,u,sum
set,1,4
plnsol,u,sum
set,1,5
plnsol,u,sum
set,1,6
plnsol,u,sum
set,1,7
plnsol,u,sum
set,1,8
plnsol,u,sum
set,1,9
plnsol,u,sum
set,1,10
plnsol,u,sum
set,1,11
plnsol,u,sum
set,1,12
plnsol,u,sum
set,1,13
plnsol,u,sum
set,1,14
plnsol,u,sum
set,1,15
plnsol,u,sum
finish


/com,---------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,sprs      ! Single Point Excitation Response Spectrum
dmprat,0.5      ! Constant Damping Ratio
grp,0.00      ! Group Modes based on significance level
svtyp,2      ! Seismic Acceleration Response Loading

sed,1       ! Excitation in X direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
```

```
solve

sed,,1      ! Excitation in Y direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,266.7,580.7,580.7,466.7,792,792,293.3,516.7,516.7
sv,0.02,355.5,311.5,295.7,253.3,192.7,159.6,128.4,122.7,96.7
solve

sed,,,1      ! Excitation in Z direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve
fini

/com,-----------------------------------------------------------------------------

/post1
/input,290,mcom

/com, *=========================================================
/com, * Displacement Sum and Equivalent Stress
/com, *===========================================================

plnsol,u,sum
*get,umax,plnsol,0,max
*get,umin,plnsol,0,min
plesol,s,eqv
*get,smax,plnsol,0,max
*get,smin,plnsol,0,min
/show,close
*stat,umax
*stat,umin
*stat,smax
*stat,smin
finish
/exit,nosave
```

demonstration-problem2-281 Input Listing

```
/batch,list
/verify,demonstration_problem2_281
JPGPRF,500,100,1
/title,Piping Model meshed with SHELL281 elements

/filnam,281

/prep7

fact = 1.5

out_dia = 7.288*fact   ! Outer Diameter
wall_thk = 0.241    ! Wall Thickness

out_rad = out_dia/2   ! Outer radius

in_rad = out_dia/2 - wall_thk  ! Inner radius

hf_thick = wall_thk/2   ! Half Thickness
midd = in_rad+hf_thick

et,1,shell281    ! SHELL281 elements

sectype,1,shell    ! Section definition
secdata,wall_thk,1,0,3
```

```
mp,ex,1,24e6
mp,nuxy,1,0.3
mp,dens,1,0.000125

/com, keypoints
/com,*************

k,1,0.0,0.0,0.0
k,2,0.0,54.45,0.0
k,3,0.0,108.9,0.0
k,4,10.632,134.568,0.0
k,5,36.3,145.2,0.0
k,6,54.15,145.2,0.0
k,7,72.0,145.2,0.0
k,8,97.668,145.2,10.632
k,9,108.3,145.2,36.3
k,10,108.3,145.2,56.80
k,11,108.3,145.2,77.3


k,12,2.7631,122.79,0
k,13,22.408,142.44,0
k,14,85.9,145,2.76
k,15,106,145,22.4


k,101,midd,0,0
k,102,0,0,midd
k,103,-midd,0,0
k,104,0,0,-midd

/com, lines
/com,*************

larc,101,102,1,midd
larc,102,103,1,midd
larc,103,104,1,midd
larc,104,101,1,midd

lsel,s,line,,1,4,1
lesize,all,,,12
lsel,all

l,1,3,12

adrag,1,2,3,4,,,5

larc,3,4,12,-36.3

adrag,6,13,11,9,,,14

larc,4,5,13,-36.3,

adrag,18,15,22,20,,,23

l,5,7,12

adrag,31,27,29,24,,,32

larc,7,8,14,-36.3

adrag,33,40,38,36,,,41

larc,8,9,15,-36.3

adrag,42,49,47,45,,,50

l,9,11,12

adrag,51,58,56,54,,,59

lesize,all,,,12
```

```
allsel,all

amap,1,16,17,101,102
amap,2,17,18,102,103
amap,3,18,19,103,104
amap,4,16,19,101,104
amap,5,16,17,20,21
amap,6,17,18,21,22
amap,7,18,19,22,23
amap,8,16,19,20,23
amap,9,21,22,24,25
amap,10,22,23,25,26
amap,11,20,23,26,27
amap,12,20,21,24,27
amap,13,24,27,28,29
amap,14,24,25,29,30
amap,15,25,26,30,31
amap,16,26,27,28,31
amap,17,28,29,32,33
amap,18,29,30,33,34
amap,19,30,31,34,35
amap,20,28,31,32,35
amap,21,32,33,36,37
amap,22,33,34,37,38
amap,23,34,35,38,39
amap,24,32,35,36,39
amap,25,36,37,40,41
amap,26,37,38,41,42
amap,27,38,39,42,43
amap,28,36,39,40,43


/com, constraints
/com,*************

nsel,s,loc,y,0
d,all,all,0
alls

lsel,s,line,,60
lsel,a,line,,63
lsel,a,line,,65
lsel,a,line,,67
nsll,s,1
d,all,all,0
alls
finish

/solution
antype,modal
outres,all,all
modopt,lanb,15     ! LANB mode extraction method
mxpand,15,,,yes     ! Expand all 15 modes
solve
fini

/post1
set,list      ! Frequencies obtained from Modal Solve
rsys,solu
/show,jpeg
/eshape,0
/efacet,2
/view,1,1,1,1
/graphics,power
eplot
/replot
set,1,1
plnsol,u,sum
set,1,2
plnsol,u,sum
set,1,3
```

```
plnsol,u,sum
set,1,4
plnsol,u,sum
set,1,5
plnsol,u,sum
set,1,6
plnsol,u,sum
set,1,7
plnsol,u,sum
set,1,8
plnsol,u,sum
set,1,9
plnsol,u,sum
set,1,10
plnsol,u,sum
set,1,11
plnsol,u,sum
set,1,12
plnsol,u,sum
set,1,13
plnsol,u,sum
set,1,14
plnsol,u,sum
set,1,15
plnsol,u,sum
finish



/com,------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectr     ! Perform Spectrum Analysis
spopt,sprs      ! Single Point Excitation Response Spectrum
dmprat,0.02      ! Constant Damping Ratio
grp,0.0      ! Group Modes based on significance level
svtyp,2      ! Seismic Acceleration Response Loading

sed,1       ! Excitation in X direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve

sed,,1      ! Excitation in Y direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,266.7,580.7,580.7,466.7,792,792,293.3,516.7,516.7
sv,0.02,355.5,311.5,295.7,253.3,192.7,159.6,128.4,122.7,96.7
solve

sed,,,1      ! Excitation in Z direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve
fini

