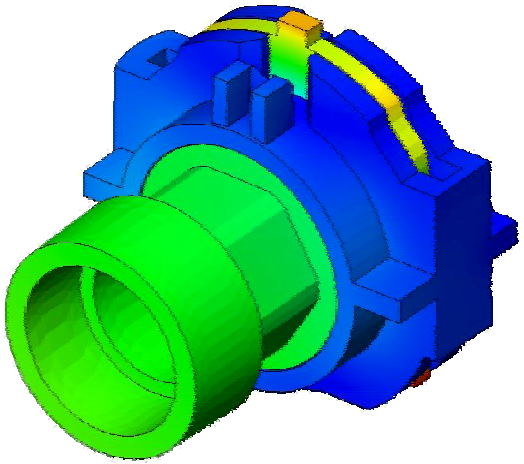
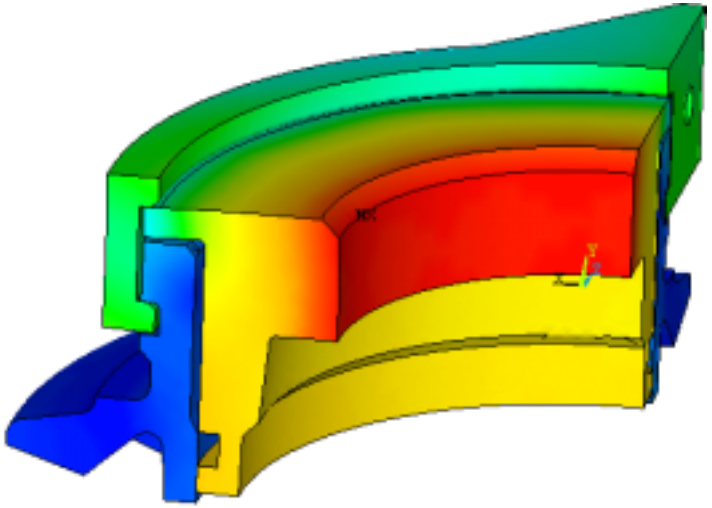
IMPACT
ENGINEERING SOLUTIONS, INC.

Techniques for Successfully Using ANSYS Contact Elements





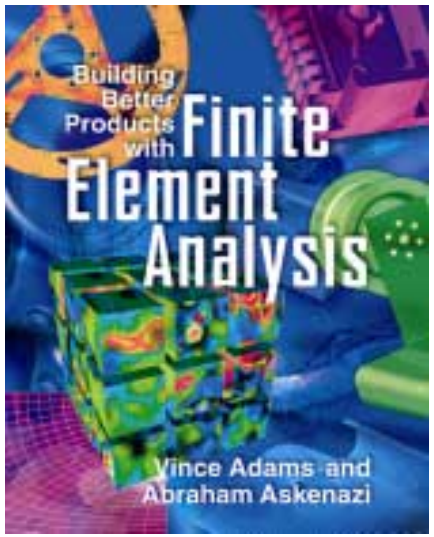
Presented by:

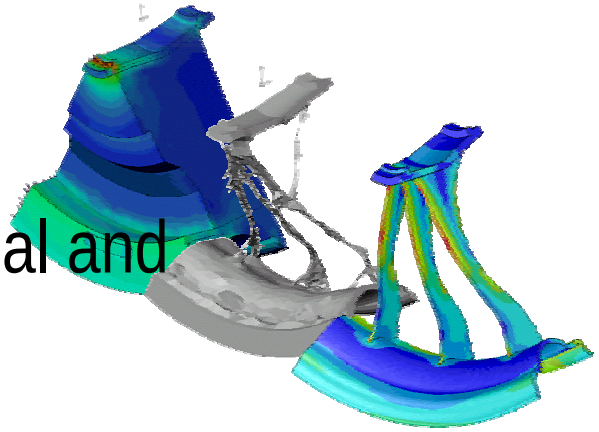
Rich Bothmann
IMPACT Engineering Solutions, Inc.
Brookfield, WI
Tel: 847-265-4140
www.impactengsol.com

IMPACT
ENGINEERING SOLUTIONS, INC.

Analysis Services Group

- Advanced FE Project Support and Education
- Local and International Recognition for Educational Offerings
  - Vince Adams & Rich Bothmann
- Over 25 Years Experience in Use, Training, and Support of FEA
- Active in Leadership of Local, National and International User's Groups

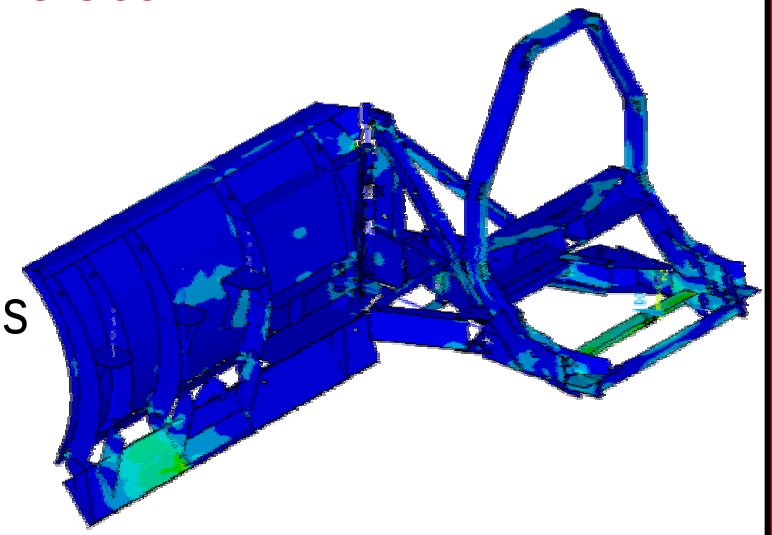




IMPACT
ENGINEERING SOLUTIONS, INC.

Analysis Capabilities and Expertise

- ANSYS
  - **Extensive experience in linear, nonlinear ,and dynamics**
  - **Certified instructor for local reseller**
  - **In conjunction with ANSYS, founding Midwest ANSYS UG**
- LS-DYNA – Drop and Crash Testing
- MSC.NASTRAN
- ComosWorks & CosmosMotion
- FE-Fatigue (nCode) Durability Analysis
- FEMAP Pre & Post-Processing
- Pro/MECHANICA



Extensive combined engineering analysis experience in a variety of materials and industries

IMPACT
ENGINEERING SOLUTIONS, INC.

What is Nonlinear Behavior…

- A Structure Is Nonlinear If the Loading Causes Significant Change in Stiffness
  - Strains Beyond Elastic Limit
  - Large Deflections (Fishing Pole)
  - Contact Between Two Bodies

IMPACT
ENGINEERING SOLUTIONS, INC.

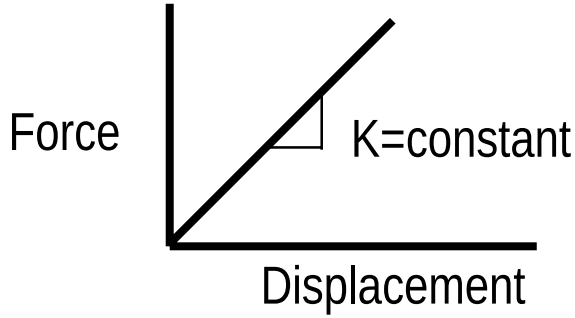
Types of Nonlinearities…

Nonlinear Analysis

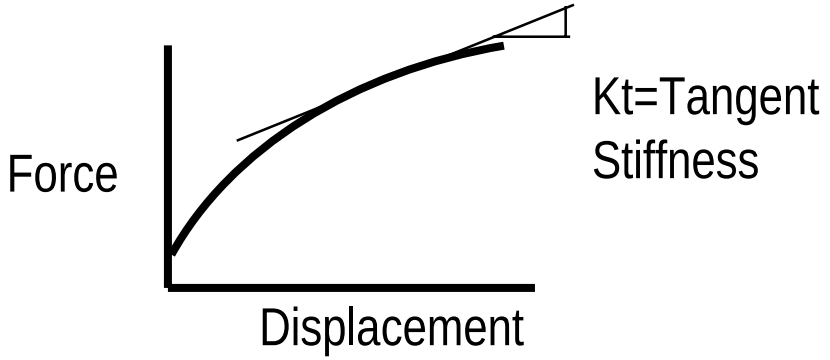
Material	Geometric	Boundary
Nonlinear Elastic	Large Displacement	Contact
Plastic	• *Small Rotation/Small Strain*	Follower Forces
Hyperelastic	• *Large Rotation/Small Strain*	
	• *Large Strain*	
	• *Geometrically Instable or Multi-Stable*	

Linear vs. Nonlinear Behavior…

- Linear structure obeys this linear relationship



- Many problems do not have a linear relationship and instead the displacement varies with force



