Getting Started Tutorials

Contents

Proprietary & Restricted Rights Notice

Availability (TAUCS)

As of version 2.1, we distribute the code in 4 formats: zip and tarred-gzipped (tgz), with or without binaries for external libraries. The bundled external libraries should allow you to build the test programs on Linux, Windows, and MacOS X without installing additional software. We recommend that you download the full distributions, and then perhaps replace the bundled libraries by higher performance ones (e.g., with a BLAS library that is specifically optimized for your machine). If you want to conserve bandwidth and you want to install the required libraries yourself, download the lean distributions. The zip and tgz files are identical, except that on Linux, Unix, and MacOS, unpacking the tgz file ensures that the configure script is marked as executable (unpack with tar zxvpf), otherwise you will have to change its permissions manually.

Chapter 1: Performing an Analysis Step-by-Step

1.1 Defining the Problem

In this chapter, we perform a complete NX Nastran analysis step-by-step. Consider the hinged steel beam shown in Figure1-1. It has a rectangular cross section and is subjected to a 100 lb concentrated force. Determine the deflection and stresses in the beam at the point of application of the load, with and without the effects of transverse shear.

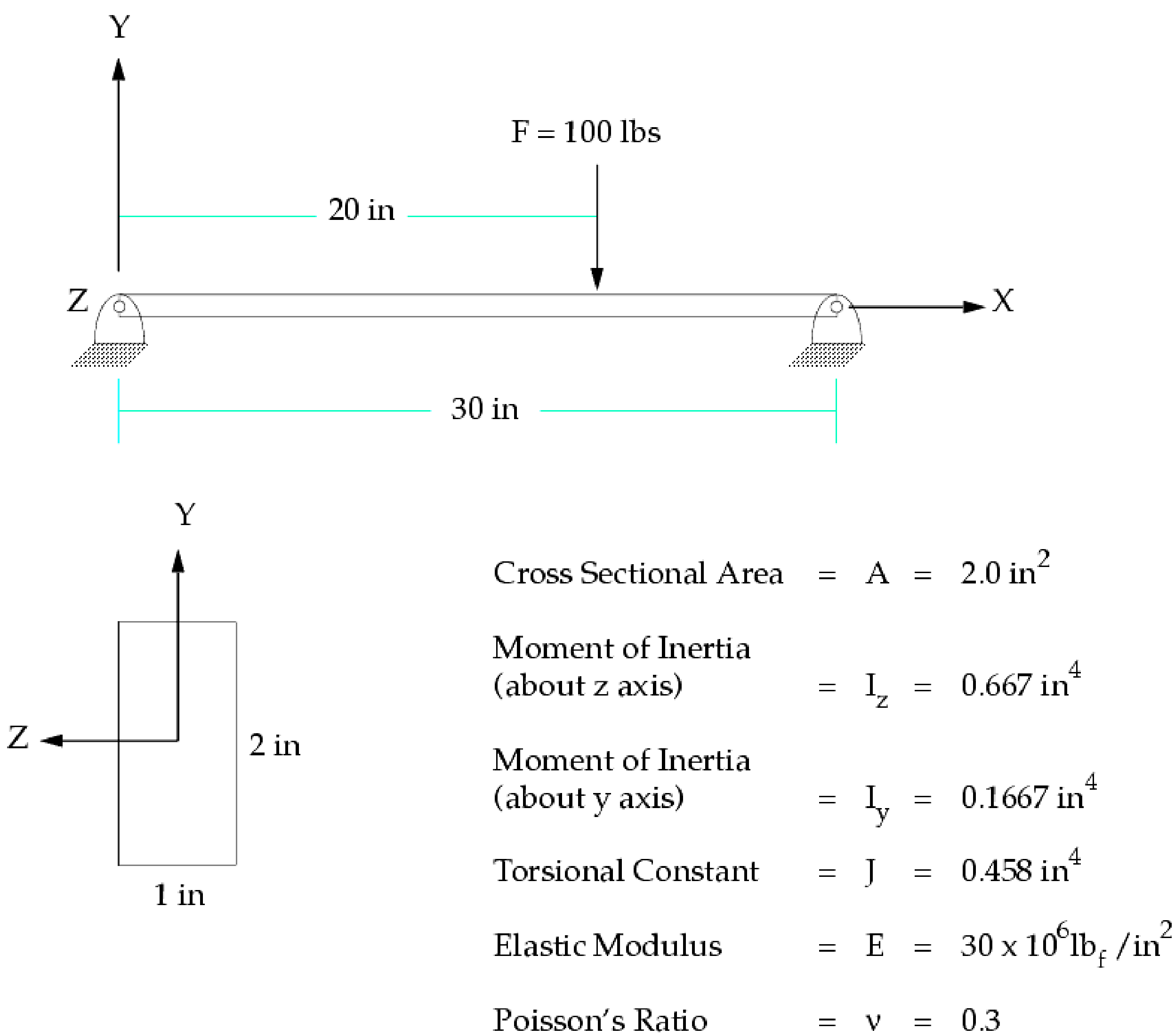


Figure 1-1. Beam Geometry and Load

1.2 Specifying the Type of Analysis

The type of analysis to be performed is specified in the Executive Control Section of the input file using the SOL (SOLution) statement. In this problem, we choose Solution 101, which is the linear static analysis solution sequence. The statement required is:

```
SOL 101
```