/com,------------------------------------------------------------------------

/post1
```

```
/input,281,mcom

/com, *=======================================================
/com, * Displacement Sum and Equivalent Stress
/com, *=========================================================

plnsol,u,sum
*get,umax,plnsol,0,max
*get,umin,plnsol,0,min
plnsol,s,eqv
*get,smax,plnsol,0,max
*get,smin,plnsol,0,min
/show,close
*stat,umax
*stat,umin
*stat,smax
*stat,smin
finish
/exit,nosave
```

demonstration-problem2-16-18 Input Listing

```
/batch,list
/verify,demonstration_problem2_16_18
JPGPRF,500,100,1
/title,Piping model meshed with PIPE16 and PIPE18 elements

/COM, PIPE16 + PIPE18

/filnam,16-18

/prep7

et,1,pipe16      ! Element 1 - PIPE16 (Straight Pipe Element)

et,2,pipe18      ! Element 2 - PIPE18 (Pipe Bend Element)


/com, Real Constants
/com,****************

fact=1.5

r,1,7.288*fact,0.241,0.0,0.0,0.0,0.0 ! Outer Diameter, Wall Thickness
r,2,7.288*fact,0.241,36.30,0.0,0.0,0.0 ! Outer Diameter, Wall Thickness, Radius of Curvature


/com, Material properties
/com, ********************


mp,ex,1,24e6
mp,nuxy,1,0.3
mp,dens,1,0.000125


/com, Nodes
/com,*******

 n,    1,    0.0000,      0.0000,      0.0000
 n,    2,    0.0000,      54.450,      0.0000
 n,    3,    0.0000,      18.150,      0.0000
 n,    4,    0.0000,      36.300,      0.0000
 n,    5,    0.0000,      108.90,      0.0000
 n,    6,    0.0000,      72.600,      0.0000
 n,    7,    0.0000,      90.750,      0.0000
 n,    8,    36.300,      145.20,      0.0000
 n,    9,    54.150,      145.20,      0.0000
```

```
 n,   10,    42.250,      145.20,      0.0000
 n,   11,    48.200,      145.20,      0.0000
 n,   12,    72.000,      145.20,      0.0000
 n,   13,    60.100,      145.20,      0.0000
 n,   14,    66.050,      145.20,      0.0000
 n,   15,    108.30,      145.20,      36.300
 n,   16,    108.30,      145.20,      56.800
 n,   17,    108.30,      145.20,      43.133
 n,   18,    108.30,      145.20,      49.967
 n,   19,    108.30,      145.20,      77.300
 n,   20,    108.30,      145.20,      63.633
 n,   21,    108.30,      145.20,      70.467
 n,   22,    10.632,      134.57,      0.0000
 n,   23,   0.31055,      113.64,      0.0000
 n,   24,    1.2369,      118.30,      0.0000
 n,   25,    2.7632,      122.79,      0.0000
 n,   26,    4.8633,      127.05,      0.0000
 n,   27,    7.5013,      131.00,      0.0000
 n,   28,    14.202,      137.70,      0.0000
 n,   29,    18.150,      140.34,      0.0000
 n,   30,    22.409,      142.44,      0.0000
 n,   31,    26.905,      143.96,      0.0000
 n,   32,    31.562,      144.89,      0.0000
 n,   33,    97.668,      145.20,      10.632
 n,   34,    76.737,      145.09,     0.31421
 n,   35,    81.393,      145.02,      1.2428
 n,   36,    85.889,      145.00,      2.7698
 n,   37,    90.148,      145.02,      4.8691
 n,   38,    94.097,      145.09,      7.5049
 n,   39,    100.80,      145.10,      14.203
 n,   40,    103.43,      145.05,      18.152
 n,   41,    105.53,      145.03,      22.411
 n,   42,    107.06,      145.05,      26.907
 n,   43,    107.99,      145.10,      31.563

/com, Straight Pipe (Tangent Elements)
/com,**********************************

type,1
mat,1
real,1

e,1,3
e,3,4
e,4,2
e,2,6
e,6,7
e,7,5
e,8,10
e,10,11
e,11,9
e,9,13
e,13,14
e,14,12
e,15,17
e,17,18
e,18,16
e,16,20
e,20,21
e,21,19



/com, Bend Pipe Elements
/com,**********************************

type,2
mat,1
real,2
```

```
e,5,24,7
e,24,26,5
e,26,22,24
e,22,29,26
e,29,31,8
e,31,8,10
e,12,35,14
e,35,37,12
e,37,33,35
e,33,40,37
e,40,42,33
e,42,15,17



/com, Constraints
/com,*************

d,1,all,0
d,19,all,0

allsel,all
finish

/com,
/com,=============
/com, Modal Solve
/com,=============
/com,

/solution
antype,modal
outres,all,all
modopt,lanb,15     ! LANB mode extraction method
mxpand,15,,,yes     ! Expand all 15 modes
solve
finish

/post1
set,list      ! Frequencies obtained from Modal Solve
/show,jpeg
/eshape,1,1
/efacet,2
/view,1,1,1,1
/graphics,power
eplot
/replot
set,1,1
plnsol,u,sum
set,1,2
plnsol,u,sum
set,1,3
plnsol,u,sum
set,1,4
plnsol,u,sum
set,1,5
plnsol,u,sum
set,1,6
plnsol,u,sum
set,1,7
plnsol,u,sum
set,1,8
plnsol,u,sum
set,1,9
plnsol,u,sum
set,1,10
plnsol,u,sum
set,1,11
plnsol,u,sum
set,1,12
plnsol,u,sum
set,1,13
```

```
plnsol,u,sum
set,1,14
plnsol,u,sum
set,1,15
plnsol,u,sum
finish


/com,--------------------------------------------------------------------------

/com,
/com,================
/com, Spectrum Solve
/com,================
/com,

/solution
antype,spectrum     ! Perform Spectrum Analysis
spopt,sprs      ! Single Point Excitation Response Spectrum
dmprat,0.02      ! Constant Damping Ratio
grp,0.00      ! Group Modes based on significance level
svtyp,2      ! Seismic Acceleration Response Loading

sed,1       ! Excitation in X direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve

sed,,1      ! Excitation in Y direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,266.7,580.7,580.7,466.7,792,792,293.3,516.7,516.7
sv,0.02,355.5,311.5,295.7,253.3,192.7,159.6,128.4,122.7,96.7
solve

sed,,,1      ! Excitation in Z direction
freq
freq,3.1,4,5,5.81,7.1,8.77,10.99,14.08,17.24
freq,25,28.5,30,34.97,55,80,140,162,588.93
sv,0.02,400,871,871,700,1188,1188,440,775,775
sv,0.02,533.2,467.2,443.6,380,289,239.4,192.6,184.1,145
solve
fini