Solving Nonlinear Problems…

- Newton-Raphson method iterates to a solution using the equation:

$$[K^T]\{\Delta u\} = \{F\} - \{F^{nr}\}$$

where :

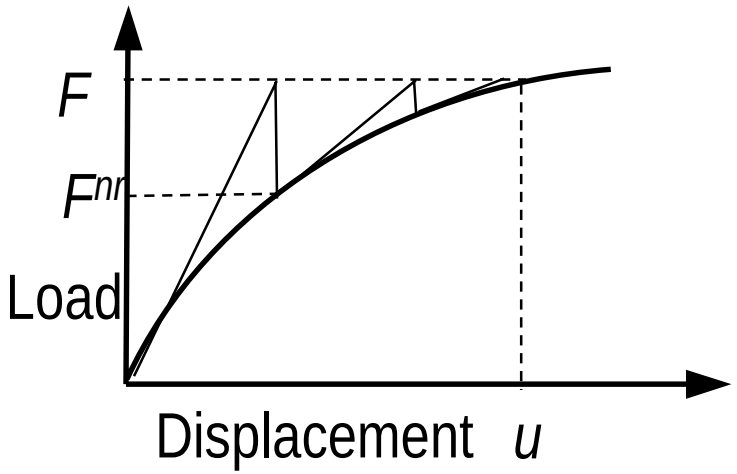
$[K^T]$ = Tangent Stiffness Matrix

$\{\Delta u\}$ = Displacement Increment

$\{F\}$ = Applied Force Vector

$\{F^{nr}\}$ = Internal Force Vector

(sum of element stresses)



170 Series Contact Element

- Conta171/172 – 2D/3D 4 Node (surface to surface)
- Conta173/174 – 2D/3D 4 Node (surface to surface)
- Conta175 – Node to Surface (line/point to surface)
- Conta178 – Node to Node

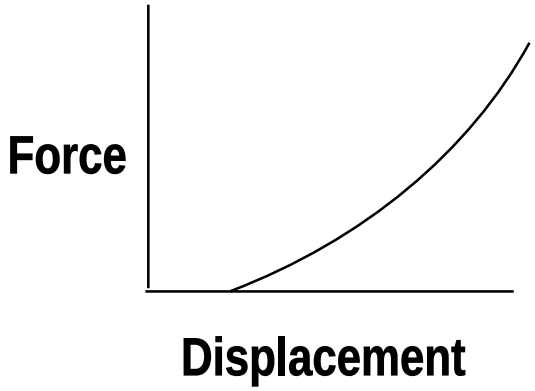
Primary Contact Algorithms (Keyopt 2)

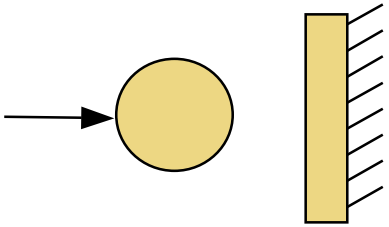
- Penalty: penalty springs
- Augmented Lagrangian: penalty springs + pressure dofs
- Lagrangian: zero penetration enforced
- Penalty/Lagrangian: zero penetration normal / penalty spring tangential

Contact Nonlinearities & the Penalty Approach

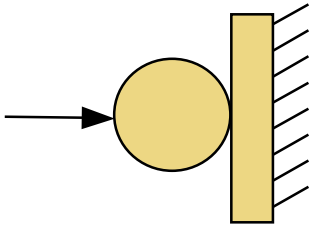
Contact Problems are Usually Hardening Structures

- More Difficult to Analyze
- Prone to Slow or Unsuccessful Convergence

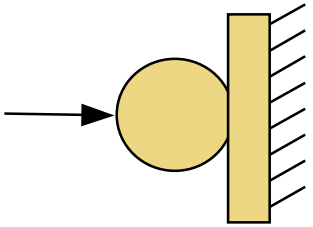




No Force is Required to Move the Sphere

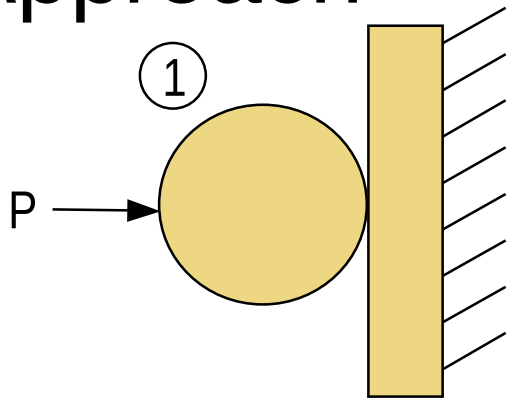


Some Force is Required to Move the Sphere

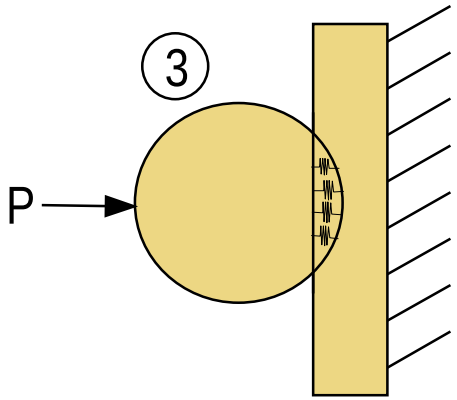


More Force is Required to Move the Sphere

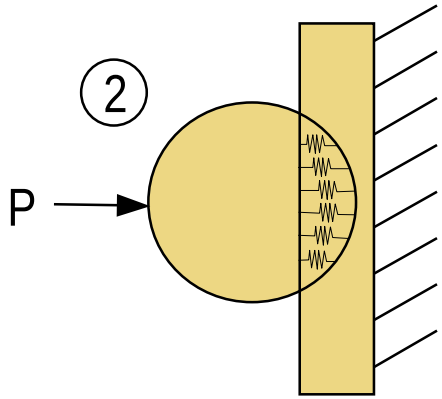
Contact Nonlinearities & the Penalty Approach



Initial Stiffness is Low

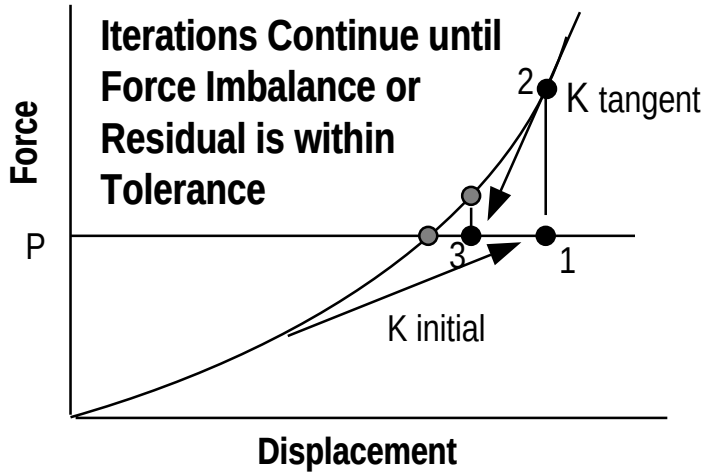


Tangent Modulus will Decrease Displacements



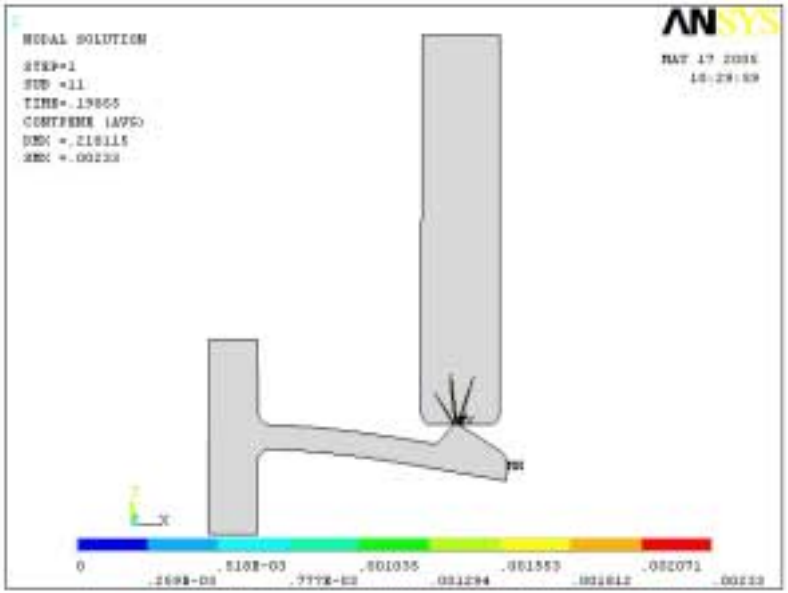
Results in Significant Interpenetration and Large Internal Forces