We will also identify the job with an ID statement and set the CPU time limit with a TIME statement as follows:

```
ID  MPM,CH 12 EXAMPLE
TIME  100
```

The end of the Executive Control Section is indicated by the CEND delimiter. Thus, the complete Executive Control Section is written as follows:

```
ID  MPM,CH 12 EXAMPLE
SOL  101
TIME 100
CEND
```

Note

Both the TIME and ID statements are optional. The default value of TIME, however, is too small for all but the most trivial problems.

The format of the ID entry (ID i1,i2) must be adheared to or a fatal error will result.

1.3 Designing the Model

The structure is a classical hinged slender beam subjected to bending behavior from a concentrated load. The CROD element will not work since it supports only extension and torsion. The CBEAM element would work, but its special capabilities are not required for this problem and its property entry is more difficult to work with. Thus, the CBAR element is a good choice. The number of elements to use is always a crucial decision; in our case the simplicity of the structure and its expected behavior allows the use of very few elements. We will choose three CBAR elements and four evenly spaced grid points as shown in Figure1-2.

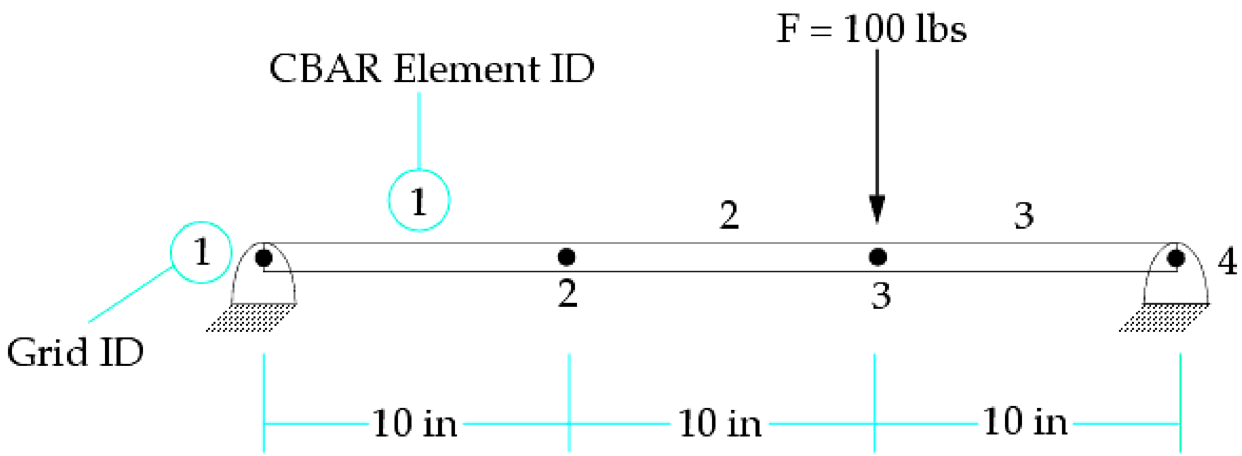


Figure 1-2. The Finite Element Model

Note that GRID points were located at the point of application of the load and at each reaction point.

1.4 Creating the Model Geometry

Coordinate System

NX Nastran has a default rectangular coordinate system called the basic system. Therefore, no special effort is required to orient our model. We will choose to define the model's coordinate system as shown in Figure1-3. The beam's element x-axis will be parallel to the basic system's x-axis by our choice of X1, X2, and X3 (x, y, and z) on the GRID entries.