/com,--------------------------------------------------------------------------

/post1
/input,16-18,mcom

/com, *========================================================
/com, * Displacement Sum and Equivalent Stress
/com, *==========================================================

plnsol,u,sum
*get,umax,plnsol,0,max
*get,umin,plnsol,0,min
plnsol,s,eqv
*get,smax,plnsol,0,max
*get,smin,plnsol,0,min
/show,close
*stat,umax
*stat,umin
*stat,smax
*stat,smin
finish
/exit,nosave
```

demonstration_problem3-289-290 Input Listing

```
/batch,list
/verify,demonstration_problem3_289_290
JPGPRF,500,100,1
/title,Piping model meshed with PIPE289 and ELBOW290 elements

/filnam,289-290

/PREP7

YoungModulus1 = .258e+8                           ! Young's Modulus
Nu = 0.3                                          ! Poissons ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu))          ! Shear Modulus
WMass = 1.042868e-03                              ! Density

WTick=0.216                                       ! Wall Thickness
OD=3.5                                            ! Outer Diameter

RADCUR=48.003                                     ! Radius curvature
temp=60                                           ! Temperature
maxm=15                                           ! Number of modes to extract

et,1,pipe289,,,                                   ! Straight pipe elements
et,2,elbow290,,6                                  ! Curved pipe elements

et,3,combin14                                 ! Spring-damper elements
keyopt,3,2,1                                      ! UX Degree Of Freedom
et,4,combin14,                                    ! Spring-damper elements
keyopt,4,2,2                                      ! UY Degree Of Freedom
et,5,combin14                                 ! Spring-damper elements
keyopt,5,2,3                                      ! UZ Degree Of Freedom
et,6,combin14                                     ! Spring-damper elements
keyopt,6,2,1                                      ! UX Degree Of Freedom
et,7,combin14                                     ! Spring-damper elements
keyopt,7,2,2                                      ! UY Degree Of Freedom

/com,
/com, Real Constants
/com,****************

sectype,1,PIPE,ctube      ! Pipe Section Definition
secdata,OD,WTick,24

r,3,0.2e+8                                        ! Stiffness
r,4,0.2e+8                                        ! Stiffness
r,5,0.2e+8                                        ! Stiffness
r,6,0.2e+5                                        ! Stiffness
r,7,0.2e+5                                        ! Stiffness


/com,---------------------------------------------------------------------------

/com,
/com, Material Properties
/com,*********************

mp,ex,1,YoungModulus1
mp,nuxy,1,Nu
mp,gxy,1,ShearModulus1
mp,dens,1,WMass

mp,ex,2,YoungModulus1
mp,nuxy,2,Nu
mp,gxy,2,ShearModulus1
mp,dens,2,WMass

/com,---------------------------------------------------------------------------

/com, Keypoints
```

```
/com,***********

k,1,0,0,0
k,2,0,12,0
k,3,35.687,60,32.110
k,4,55,60,49.5
k,5,74.329,60,66.882
k,6,110,12,99
k,7,110,0,99
k,8,110,-24,99,
k,9,110,-48,99,
k,10,110,-72,99
k,11,110,-96,99
k,12,110,-120,99
k,13,110,-144,99
k,14,110,-168,99
k,15,110,-198,99
k,16,110,-228,99
k,17,110,-252,99
k,18,110,-276,99
k,19,110,-300,99
k,20,110,-324,99
k,21,99.6,-349.4,99
k,22,89.2,-374.8,99
k,23,78.8,-400,99
k,24,68.4,-425.6,99
k,25,58,-451,99
k,26,58,-475,99
k,27,58,-487,99
k,28,103.537,-535,114.179
k,29,124.269,-535,121.1
k,30,145,-535,128
k,31,184.975,-535,123.615
k,32,214.8,-536,102.8
k,33,254.585,-535,81.849
k,34,279.312,-535,75
k,35,331,-535,75
k,36,383,-535,75

/com,
/com, Elastic support Keypoints
/com,***************************

k,37,10,0,0
k,38,0,10,0
k,39,0,0,10
k,40,55,70,49.5
k,41,110,0,109
k,42,120,0,99
k,43,110,-168,109
k,44,120,-168,109
k,45,110,-324,109
k,46,120,-324,99
k,47,58,-475,109
k,48,68,-475,99
k,49,103.537,-545,114.179
k,50,103.537,-535,104.179
k,51,393,-535,75
k,52,383,-545,75
k,53,383,-535,85

/com,---------------------------------------------------------------------------

/com,
/com, Modeling of Straight Pipe (Tangent)
/com,***********************************

l, 1, 2
l, 3, 4
l, 4, 5
l, 6, 7
l, 7, 8
```



```
l, 8, 9
l, 9,10
l,10,11
l,11,12
l,12,13
l,13,14
l,14,15
l,15,16
l,16,17
l,17,18
l,18,19
l,19,20
l,20,21
l,21,22
l,22,23
l,23,24
l,24,25
l,25,26
l,26,27
l,28,29
l,29,30
l,31,32
l,32,33
l,34,35
l,35,36             ! line number 30

/com,
/com, Modeling of Pipe Bend
/com,**********************

larch,2,3,4,RADCUR
larch,5,6,4,RADCUR
larch,27,28,26,RADCUR
larch,30,31,29,RADCUR
larch,33,34,32,RADCUR           ! line number 35

/com, Elastic supports and anchors
/com,*****************************

l,1,37
l,36,51
l,4,40
l,7,41
l,26,47
l,28,49

l,1,38
l,36,52
l,7,42
l,26,48
l,28,50

l,1,39
l,36,53

l,14,43
l,20,45

l,14,44
l,20,46

/com, **********************************
/com, Meshing for Straight pipe
/com, **********************************

type,1
secnum,1
mat,1


lsel,s,,,2,29
allsel,below,line
```

```
lesize,all,,,4
lmesh,all

allsel,all,all

/com, **********************************
/com, Meshing for bend pipe
/com, **********************************

type,2
secnum,1
mat,2

/com, *****************************************
/com, Note: The end elements are
/com, modeled using elbow elements
/com, in order to compare with the shell281
/com, results.
/com, With elbow290 in addition to constraining
/com, the nodal DOF you can also constrain the
/com, section constraints which is not possible
/com, with pipe289 elements.

lsel,s,line,,1
lsel,a,line,,30
lesize,all,,,6
lmesh,all
lsel,all


lsel,s,,,31,35
allsel,below,line
lesize,all,,,4
lmesh,all

allsel,all,all


/com, ************************************************************
/com,  Using ELBOW, to convert some PIPE289 into ELBOW290 near
/com,  the pipe ends
/com, ************************************************************

elbow,on,,,sect

esel,s,ename,,290
nsle,s
esln,s
nsle,s
esln,s
nsle,s
esln,s
esel,u,ename,,290
emodif,all,type,2
allsel,all