Iterations Continue until Force Imbalance or Residual is within Tolerance

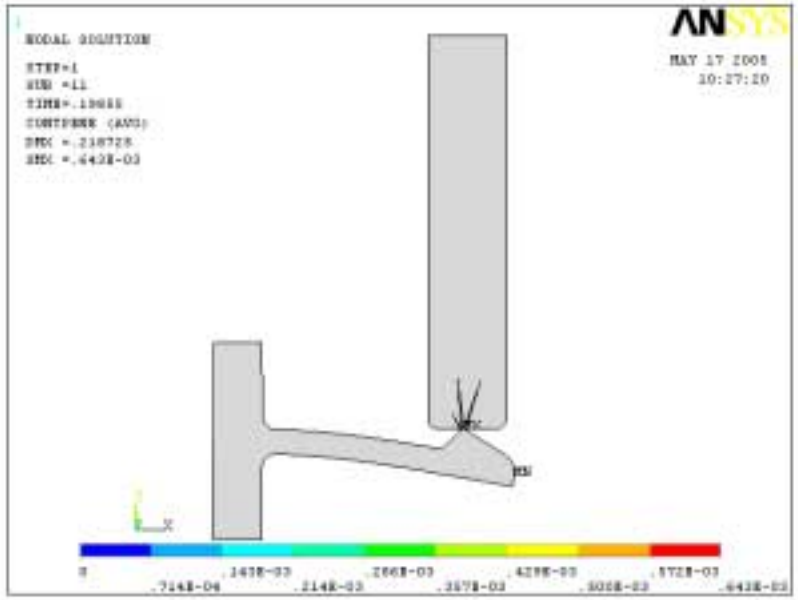


IMPACT
ENGINEERING SOLUTIONS, INC.

Penalty vs. Augmented Lagrangian,



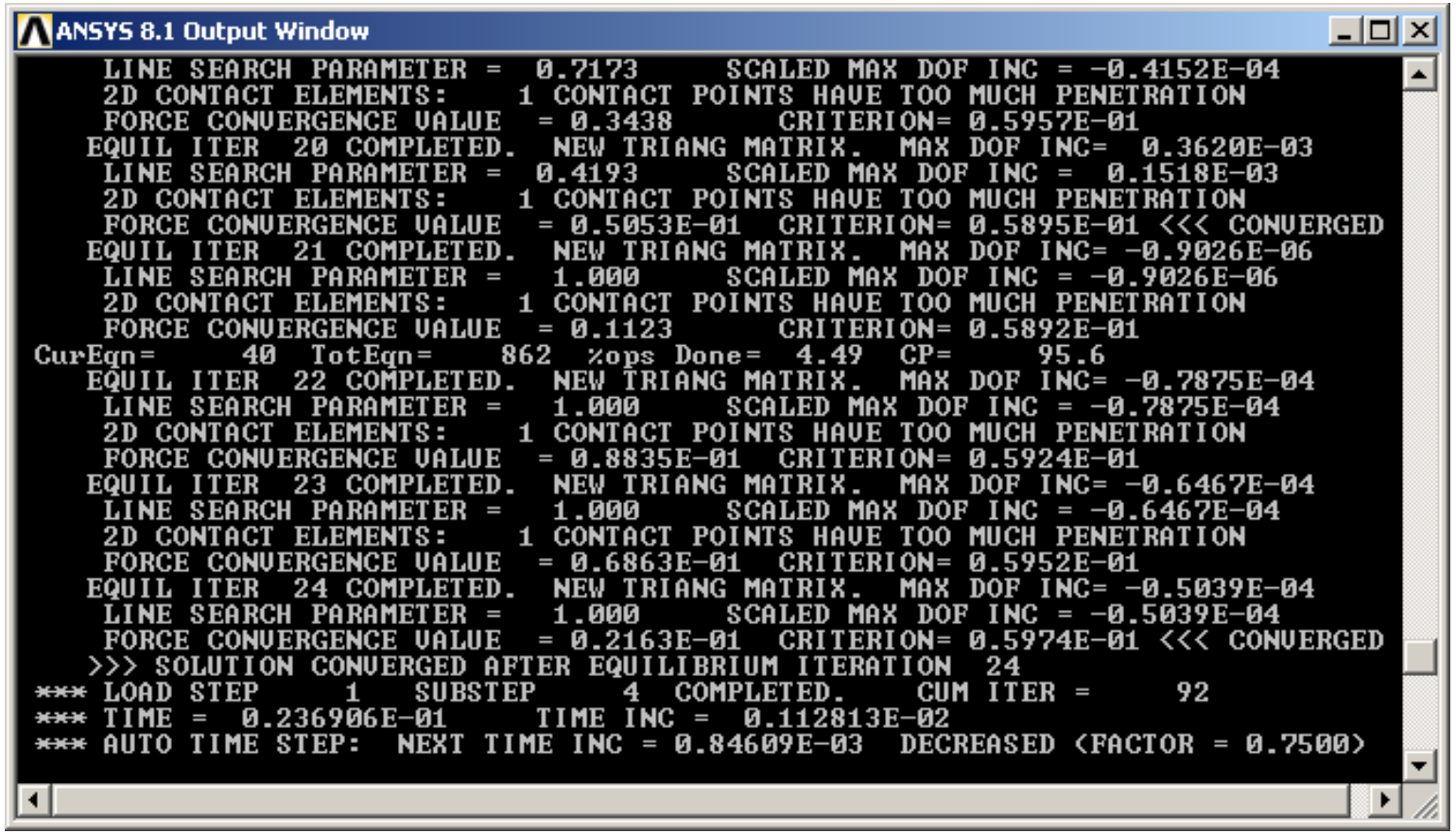
Penalty Method
74 Iterations
0.00233 in of penetration



Augmented Lagrangian Method
88 Iterations
0.00064 in of penetration

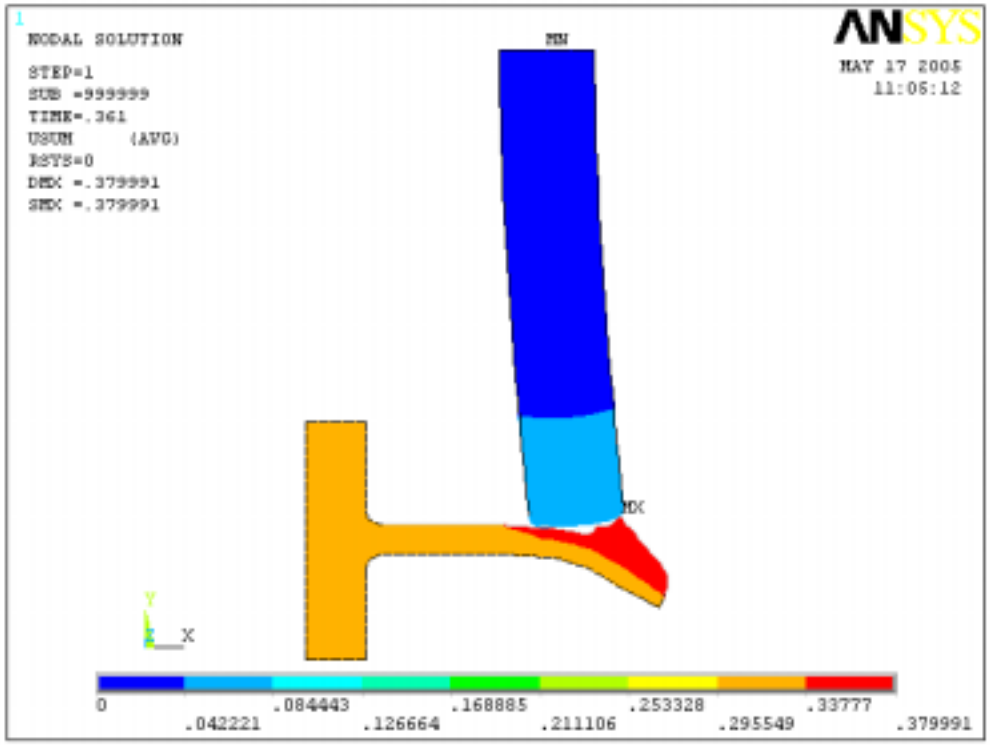
IMPACT
ENGINEERING SOLUTIONS, INC.

Penalty vs. Augmented Lagrangian



IMPACT
ENGINEERING SOLUTIONS, INC.

Pure Lagrange



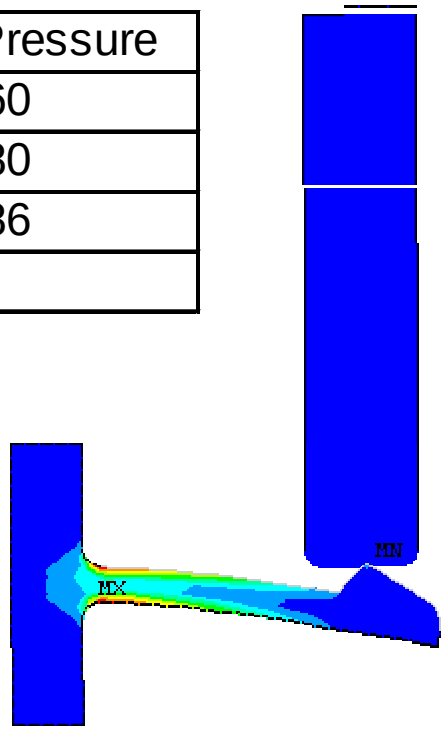
Pure Lagrange Never Converged >230 iterations, Distorted Element Errors

Dealing with Convergence Issues

- Penalty Stiffness (FKN)
  - Default=1, Start with something small
  - Stiffness Update (KEYOPT 10)
    - 0, each load step
    - 1, each substep
    - 2, each iteration
- Penetration Tolerance (FTOLN)
  - If penalty stiffness decreased, consider increasing FTOLN

Stress vs. FKN

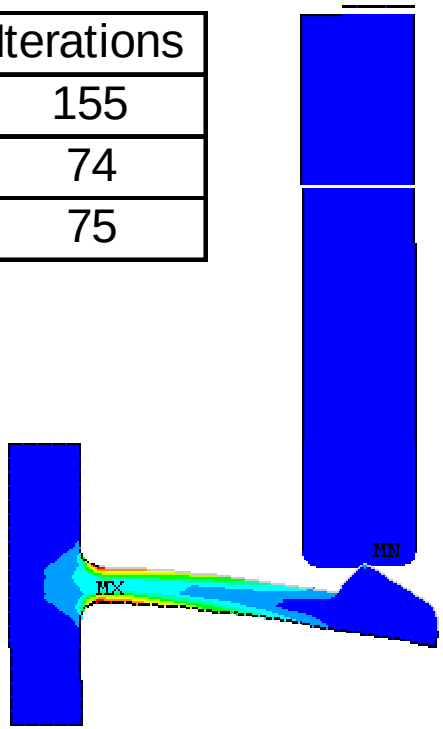
FKN	Iterations	Max Stress	Contact Pressure
0.001	426	19217	4160
0.01	74	19173	3880
0.1	213	19527	4886
1	Didn't Converge		



IMPACT
ENGINEERING SOLUTIONS, INC.

Stiffness Update vs. Iterations

Keyopt 10	Description	Iterations
0	Update Each Loadstep (old default)	155
1	Update Each Substep (new default)	74
2	Update Each Iteration	75



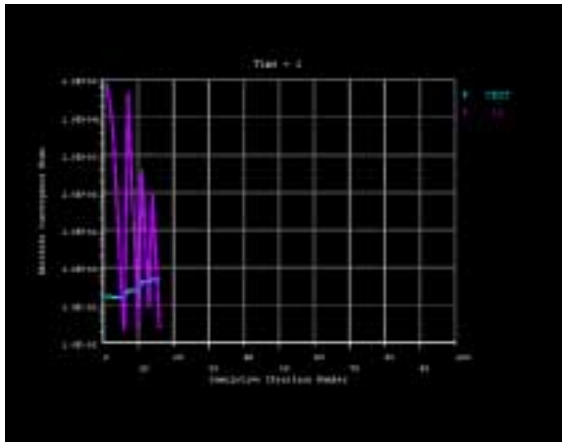
IMPACT
ENGINEERING SOLUTIONS, INC.

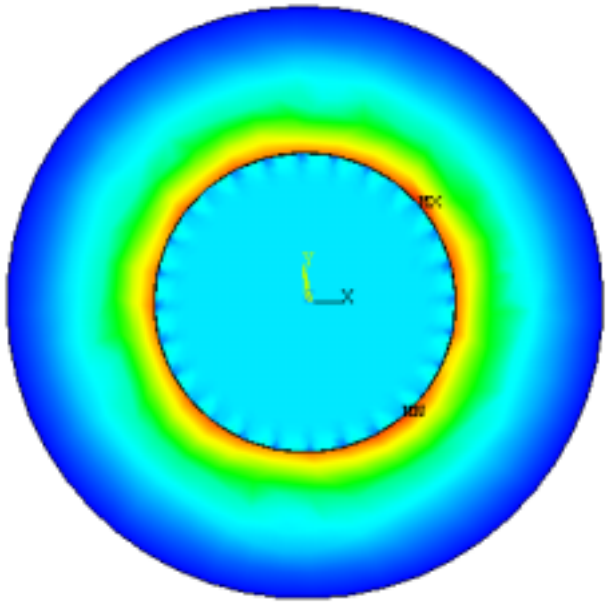
Other Convergence Issues…

- Too much initial penetration
  - KEYOPT 9 = 1, excludes initial penetration
    = 2, ramps initial penetration
- Rigid Motion
  - Parts not initially touching
  - Relying on contact to hold parts together usually results in convergence problems
  - Many Techniques to deal with this issue, sometimes problems requires more than one method.

Interference Problems…

Set Keyopt 9 = 2





IMPACT
ENGINEERING SOLUTIONS, INC.

Eliminating Rigid Motion…

- Build Geometry so it is Just Touching
- Adjust Initial Contact Conditions
- Displacement Control
- Weak (or not so weak) Springs (or possibly FKOP)
- Include Friction
- Dynamics
- CNCHECK/ADJUST (New)

IMPACT
ENGINEERING SOLUTIONS, INC.

Automated Adjustment of Initial Contact Conditions …

- KEYOPT 5 = 1-3, Close Gap/Reduce Penetration (Auto CNOF)
  = 4, Offset individual nodes to target surface (ICONT)
- CNCHECK/ADJUST: Use CNCHECK to determine if gap or penetration exists.

IMPACT
ENGINEERING SOLUTIONS, INC.

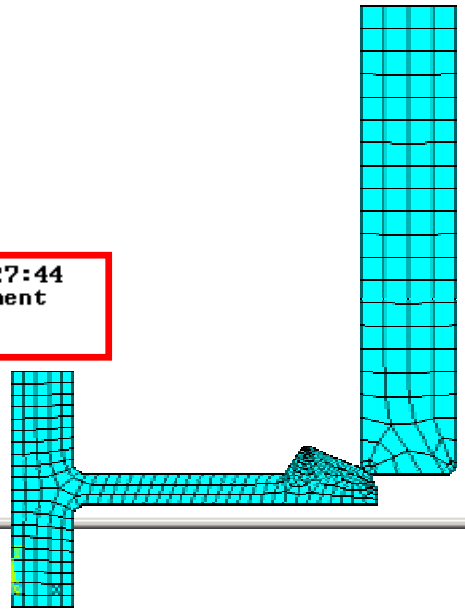
Checking Contact Conditions…

Issue CNCHECK to Determine Contact Status

CNCHECK Command

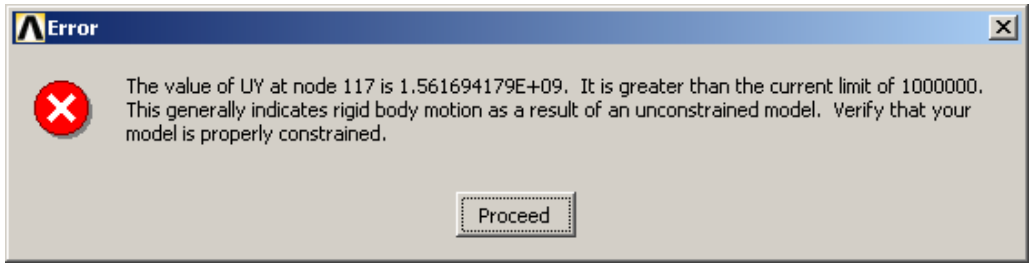
File

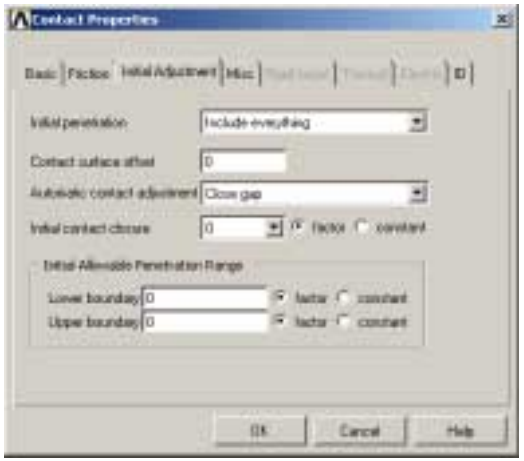
```
*** NOTE ***                            CP=     32.312   TIME= 09:27:44
Deformable-deformable contact pair identified by real constant set 3
and contact element type 3 has been set up.
Contact algorithm: Augmented Lagrange method
Contact detection at: Gauss integration point
Contact stiffness factor FKN                  0.10000E-01
The resulting contact stiffness               0.12487E+08
Penetration tolerance factor FTOLN            0.10000
The resulting penetration tolerance           0.16017E-02
Frictionless contact pair is defined
Update contact stiffness for each sub-load step
Average contact surface length                0.13918E-01
Average contact pair depth                    0.16017E-01
Default pinball region factor PINB             1.0000
The resulting pinball region                  0.16017E-01
Auto contact offset used to close gap         0.71399E-03
*WARNING*: Initial penetration is included.

*** NOTE ***                            CP=     32.312   TIME= 09:27:44
Min.  Initial gap 7.069245763E-04 was detected between contact element
389 and target element 367.
The gap is closed due to initial adjustment.
*****************************************


1 CONTACT PAIR IS SELECTED
    CONTACT PAIR HAVING REAL ID =     3 IS INITIALLY OPEN
     BUT MAY BE AUTOMATICALLY CLOSED
```