/com, ****************************
/com,  Spring - damper elements
/com, ******************************

type,3
real,3

lsel,s,,,36,41
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all
```

```
type,4
real,4

lsel,s,,,42,46
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,5
real,5

lsel,s,,,47,48
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,6
real,6

lsel,s,,,49,50
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all

type,7
real,7

lsel,s,,,51,52
allsel,below,line
lesize,all,,,1
lmesh,all

allsel,all,all


n1 = node(55,60,49.500)
n2 = node(55,70,49.500)
n3 = node(35.687,60,32.110)

n4 = node(110,0,99.00)
n5 = node(110,0,109.00)
n6 = node(120,0,99.00)

n7 = node(110,-168.0,99.00)
n8 = node(110,-168.0,109.00)
n9 = node(120,-168.0,109.00)

n10 = node(110,-324.0,99.00)
n11 = node(110,-324,109.00)
n12 = node(120,-324,99.00)

n13 = node(58,-475,99.00)
n14 = node(58,-475,109.00)
n15 = node(68,-475,99)

n16 = node(103.54,-535,114.18)
n17 = node(103.54,-545,114.18)
n18 = node(103.54,-535,104.18)

n19 = node(10,0,0)
n20 = node(393,-535,75)
n21 = node(55,70,49.500)
n22 = node(110.0,0,109.0)
n23 = node(58.00,-475,109.00)
n24 = node(103.54,-545,114.18)
n25 = node(0,10,0)
```

```
n26 = node(0,0,0)
n27 = node(383,-535,75)

n28 = node(383,-545,75)
n29 = node(120,0,99)
n30 = node(68,-475,99)
n31 = node(103.54,-535,104.18)
n32 = node(0,0,10)
n33 = node(383.00,-535,85)
n34 = node(110,-168,109)
n35 = node(110,-324,109)
n36 = node(120,-168,109)
n37 = node(120,-324,99)

allsel,all
/com, rotate nodes with less than 3 supports
/com,
/com, rotate nodes with less than 3 supports
/com,

n1 = 2
n2 = 292
n3 = 1
ics = 11
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0

n1 = 19
n2 = 293
n3 = 298
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 75
n2 = 303
n3 = 305
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 123
n2 = 304
n3 = 306
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 171
n2 = 294
n3 = 299
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
```

```
nrotat,n3
csys,0

n1 = 187
n2 = 295
n3 = 300
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

allsel,all,all

/com,-------------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,,node,,290,306
d,all,all
allsel

d,230,rotx,,,,,roty,rotz
d,243,rotx,,,,,roty,rotz

d,230,sect,0
d,243,sect,0
allsel,all,all

finish


/com,-------------------------------------------------------------------------------

/com
/com,==============
/com, Modal solve
/com,==============
/com,

/solution
antype,modal       ! Perform Modal Analysis
modopt,lanb,maxm
lumpm,on        ! Use Lumped Mass Approximation
mxpand,maxm,,,yes       ! Expand solution with Element Calculations ON
solve
finish

/post1
set,list        ! Frequencies obtained from Modal solve
/show,jpeg
/eshape,5
/efacet,2
/view,1,1,2,3
/ang,1
/auto,1
/graphics,power
eplot
/replot
set,1,1
plnsol,u,sum
set,1,2
plnsol,u,sum
set,1,3
plnsol,u,sum
set,1,4
plnsol,u,sum
set,1,5
```

```
plnsol,u,sum
set,1,6
plnsol,u,sum
set,1,7
plnsol,u,sum
set,1,8
plnsol,u,sum
set,1,9
plnsol,u,sum
set,1,10
plnsol,u,sum
set,1,11
plnsol,u,sum
set,1,12
plnsol,u,sum
set,1,13
plnsol,u,sum
set,1,14
plnsol,u,sum
set,1,15
plnsol,u,sum
finish


/com,-----------------------------------------------------------------------

/com,
/com,==================
/com, Spectrum solve
/com,==================
/com,

/solution
antype,spectrum       ! Perform Spectrum Analysis
spopt,sprs,15       ! Single Point Excitation Response Spectrum
srss,0.0        ! SRSS mode combination

gval = 386.4

svtyp, 2, gval       ! Seismic Acceleration Response Loading
freq, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83,  23.25,  29.41
sv,,  2.275, 2.275,  1.0,    0.8,  0.925,  0.925,   0.8 ,   1.0 ,    1.0
freq,  34.48
sv,,   0.875
sed,1,0,0        ! Excitation in X direction
SOLVE

svtyp, 2, gval       ! Seismic Acceleration Response Loading
freq
freq, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83,  23.25,  29.41
sv,, 1.517, 1.517, 0.667,  0.534,  0.617,  0.617,   0.534, 0.667,  0.667
freq,  34.48
sv,,   0.584
sed,0,1,0        ! Excitation in Y direction
SOLVE
fini

/com,-----------------------------------------------------------------------

/post1
/input,289-290,mcom

/com, *=======================================================
/com, * Displacement Sum and Equivalent Stress
/com, *=========================================================

/auto,1
plnsol,u,sum
*get,umax,plnsol,0,max
*get,umin,plnsol,0,min
plnsol,s,eqv
*get,smax,plnsol,0,max
```

```
*get,smin,plnsol,0,min
/show,close
*stat,umax
*stat,umin
*stat,smax
*stat,smin
finish
/exit,nosave
```

demonstration-problem3-281 Input Listing

```
/batch,list
/verify,demonstration_problem3_281
JPGPRF,500,100,1
/title,Piping model meshed with SHELL281 elements

/filname,281

/prep7

YoungModulus1 = .258e+8                         ! Young's Modulus
Nu = 0.3                                        !Poissons ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu))        !Shear Modulus
WMass = 1.042868e-03                            !Density

WTick=0.216                                     !Wall Thickness
OD=3.5                                          ! Outer Diameter

RADCUR=48.003                                   !Radius curvature
temp=60                                         ! Temperature
maxm=15

out_rad = OD/2      ! Outer Radius

in_rad = OD/2 - WTick     ! Inner Radius

hf_thick = WTick/2     ! Half Thicknes

midd = in_rad + hf_thick

et,1,shell281      ! SHELL281 elements

sectype,1,shell      ! Shell Section Definition
secdata,WTick,1,0,3

et,3,combin14                               ! Spring-damper elements
keyopt,3,2,1                                    ! UX Degree Of Freedom
et,4,combin14,                                  ! Spring-damper elements
keyopt,4,2,2                                    ! UY Degree Of Freedom
et,5,combin14                               ! Spring-damper elements
keyopt,5,2,3                                    ! UZ Degree Of Freedom
et,6,combin14                                   ! Spring-damper elements
keyopt,6,2,1                                    ! UX Degree Of Freedom
et,7,combin14                                   ! Spring-damper elements
keyopt,7,2,2                                    ! UY Degree Of Freedom


et,8,conta175      ! Contact175 element
keyopt,8,2,2      ! Multipoint Constraint
keyopt,8,4,2      ! Contact normal direction
keyopt,8,12,6      ! Bonded

et,9,targe170      ! Target170 element
keyopt,9,2,1      ! Boundary conditions for target nodes



r,3,0.2e+8                                      ! Stiffness
r,4,0.2e+8                                      ! Stiffness
```

```
r,5,0.2e+8                                    ! Stiffness
r,6,0.2e+5                                    ! Stiffness
r,7,0.2e+5                                    ! Stiffness


/com,
/com, Material Properties
/com,*********************

mp,ex,1,YoungModulus1
mp,nuxy,1,Nu
mp,gxy,1,ShearModulus1
mp,dens,1,WMass


/com, Keypoints
/com,***********

k,1,0,0,0
k,2,0,12,0
k,3,35.687,60,32.110
k,4,55,60,49.5
k,5,74.329,60,66.882
k,6,110,12,99
k,7,110,0,99
k,8,110,-24,99,
k,9,110,-48,99,
k,10,110,-72,99
k,11,110,-96,99
k,12,110,-120,99
k,13,110,-144,99
k,14,110,-168,99
k,15,110,-198,99
k,16,110,-228,99
k,17,110,-252,99
k,18,110,-276,99
k,19,110,-300,99
k,20,110,-324,99
k,21,99.6,-349.4,99
k,22,89.2,-374.8,99
k,23,78.8,-400,99
k,24,68.4,-425.6,99
k,25,58,-451,99
k,26,58,-475,99
k,27,58,-487,99
k,28,103.537,-535,114.179
k,29,124.269,-535,121.1
k,30,145,-535,128
k,31,184.975,-535,123.615
k,32,214.8,-536,102.8
k,33,254.585,-535,81.849
k,34,279.312,-535,75
k,35,331,-535,75
k,36,383,-535,75

/com,
/com, Elastic support Keypoints
/com,***************************

k,37,10,0,0
k,38,0,10,0
k,39,0,0,10
k,40,55,70,49.5
k,41,110,0,109
k,42,120,0,99
k,43,110,-168,109
k,44,120,-168,109
k,45,110,-324,109
k,46,120,-324,99
k,47,58,-475,109
k,48,68,-475,99
k,49,103.537,-545,114.179
```