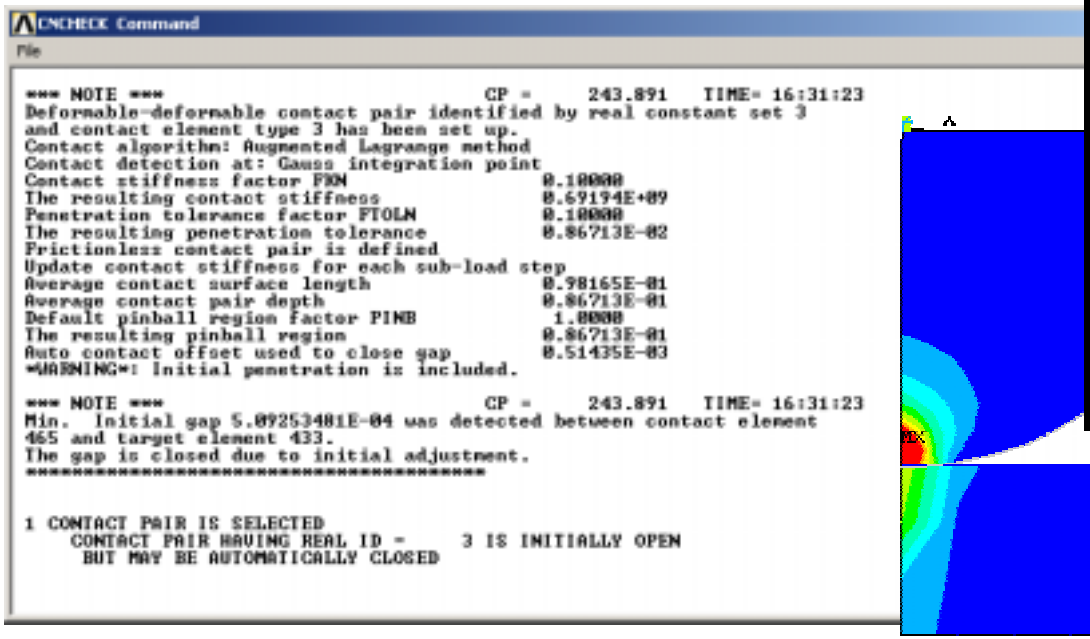


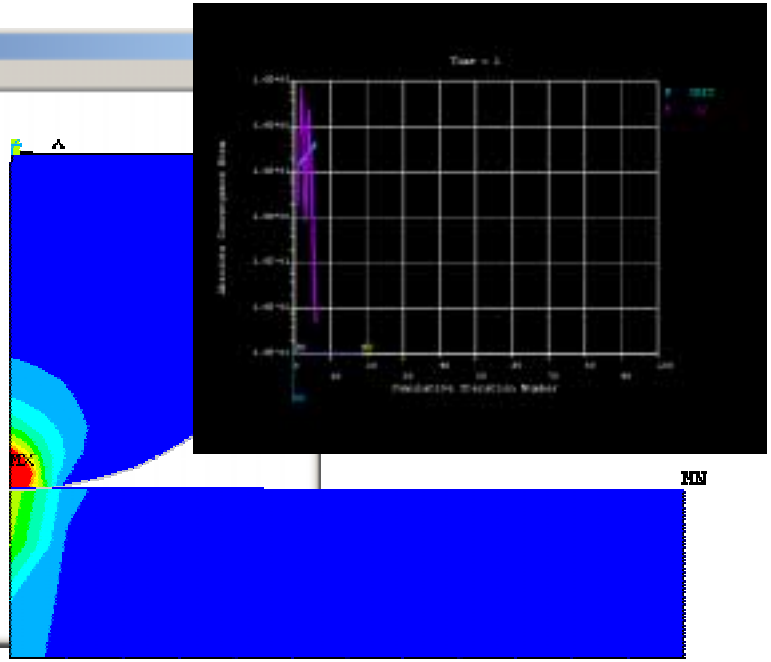
IMPACT
ENGINEERING SOLUTIONS, INC.

Using Auto CNOF…







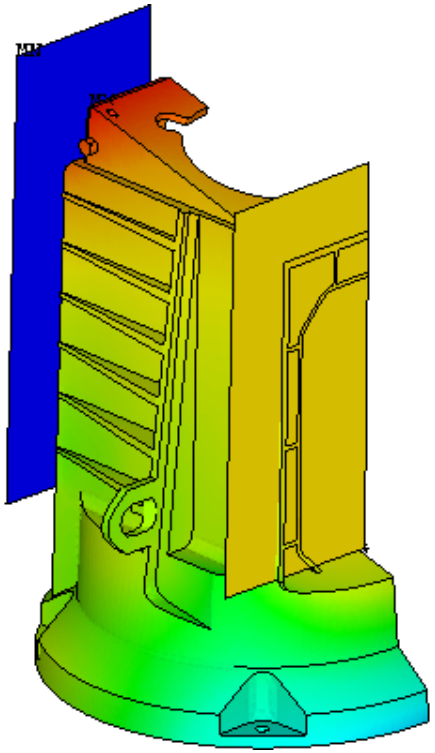


Displacement Control…

- Very Robust and Most Used Method
- Use Alone or with Subsequent Force Control
  - Apply displacement control and obtain solution
  - Replace displacement with reaction load and obtain solution
  - Apply final load and obtain solution

IMPACT
ENGINEERING SOLUTIONS, INC.

Displacement Control Examples…

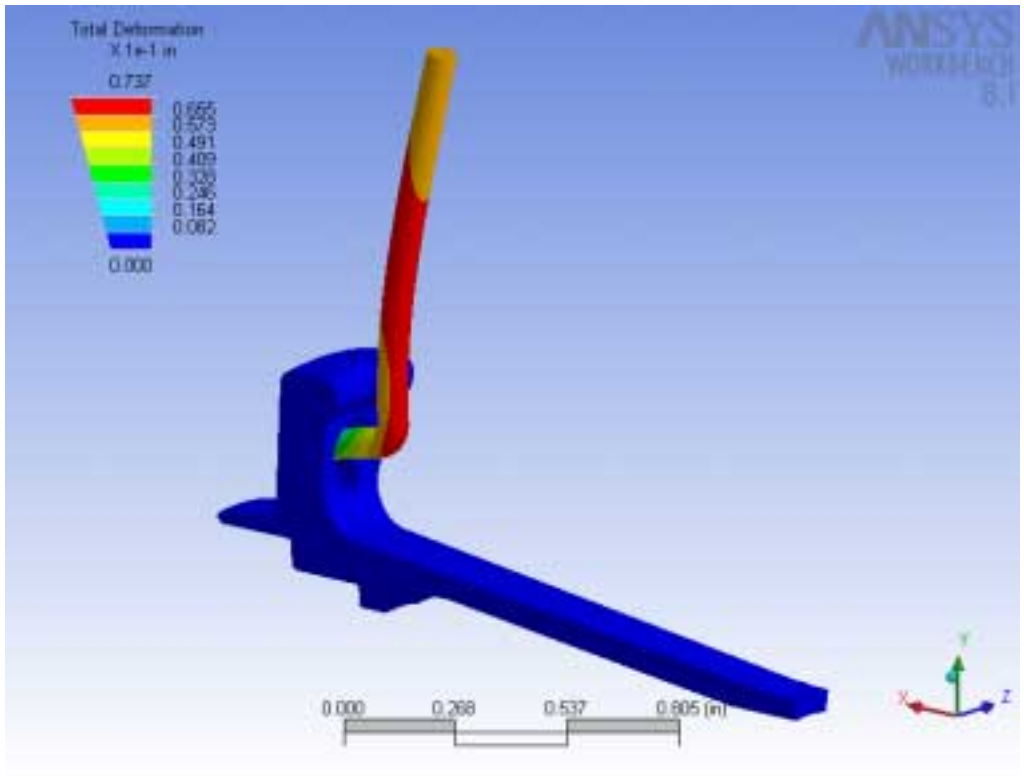


Click to Animate

Displacement Control Used for Crush Tests

IMPACT
ENGINEERING SOLUTIONS, INC.