```
k,50,103.537,-535,104.179
k,51,393,-535,75
k,52,383,-545,75
k,53,383,-535,85


/com,
/com,  Forming the area
/com, *************************

k,101,midd,0,0
k,102,0,0,midd
k,103,-midd,0,0
k,104,0,0,-midd

larc,101,102,1,midd
larc,102,103,1,midd
larc,103,104,1,midd
larc,104,101,1,midd

lsel,s,line,,1,4,1
lesize,all,,,12
lsel,all

l,1,2,2

adrag,1,2,3,4,,,5

larc,2,3,4,RADCUR

adrag,6,13,11,9,,,14

l,3,4

adrag,18,15,22,20,,,23

l,4,5

adrag,24,31,29,27,,,32

larc,5,6,4,RADCUR

adrag,33,40,38,36,,,41

l,6,7

adrag,42,45,47,49,,,50

l,7,8

adrag,51,54,56,58,,,59

l,8,9

adrag,60,63,65,67,,,68

l,9,10

adrag,69,72,74,76,,,77


l,10,11

adrag,78,81,83,85,,,86

l,11,12

adrag,87,90,92,94,,,95

l,12,13

adrag,96,99,101,103,,,104
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l,13,14
adrag,105,108,110,112,,,113
l,14,15
adrag,114,117,119,121,,,122
l,15,16
adrag,123,126,128,130,,,131
/com, ***************************************
l,16,17
adrag,132,135,137,139,,,140
l,17,18
adrag,141,144,146,148,,,149
l,18,19
adrag,150,153,155,157,,,158
l,19,20
adrag,159,162,164,166,,,167
l,20,21
adrag,168,171,173,175,,,176
l,21,22
adrag,177,180,182,184,,,185
l,22,23
adrag,186,189,191,193,,,194
l,23,24
adrag,195,198,200,202,,,203
l,24,25
adrag,204,207,209,211,,,212
l,25,26
adrag,213,216,218,220,,,221
l,26,27
adrag,222,225,227,229,,,230
larch,27,28,26,RADCUR
adrag,231,234,236,238,,,239
l,28,29
adrag,240,243,245,247,,,248
l,29,30
adrag,249,252,254,256,,,257
larch,30,31,29,RADCUR
```

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adrag,258,261,263,265,,,266

l,31,32

adrag,267,270,272,274,,,275

l,32,33

adrag,276,279,281,283,,,284


larch,33,34,32,RADCUR           ! line number 35

adrag,285,288,290,292,,,293

l,34,35

adrag,294,297,299,301,,,302

l,35,36

adrag,303,306,308,310,,,311

allsel,all

lesize,all,,,10


/com,
/com,  Meshing the area
/com, ***************************

type,1
mat,1
secnum,1
shpp,off

amap,1,54,55,101,102
amap,2,55,56,102,103
amap,3,56,57,103,104
amap,4,54,57,101,104
amap,5,54,55,58,59
amap,6,55,56,59,60
amap,7,56,57,60,61
amap,8,54,57,58,61
amap,9,59,60,62,63
amap,10,60,61,63,64
amap,11,58,61,64,65
amap,12,58,59,62,65
amap,13,62,63,66,67
amap,14,63,64,67,68
amap,15,64,65,68,69
amap,16,62,65,66,69
amap,17,66,67,70,71
amap,18,67,68,71,72
amap,19,68,69,72,73
amap,20,66,69,70,73
amap,21,70,71,74,75
amap,22,71,72,75,76
amap,23,72,73,76,77
amap,24,70,73,74,77
amap,25,74,75,78,79
amap,26,75,76,79,80
amap,27,76,77,80,81
amap,28,74,77,78,81
amap,29,78,79,82,83
amap,30,79,80,83,84

amap,31,80,81,84,85
amap,32,78,81,82,85
amap,33,82,83,86,87
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amap,34,83,84,87,88
amap,35,84,85,88,89
amap,36,82,85,86,89
amap,37,86,87,90,91
amap,38,87,88,91,92
amap,39,88,89,92,93
amap,40,86,89,90,93
amap,41,90,91,94,95
amap,42,91,92,95,96
amap,43,92,93,96,97
amap,44,90,93,94,97
amap,45,94,95,98,99
amap,46,95,96,99,100
amap,47,96,97,100,105
amap,48,94,97,98,105
amap,49,98,99,106,107
amap,50,99,100,107,108
amap,51,100,105,108,109
amap,52,98,105,106,109
amap,53,106,107,110,111
amap,54,107,108,111,112
amap,55,108,109,112,113
amap,56,106,109,110,113
amap,57,110,111,114,115
amap,58,111,112,115,116
amap,59,112,113,116,117
amap,60,110,113,114,117

amap,61,114,115,118,119
amap,62,115,116,119,120
amap,63,116,117,120,121
amap,64,114,117,118,121
amap,65,118,119,122,123
amap,66,119,120,123,124
amap,67,120,121,124,125
amap,68,118,121,122,125
amap,69,122,123,126,127
amap,70,123,124,127,128
amap,71,124,125,128,129
amap,72,122,125,126,129
amap,73,126,127,130,131
amap,74,127,128,131,132
amap,75,128,129,132,133
amap,76,126,129,130,133
amap,77,130,131,134,135
amap,78,131,132,135,136
amap,79,132,133,136,137
amap,80,130,133,134,137
amap,81,134,135,138,139
amap,82,135,136,139,140
amap,83,136,137,140,141
amap,84,134,137,138,141
amap,85,138,139,142,143
amap,86,139,140,143,144
amap,87,140,141,144,145
amap,88,138,141,142,145
amap,89,142,143,146,147
amap,90,143,144,147,148
amap,91,144,145,148,149
amap,92,142,145,146,149
amap,93,146,147,150,151
amap,94,147,148,151,152
amap,95,148,149,152,153
amap,96,146,149,150,153
amap,97,150,151,154,155
amap,98,151,152,155,156
amap,99,152,153,156,157
amap,100,150,153,154,157


amap,101,154,155,158,159
amap,102,155,156,159,160
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amap,103,156,157,160,161
amap,104,154,157,158,161
amap,105,158,159,162,163
amap,106,159,160,163,164
amap,107,160,161,164,165
amap,108,158,161,162,165
amap,109,162,163,166,167
amap,110,163,164,167,168
amap,111,164,165,168,169
amap,112,162,165,166,169
amap,113,166,167,170,171
amap,114,167,168,171,172
amap,115,168,169,172,173
amap,116,166,169,170,173
amap,117,170,171,174,175
amap,118,171,172,175,176
amap,119,172,173,176,177
amap,120,170,173,174,177



amap,121,174,175,178,179
amap,122,175,176,179,180
amap,123,176,177,180,181
amap,124,174,177,178,181
amap,125,178,179,182,183
amap,126,179,180,183,184
amap,127,180,181,184,185
amap,128,178,181,182,185
amap,129,182,183,186,187
amap,130,183,184,187,188
amap,131,184,185,188,189
amap,132,182,185,186,189
amap,133,186,187,190,191
amap,134,187,188,191,192
amap,135,188,189,192,193
amap,136,186,189,190,193
amap,137,190,191,194,195
amap,138,191,192,195,196
amap,139,192,193,196,197
amap,140,190,193,194,197

shpp,on

/com,
/com, Defining MPC contacts
/com, **********************


/com, support at node 1

tshap,pilot
n,1000000,0,0,0
type,9
real,9
e,1000000

type,8
real,9
lsel,s,line,,1,4,1
nsll,s,1
esln,s
esurf
allsel,all


/com,  support at end node

tshap,pilot
n,1000001,383,-535,75
type,9
real,10
```

```
e,1000001

type,8
real,10
lsel,s,line,,312
lsel,a,line,,315