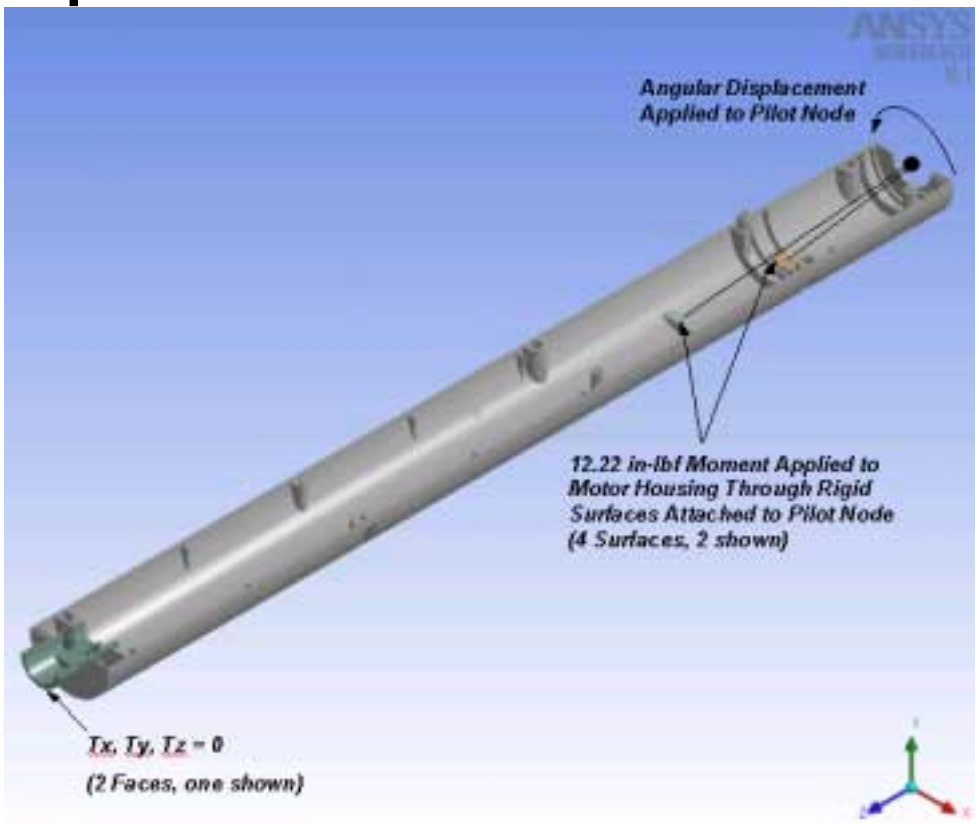
Displacement Control Examples…



1. ***Apply UY***
2. ***Replace UY with Reaction***
3. ***Apply Final Load***

Displacement Control Used in Conjunction with Force Control

Displacement Control Examples…



1. ***Apply RY***
2. ***Replace RY with Reaction***
3. ***Apply Final Moment***

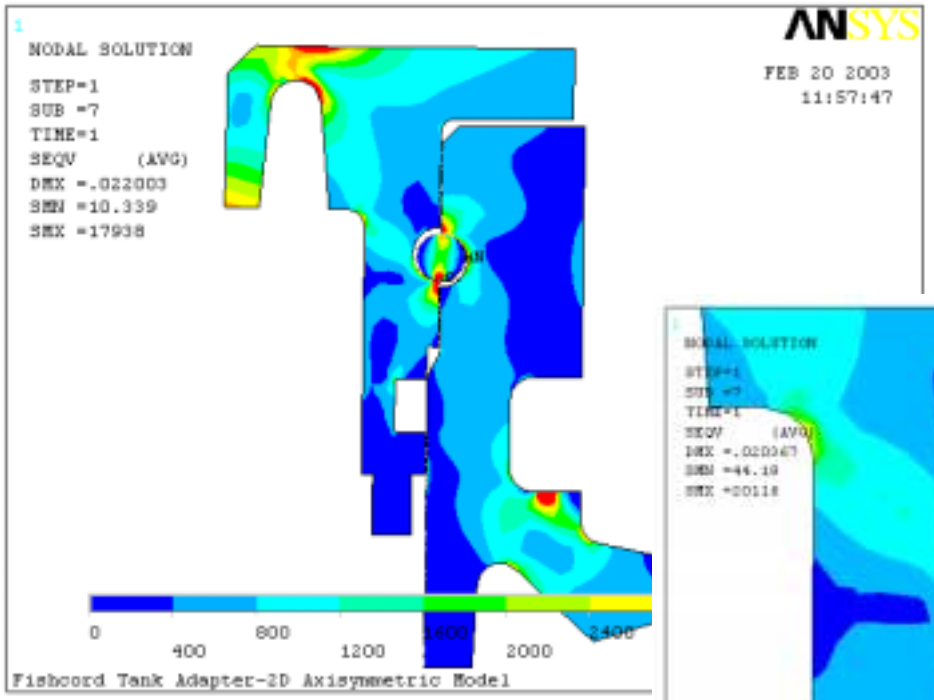
Displacement Control Used in Conjunction with Force Control

Weak Springs…

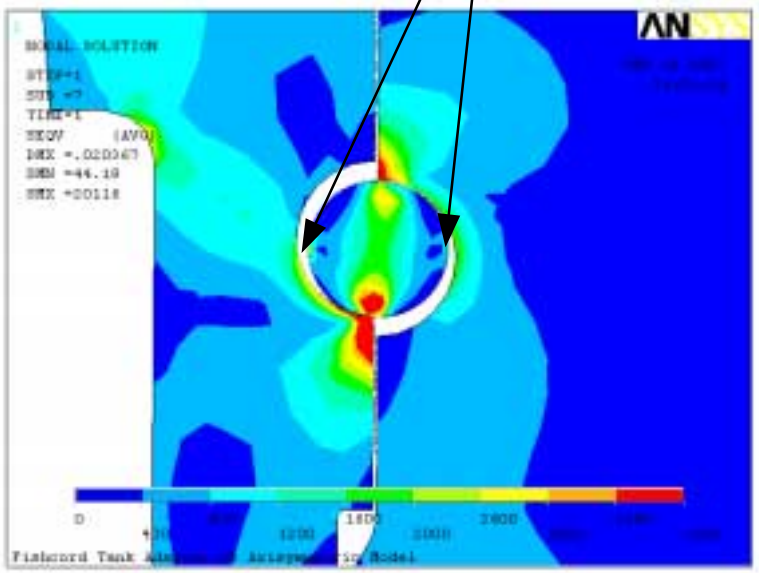
- Small amount of stiffness to prevent parts from flying off into space.
- Springs can attach parts to one another or to ground.
- Adjust stiffness values so that springs don't impact results.
- For complicated assemblies, consider using multiple real sets for different springs.

IMPACT
ENGINEERING SOLUTIONS, INC.