lsel,a,line,,317
lsel,a,line,,319
nsll,s,1
esln,s
esurf
allsel,all


/com,  support at key point 7

tshap,pilot
n,1000002,110,0,99
type,9
real,11
e,1000002

type,8
real,11
lsel,s,line,,51
lsel,a,line,,54
lsel,a,line,,56
lsel,a,line,,58
nsll,s,1
esln,s
esurf
allsel,all


/com,  support at key point 14

tshap,pilot
n,1000003,110,-168,99
type,9
real,12
e,1000003

type,8
real,12
lsel,s,line,,114
lsel,a,line,,117
lsel,a,line,,119
lsel,a,line,,121
nsll,s,1
esln,s
esurf
allsel,all

/com,  support at key point 20

tshap,pilot
n,1000004,110,-324,99
type,9
real,13
e,1000004

type,8
real,13
lsel,s,line,,168
lsel,a,line,,171
lsel,a,line,,173
lsel,a,line,,175
nsll,s,1
esln,s
esurf
allsel,all
```

```
/com,  support at key point 26

tshap,pilot
n,1000005,58,-475,99
type,9
real,14
e,1000005

type,8
real,14
lsel,s,line,,222
lsel,a,line,,225
lsel,a,line,,227
lsel,a,line,,229
nsll,s,1
esln,s
esurf
allsel,all

/com,  support at key point 28

tshap,pilot
n,1000006,103.537,-535,114.179
type,9
real,15
e,1000006

type,8
real,15
lsel,s,line,,240
lsel,a,line,,243
lsel,a,line,,245
lsel,a,line,,247
nsll,s,1
esln,s
esurf
allsel,all


/com,  support at key point 4

tshap,pilot
n,1000007,55,60,49.5
type,9
real,16
e,1000007

type,8
real,16
lsel,s,line,,24
lsel,a,line,,31
lsel,a,line,,29
lsel,a,line,,27
nsll,s,1
esln,s
esurf
allsel,all

/com, Nodes for elastic support
/com, ******************************

n,2000000,2,0,0
n,2000001,0,2,0
n,2000002,0,0,2

n,2000003,55,62,49.5

n,2000004,110,0,101

n,2000005,112,0,99

n,2000006,110,-168,101
```

```
n,2000007,112,-168,101

n,2000008,110,-324,101

n,2000009,112,-324,99

n,2000010,58,-475,101

n,2000011,60,-475,99

n,2000012,103.537,-537,114.179

n,2000013,103.537,-535,112.179

n,2000014,385,-535,75

n,2000015,383,-537,75

n,2000016,383,-535,77

/com, ****************************
/com,  Spring - damper elements
/com, ******************************

type,3
real,3

e,1000000,2000000
e,1000001,2000014
e,1000007,2000003
e,1000002,2000004
e,1000005,2000010
e,1000006,2000012

allsel,all,all

type,4
real,4

e,1000000,2000001
e,1000001,2000015
e,1000002,2000005
e,1000005,2000011
e,1000006,2000013

allsel,all,all

type,5
real,5

e,1000000,2000002
e,1000001,2000016

allsel,all,all

type,6
real,6

e,1000003,2000006
e,1000004,2000008

allsel,all,all

type,7
real,7

e,1000003,2000007
e,1000004,2000009

allsel,all,all
```

```
/com, rotate nodes with less than 3 supports
/com,

n,3000000,35.687,60,32.110

n1 = 1000007
n2 = 2000003
n3 = 3000000
ics = 11
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
csys,0


n1 = 1000002
n2 = 2000004
n3 = 2000005
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0


n1 = 1000003
n2 = 2000006
n3 = 2000007
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 1000004
n2 = 2000008
n3 = 2000009
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 1000005
n2 = 2000010
n3 = 2000011
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0

n1 = 1000006
n2 = 2000012
n3 = 2000013
ics = ics + 1
wplane,,nx(n1),ny(n1),nz(n1),nx(n2),ny(n2),nz(n2),nx(n3),ny(n3),nz(n3)
cswplane,ics,0
nrotat,n1
nrotat,n2
nrotat,n3
csys,0
```

```
allsel,all,all



/com,
/com, Constraints
/com,*************

nsel,,node,,2000000,2000016
d,all,all
allsel

nsel,s,node,,1000000

d,all,rotx,0
d,all,roty,0
d,all,rotz,0
allsel,all

nsel,s,node,,1000001

d,all,rotx,0
d,all,roty,0
d,all,rotz,0
allsel,all

finish

/com,------------------------------------------------------------------------------

/com
/com,==============
/com, Modal solve
/com,==============
/com,

/solution
antype,modal   ! Perform ModalAnalysis
modopt,lanb,maxm   ! Use LANB eigensolver
lumpm,on    ! Use Lumped Mass Approximation
mxpand,maxm,,,yes   ! Expand all modes
solve
finish

/post1
set,list    ! List Frequencies obtained from Modal Solve
/show,jpeg
/eshape,0
/efacet,2
/view,1,1,2,3
/ang,1
/auto,1
/graphics,power
eplot
/replot
set,1,1
plnsol,u,sum
set,1,2
plnsol,u,sum
set,1,3
plnsol,u,sum
set,1,4
plnsol,u,sum
set,1,5
plnsol,u,sum
set,1,6
plnsol,u,sum
set,1,7
plnsol,u,sum
set,1,8
plnsol,u,sum
```

```
set,1,9
plnsol,u,sum
set,1,10
plnsol,u,sum
set,1,11
plnsol,u,sum
set,1,12
plnsol,u,sum
set,1,13
plnsol,u,sum
set,1,14
plnsol,u,sum
set,1,15
plnsol,u,sum
finish


/com,------------------------------------------------------------------------

/com,
/com,==================
/com, Spectrum solve
/com,==================
/com,

/solution
antype,spectrum    ! Perform Spectrum Analysis
spopt,sprs,15    ! Single Point Response Spectrum Analysis
srss,0.0     ! SRSS mode combination

gval = 386.4

svtyp, 2, gval    ! Seismic Acceleration Response Loading
freq, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83,  23.25,  29.41
sv,,  2.275, 2.275,  1.0,    0.8,  0.925,  0.925,   0.8 ,   1.0 ,    1.0
freq,  34.48
sv,,   0.875
sed,1,0,0     ! Excitation in X direction
solve

svtyp, 2, gval    ! Seismic Acceleration Response Loading
freq
freq, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83,  23.25,  29.41
sv,, 1.517, 1.517, 0.667,  0.534,  0.617,  0.617,   0.534, 0.667,  0.667
freq,  34.48
sv,,   0.584
sed,0,1,0     ! Excitation in Y direction
SOLVE
finish

/com,--------------------------------------------------------------------------

/post1
/input,281,mcom

/com, *======================================================
/com, * Displacement Sum and Equivalent Stress
/com, *========================================================
/auto,1
plnsol,u,sum
*get,umax,plnsol,0,max
*get,umin,plnsol,0,min
plnsol,s,eqv
*get,smax,plnsol,0,max
*get,smin,plnsol,0,min
/show,close
*stat,umax
*stat,umin
*stat,smax
*stat,smin
finish
```

```
/exit,nosave
```