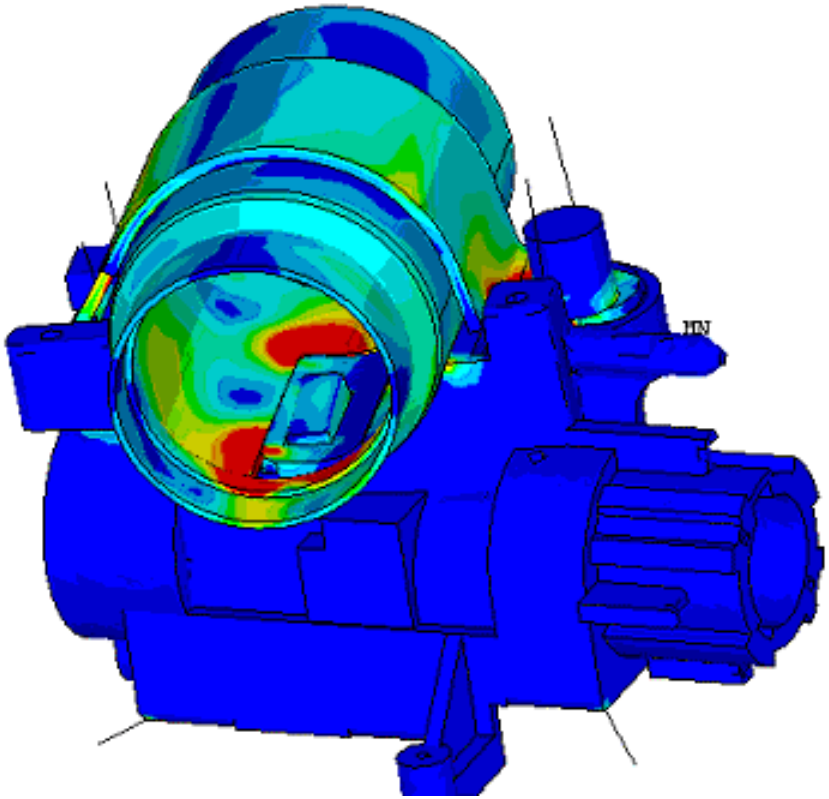
Weak Spring Examples…



Weak Springs Added at 2 Locations to Prevent Fishcord from Spinning



Weak Spring Examples…



Weak springs attach housing and strap to ground

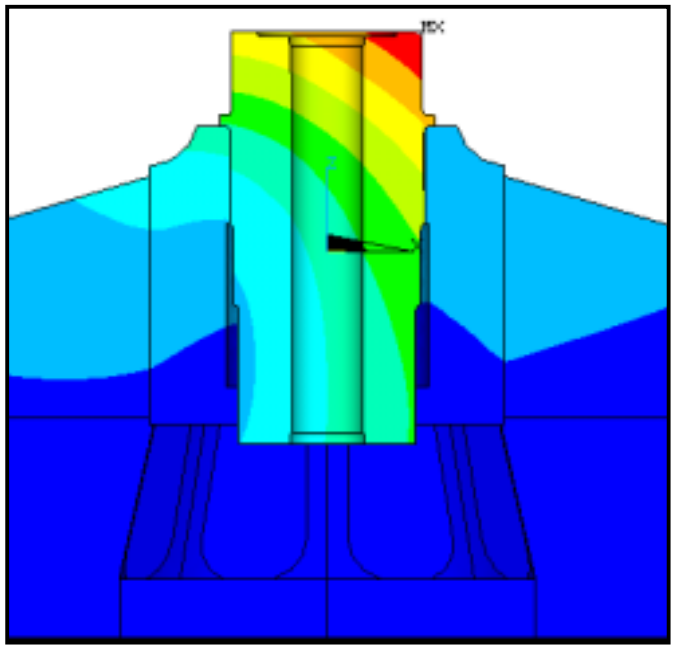
Weak springs attach lock bolt to housing

Different spring constants for all. Starting value 10N/mm

Friction was also used

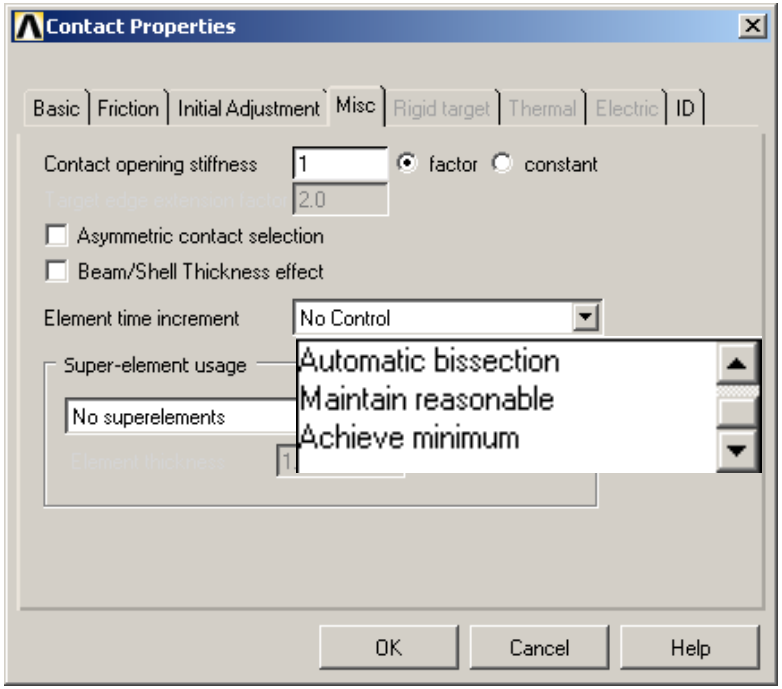
Friction…

In some instances a small amount of friction (mu=0.1) can be used to control lateral sliding



Dynamics…

- Solving F=ma eliminates rigid motion issues.
- Use of “slow dynamics” to solve static problems can overcome rigid motion issues. Include density and damping and verify system comes to rest
- When performing true dynamic problems with contact, use Element Time Increment Control (keyopt 7=2, maintain reasonable). This keeps time step a fraction of the system’s apparent frequency



IMPACT
ENGINEERING SOLUTIONS, INC.

Dynamics Examples…

Click to Animate

IMPACT
ENGINEERING SOLUTIONS, INC.

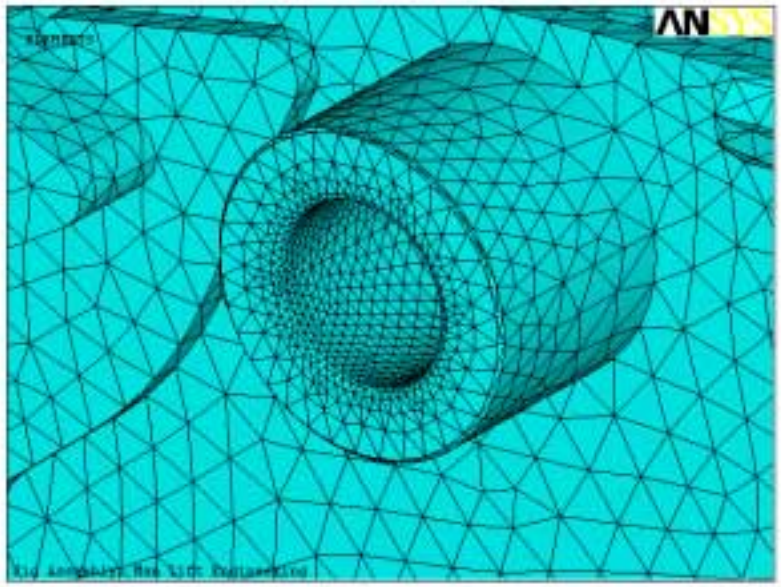
Dynamics Examples…

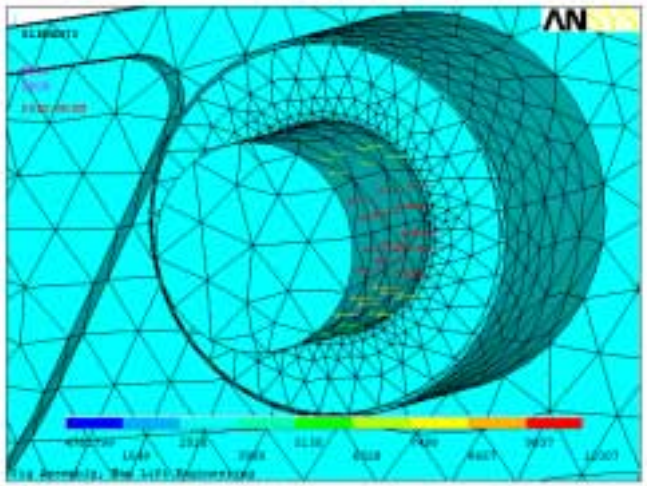
Click to Animate

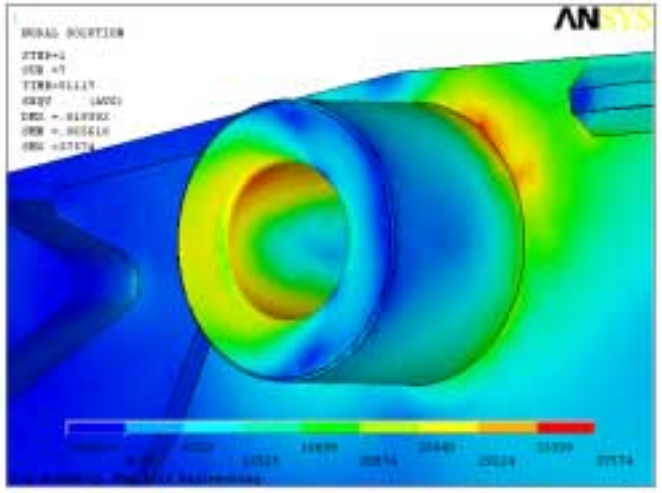
Mesh Issues

- Finer Mesh on Contact surface/ Coarser on Target
- Faceting negatively affects curved contact surfaces
  - Use fine mesh
  - Exclude penetration (keyopt 9 = 1)
  - Auto CNOF/ICONT (keyopt 5)

Mesh Issues







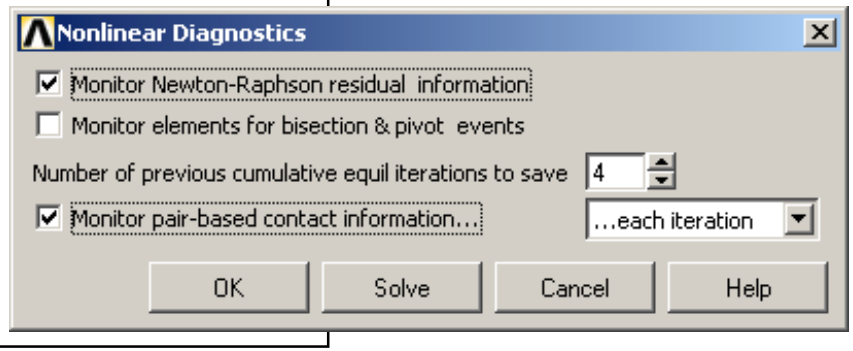
Refined Mesh + keyopt 9 = 1
Eliminated Convergence Problems

IMPACT
ENGINEERING SOLUTIONS, INC.

Nonlinear Diagnostics…

Version 9.0 added contact pair based diagnostics

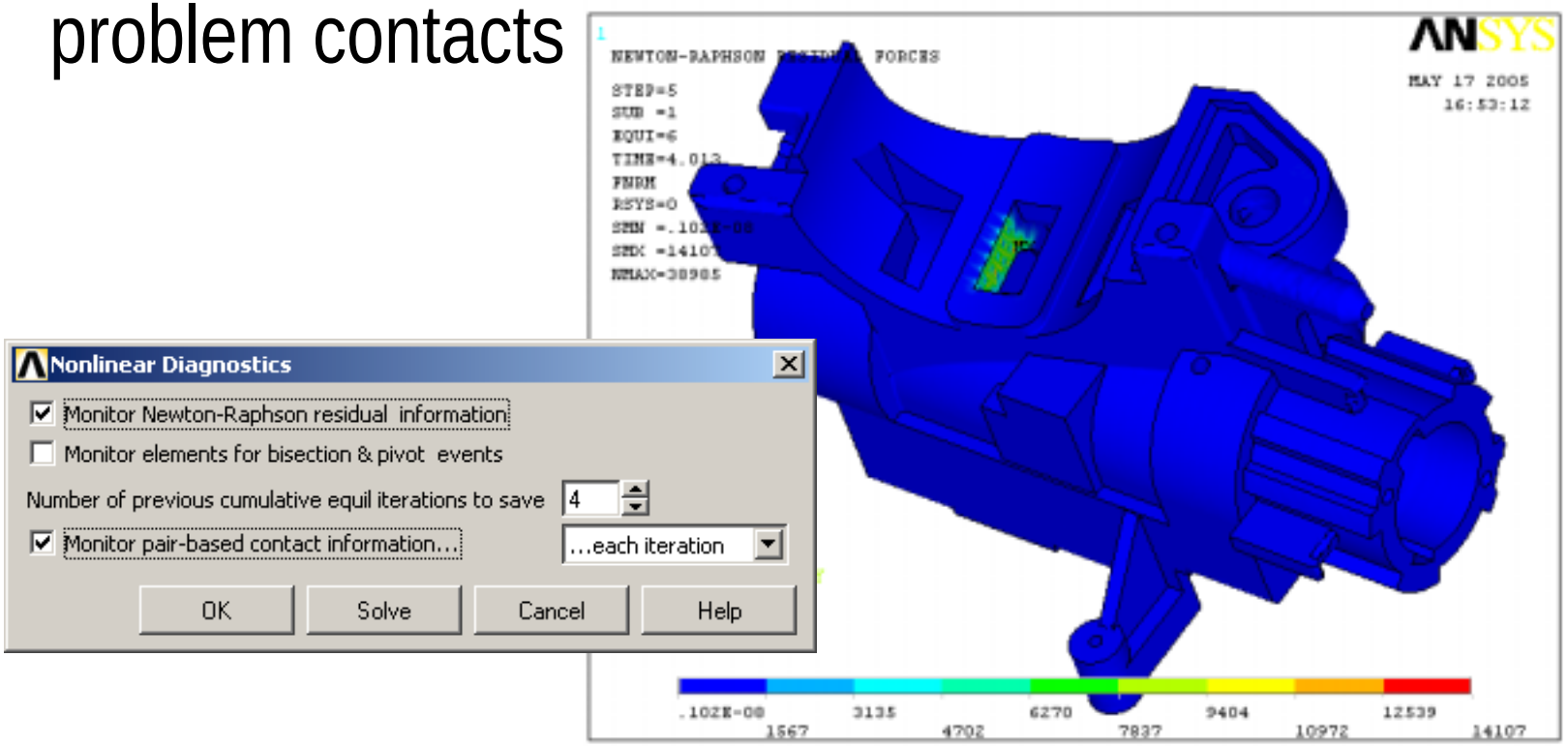
```
<COLUMN ID="    1">Contact Pair ID</COLUMN>
<COLUMN ID="    2">Number of Contact Elements in Contact</COLUMN>
<COLUMN ID="    3">Number of Contact Elements in Contact (Sticking)</COLUMN>
<COLUMN ID="    4">Max. Chattering Level</COLUMN>
<COLUMN ID="    5">Max. Penetration/Min. Gap</COLUMN>
<COLUMN ID="    6">Max. Closed Gap</COLUMN>
<COLUMN ID="    7">Max. Normal Stiffness</COLUMN>
<COLUMN ID="    8">Min. Normal Stiffness</COLUMN>
<COLUMN ID="    9">Max. Resulting Pinball</COLUMN>
<COLUMN ID="   10">Max. Elastic Slip Distance</COLUMN>
<COLUMN ID="   11">Max. Tangential Stiffness</COLUMN>
<COLUMN ID="   12">Min. Tangential Stiffness</COLUMN>
<COLUMN ID="   13">Max. Sliding Distance</COLUMN>
<COLUMN ID="   14">Max. Contact Pressure</COLUMN>
<COLUMN ID="   15">Max. Friction Stress</COLUMN>
<COLUMN ID="   16">Average contact depth</COLUMN>
```




```
<COLDATA LOAD_STEP="      4" SUBSTEP="      1" ITERATION="     12" TIME="    4.000000    ">
      15       15        0        6    0.1454140E-01    0.1449895E-01     9438.894          9438.894          3.595
      16       26        0        4    0.2732463E-02    0.2732463E-02     6961.772          6961.772          1.995
      17       23        0        9    0.7467515E-03    0.7467515E-03     17146.35          17146.35          1.981
      18      188        0        6    0.3437961E-02    0.3437961E-02     5294.488          5294.488          2.625
      19        7        0        0    0.1581632E-01    0.2263677E-01     8796.823          8796.823         0.7315
      20        0        0        0   -0.7152283E-01     0.000000         0.000000          0.000000          3.118
      21        0        0        0   -0.9641240E-01     0.000000         0.000000          0.000000          3.344
</COLDATA>
<COLDATA LOAD_STEP="      4" SUBSTEP="      1" ITERATION="     13" TIME="    4.000000    ">
      15       15        0        6    0.1454691E-01    0.1450446E-01     9438.894          9438.894          3.595
      16       26        0        4    0.2733085E-02    0.2733085E-02     6961.772          6961.772          1.995
      17       23        0        9    0.7451408E-03    0.7451408E-03     17146.35          17146.35          1.981
      18      188        0        6    0.3443273E-02    0.3443273E-02     5294.488          5294.488          2.625
      19        7        0        0    0.1584254E-01    0.2253283E-01     8796.823          8796.823         0.7315
      20        0        0        0   -0.7152241E-01     0.000000         0.000000          0.000000          3.118
      21        0        0        0   -0.9641095E-01     0.000000         0.000000          0.000000          3.344
</COLDATA>
```

Nonlinear Diagnostics…

Plotting Residual Norms can also help locate problem contacts



Other Methods of Dealing with Convergence…

- Increase Convergence Tolerance… Note this may simply allow you to converge to a wrong solution
- Specify a min ref convergence value
- Adjust Pinball Region

IMPACT
ENGINEERING SOLUTIONS, INC.

Summary…

- Try to converge using easy settings first then tighten settings to determine sensitivity
  - Small FKN
  - Large FTOLN
- Use displacement control whenever you can
- Get to know ANSYS' automatic methods for dealing with rigid motion
- In situations where auto methods don't work consider the application and apply springs, friction, etc.
- Setup NL Diagnostics and look at contact penetration to see how various contacts are behaving