demonstration-problem3-16-18 Input Listing

```
/batch,list
/verify,demonstration_problem3_16_18
JPGPRF,500,100,1
/title,Piping model meshed with PIPE16 and PIPE18 elements
/filname,16-18

/PREP7
YoungModulus1 = .258e+8                        ! Young's Modulus
Nu = 0.3                                       ! Poissons ratio
ShearModulus1 = YoungModulus1/(2*(1+Nu))       ! Shear Modulus
WMass=1.042868e-03                             ! Density
WTick=0.216                                    ! Wall Thickness
OD=3.5                                         ! Outer Diameter
RADCUR=48.003                                  ! Radius curvature
temp=60                                        ! Temperature
maxm=15                                        ! Number of modes to extract


et,1,pipe16                                    ! Straight pipe elements
et,2,pipe18                                    ! Curved pipe elements
et,3,combin14                              ! Spring-damper elements
keyopt,3,2,1                                   ! UX Degree Of Freedom
et,4,combin14,                                 ! Spring-damper elements
keyopt,4,2,2                                   ! UY Degree Of Freedom
et,5,combin14                              ! Spring-damper elements
keyopt,5,2,3                                   ! UZ Degree Of Freedom
et,6,combin14                                  ! Spring-damper elements
keyopt,6,2,1                                   ! UX Degree Of Freedom
et,7,combin14                                  ! Spring-damper elements
keyopt,7,2,2                                   ! UY Degree Of Freedom


/com,
/com, Real Constants
/com,****************

r,1,OD,WTick
r,2,OD,WTick,RADCUR
r,3,0.2e+8                                     ! Stiffness
r,4,0.2e+8                                     ! Stiffness
r,5,0.2e+8                                     ! Stiffness
r,6,0.2e+5                                     ! Stiffness
r,7,0.2e+5                                     ! Stiffness


/com,----------------------------------------------------------------------------

/com,
/com, Material Properties
/com,*********************

mp,ex,1,YoungModulus1
mp,nuxy,1,Nu
mp,gxy,1,ShearModulus1
mp,dens,1,WMass

mp,ex,2,YoungModulus1
mp,nuxy,2,Nu
mp,gxy,2,ShearModulus1
mp,dens,2,WMass

/com,----------------------------------------------------------------------------

/com, Nodes
/com,********
```

```
n,1,0,0,0
n,2,0,12,0
n,3,35.687,60,32.110
n,4,55,60,49.5
n,5,74.329,60,66.882
n,6,110,12,99
n,7,110,0,99
n,8,110,-24,99,
n,9,110,-48,99,
n,10,110,-72,99
n,11,110,-96,99
n,12,110,-120,99
n,13,110,-144,99
n,14,110,-168,99
n,15,110,-198,99
n,16,110,-228,99
n,17,110,-252,99
n,18,110,-276,99
n,19,110,-300,99
n,20,110,-324,99
n,21,99.6,-349.4,99
n,22,89.2,-374.8,99
n,23,78.8,-400,99
n,24,68.4,-425.6,99
n,25,58,-451,99
n,26,58,-475,99
n,27,58,-487,99
n,28,103.537,-535,114.179
n,29,124.269,-535,121.1
n,30,145,-535,128
n,31,184.975,-535,123.615
n,32,214.8,-536,102.8
n,33,254.585,-535,81.849
n,34,279.312,-535,75
n,35,331,-535,75
n,36,383,-535,75

/com,
/com, Elastic support Nodes
/com,***********************

n,37,10,0,0
n,38,0,10,0
n,39,0,0,10
n,40,55,70,49.5
n,41,110,0,109
n,42,120,0,99
n,43,110,-168,109
n,44,120,-168,109
n,45,110,-324,109
n,46,120,-324,99
n,47,58,-475,109
n,48,68,-475,99
n,49,103.537,-545,114.179
n,50,103.537,-535,104.179
n,51,393,-535,75
n,52,383,-545,75
n,53,383,-535,85

/com,-----------------------------------------------------------------------------

/com,
/com, Straight Pipe (Tangent) Elements
/com,*********************************

mat,1        ! Material ID 1
type,1       ! Element Type 1
real,1       ! Real Constant 1

e, 1, 2
e, 3, 4
```

```
e, 4, 5
e, 6, 7
e, 7, 8
e, 8, 9
e, 9,10
e,10,11
e,11,12
e,12,13
e,13,14
e,14,15
e,15,16
e,16,17
e,17,18
e,18,19
e,19,20
e,20,21
e,21,22
e,22,23
e,23,24
e,24,25
e,25,26
e,26,27
e,28,29
e,29,30
e,31,32
e,32,33
e,34,35
e,35,36

/com,
/com, Pipe Bend Elements
/com,*******************

mat,2
type,2
real,2

e,2,3,4
e,5,6,4
e,27,28,26
e,30,31,29
e,33,34,32


/com, Elastic supports and anchors
/com,******************************

/com, rotate nodes with less than 3 supports
/com,

wplane,,nx(4),ny(4),nz(4),nx(40),ny(40),nz(40),nx(3),ny(3),nz(3)
cswplane,11,0
nrotat,4
nrotat,40
csys,0

wplane,,nx(7),ny(7),nz(7),nx(41),ny(41),nz(41),nx(42),ny(42),nz(42)
cswplane,12,0
nrotat,7
nrotat,41,42
csys,0

wplane,,nx(14),ny(14),nz(14),nx(43),ny(43),nz(43),nx(44),ny(44),nz(44)
cswplane,13,0
nrotat,14
nrotat,43,44
csys,0

wplane,,nx(20),ny(20),nz(20),nx(45),ny(45),nz(45),nx(46),ny(46),nz(46)
cswplane,14,0
nrotat,20
nrotat,45,46
```

```
csys,0

wplane,,nx(26),ny(26),nz(26),nx(47),ny(47),nz(47),nx(48),ny(48),nz(48)
cswplane,15,0
nrotat,26
nrotat,47,48
csys,0

wplane,,nx(28),ny(28),nz(28),nx(49),ny(49),nz(49),nx(50),ny(50),nz(50)
cswplane,16,0
nrotat,28
nrotat,49,50
csys,0

type,3
real,3
e,1,37
e,36,51
e,4,40
e,7,41
e,26,47
e,28,49

type,4
real,4
e,1,38
e,36,52
e,7,42
e,26,48
e,28,50

type,5
real,5
e,1,39
e,36,53

type,6
real,6
e,14,43
e,20,45

type,7
real,7
e,14,44
e,20,46

/com,-------------------------------------------------------------------------

/com,
/com, Constraints
/com,*************

nsel,,node,,37,53
d,all,all
allsel

d,1,rotx,,,,,roty,rotz
d,36,rotx,,,,,roty,rotz
allsel,all
fini

/com,-------------------------------------------------------------------------

/com
/com,==============
/com, Modal solve
/com,==============
/com,

/solution
antype,modal       ! Perform Modal Analysis
modopt,lanb,maxm
```

```
lumpm,on        ! Use Lumped Mass Approximation
mxpand,maxm,,,yes       ! Expand solution with Element Calculations ON
solve
finish


/post1
set,list        ! Frequencies obtained from Modal Solution
/show,jpeg
/eshape,5
/efacet,2
/view,1,1,2,3
/ang,1
/auto,1
/graphics,power
eplot
/replot
set,1,1
plnsol,u,sum
set,1,2
plnsol,u,sum
set,1,3
plnsol,u,sum
set,1,4
plnsol,u,sum
set,1,5
plnsol,u,sum
set,1,6
plnsol,u,sum
set,1,7
plnsol,u,sum
set,1,8
plnsol,u,sum
set,1,9
plnsol,u,sum
set,1,10
plnsol,u,sum
set,1,11
plnsol,u,sum
set,1,12
plnsol,u,sum
set,1,13
plnsol,u,sum
set,1,14
plnsol,u,sum
set,1,15
plnsol,u,sum
finish


/com,---------------------------------------------------------------------------

/com,
/com,==================
/com, Spectrum solve
/com,==================
/com,

/solution
antype,spectrum       ! Perform Spectrum Analysis
spopt,sprs,15       ! Single Point Excitation Response Spectrum
srss,0.0        ! SRSS mode combination

gval = 386.4

svtyp, 2, gval       ! Seismic Acceleration Response Loading
freq, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83,  23.25,  29.41
sv,,  2.275, 2.275,  1.0,    0.8,  0.925,  0.925,   0.8 ,   1.0 ,    1.0
freq,  34.48
sv,,   0.875
sed,1,0,0        ! Excitation in X direction
SOLVE
```

```
svtyp, 2, gval       ! Seismic Acceleration Response Loading
freq
freq, 2.5  , 5.0  ,  8.0,  12.35,  13.51,  16.95,  20.83,  23.25,  29.41
sv,, 1.517, 1.517, 0.667,  0.534,  0.617,  0.617,   0.534, 0.667,  0.667
freq,  34.48
sv,,   0.584
sed,0,1,0        ! Excitation in Y direction
SOLVE
fini

/com,------------------------------------------------------------------------

/post1
avprin,,0.3
/input16-18,,mcom

/com, *=====================================================
/com, * Displacements Sum and Equivalent Stress
/com, *=======================================================
/auto,1
plnsol,u,sum
*get,umax,plnsol,0,max
*get,umin,plnsol,0,min
plnsol,s,eqv
*get,smax,plnsol,0,max
*get,smin,plnsol,0,min
/show,close
*stat,umax
*stat,umin
*stat,smax
*stat,smin
finish
/exit,nosave
```