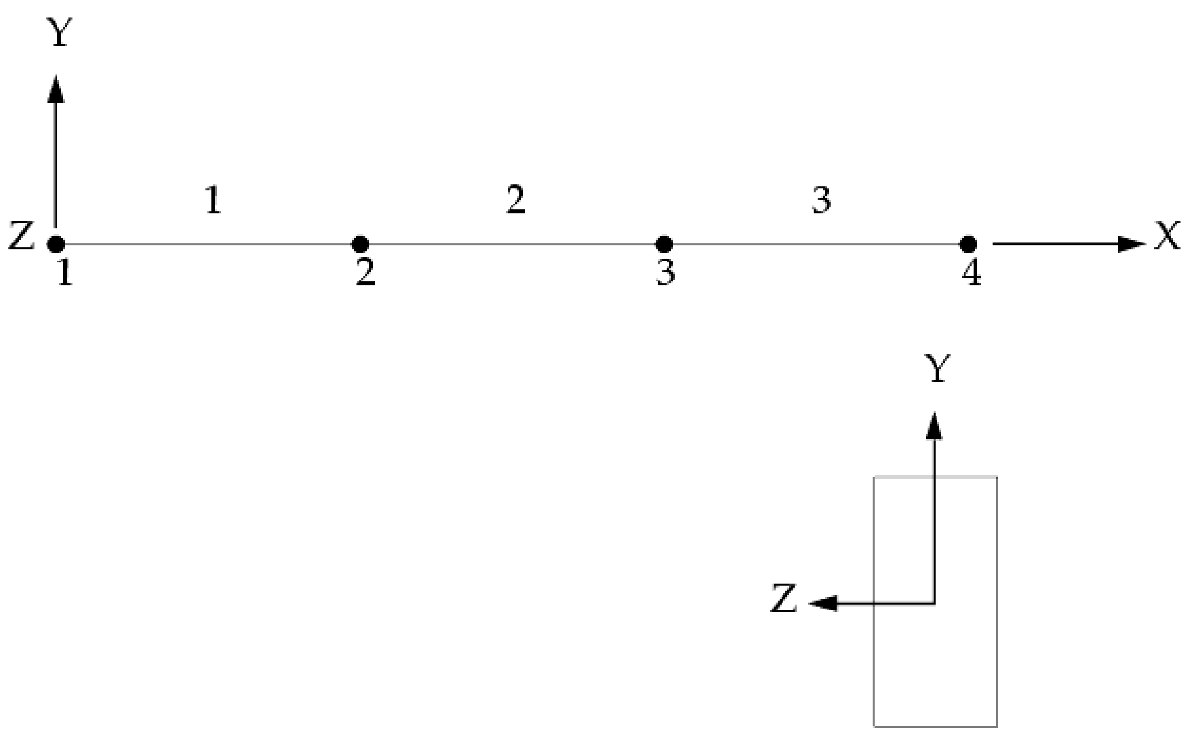


Figure 1-3. Model Coordinate System

GRID Points

GRID points are defined in the Bulk Data Section of the input file. The format of the GRID entry is:

1	2	3	4	5	6	7	8	9	10
GRID	ID	CP	X1	X2	X3	CD	PS	SEID	

Field	Contents
ID	Grid point identification number. (0 < Integer < 1000000)
CP	Identification number of coordinate system in which the location of the grid point is defined. ((Integer ≥0 or blank)
X1, X2, X3	Location of the grid point in coordinate system CP. (Real; Default = 0.0)
CD	Identification number of coordinate system in which the displacements, degrees of freedom, constraints, and solution vectors are defined at the grid point. (Integer ≥-1 or blank)
PS	Permanent single-point constraints associated with the grid point. (Any of the Integers 1 through 6 with no embedded blanks, or blank)
SEID	Superelement identification number. (Integer ≥0 ; Default = 0)

The default basic coordinate system is defined by leaving field 3 (CP) blank (the basic coordinate system's ID number is zero).

The values of X1, X2, and X3 (in our rectangular system these mean x, y, and z) in fields 4, 5, and 6 are as follows:

GRID	X	Y	Z
1	0.	0.	0.
2	10.0	0.	0.
3	20.0	0.	0.
4	30.0	0.	0.

Field 7 (CD) is left blank since we want grid point displacements and constraints to be defined in the basic coordinate system. The constraints for this problem could be defined on field 8 (PS) of grid points 1 and 4. Instead, we will use SPC1 entries and leave field 8 blank.

Finally, field 9 is left blank since superelements are not part of this problem.

The completed GRID entries are written as follows:

1	2	3	4	5	6	7	8	9	10
GRID	1		0.	0.	0.				
GRID	2		10.0	0.	0.				
GRID	3		20.0	0.	0.				
GRID	4		30.0	0.	0.				

Or, in free field format, the GRID entries are written

```
GRID,1,,0.,0.,0.
GRID,2,,10.,0.,0.
GRID,3,,20.,0.,0.
GRID,4,,30.,0.,0.
```

1.5 Defining the Finite Elements

The CBAR Entry

Elements are defined in the Bulk Data Section of the input file. The format of the CBAR simple beam element is as follows:

1	2	3	4	5	6	7	8	9	10
CBAR	EID	PID	GA	GB	X1	X2	X3		
	PA	PB	W1A	W2A	W3A	W1B	W2B	W3B	

Field	Contents
EID	Unique element identification number. (Integer > 0)
PID	Property identification number of a PBAR entry. (Integer > 0 or blank; Default is EID unless BAROR entry has nonzero entry in field 3)
GA, GB	Grid point identification numbers of connection points. (Integer > 0; GA ≠GB)
X1, X2, X3	Components of orientation vector $\vec{v}$, from GA, in the displacement coordinate system at GA. (Real)
G0	Alternate method to supply the orientation vector $\vec{v}$ using grid point G0. Direction of $\vec{v}$ is from GA to G0. (Integer > 0)
PA, PB	Pin flags for bar ends A and B, respectively. Used to remove connections between the grid point and selected degrees of freedom of the bar. The degrees of freedom are defined in the element's coordinate system. The bar must have stiffness associated with the PA and PB degrees of freedom to be released by the pin flags. For example, if PA = 4 is specified, the PBAR entry must have a value for J, the torsional stiffness. (Up to 5 of the unique Integers 1 through 6 anywhere in the field with no embedded blanks; Integer > 0)
W1A, W2A, W3A, W1B, W2B, W3B	Components of offset vectors $\vec{w}_b$ and $\vec{w}_b$, respectively, in displacement coordinate systems at points GA and GB, respectively. (Real or blank)

The property identification number (PID) is arbitrarily chosen to be 101—this label points to a PBAR beam property entry. The same PID is used for each of the three CBAR elements.

GA and GB are entered for each beam element, starting with GA (end A) of CBAR element 1 at (0., 0., 0.). Recall that the direction of the X-element axis is defined as the direction from GA to GB.

The beam orientation vector $\vec{V}$, described by GA and the components X1, X2, and X3, is arbitrarily chosen by setting X1 = 0.0, X2 = 1.0, and X3 = 0.0. Orientation vector $\vec{V}$ is shown in Figure 1-4.

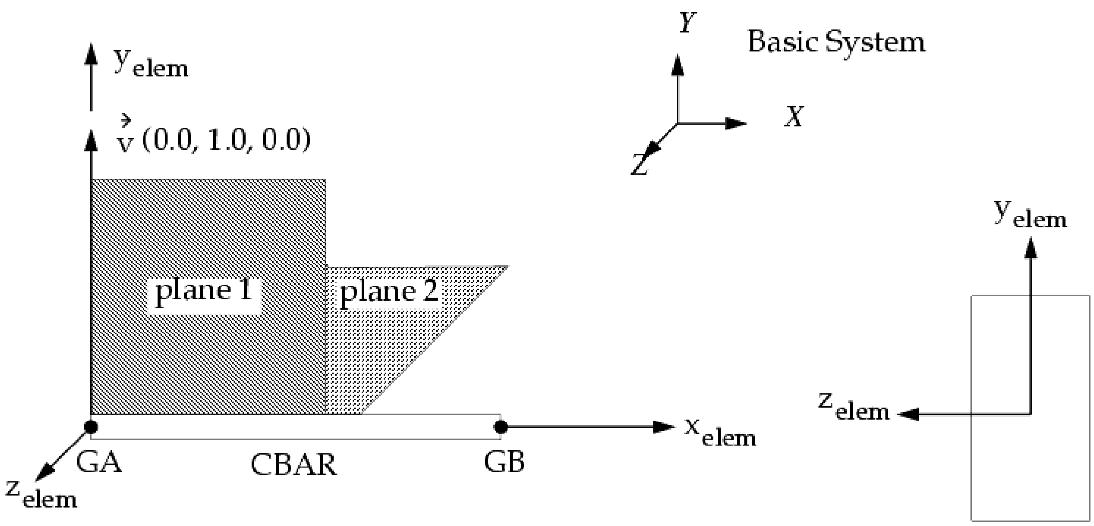


Figure 1-4.

$\vec{V}$ and x_{elem} defines Plane 1 and the y_{elem} Axis

Plane 1 is thus formed by $\vec{V}$ and the x-element axis. The y-element axis (y_{elem}) is perpendicular to the x-element axis and lies in plane 1.

Plane 2 is perpendicular to plane 1, and the z-element axis (z_{elem}) is formed by the cross product of the x-element and y-element axes.

The completed CBAR entries are written as follows:

1	2	3	4	5	6	7	8	9	10
CBAR	1	101	1	2	0.	1.	0.		
CBAR	2	101	2	3	0.	1.	0.		
CBAR	3	101	3	4	0.	1.	0.		

Or, in free field format, the CBAR entries appear as:

```
CBAR,1,101,1,2,0.,1.,0.
CBAR,2,101,2,3,0.,1.,0.
CBAR,3,101,3,4,0.,1.,0.
```

Continuations of the CBAR entries are not required since pin flags and offset vectors are not used in this model.

The PBAR Entry

The format of the PBAR entry is as follows:

1	2	3	4	5	6	7	8	9	10
PBAR	PID	MID	A	I1	I2	J	NSM		
	C1	C2	D1	D2	EI	E2	F1	F2	
	K1	K2	I12						

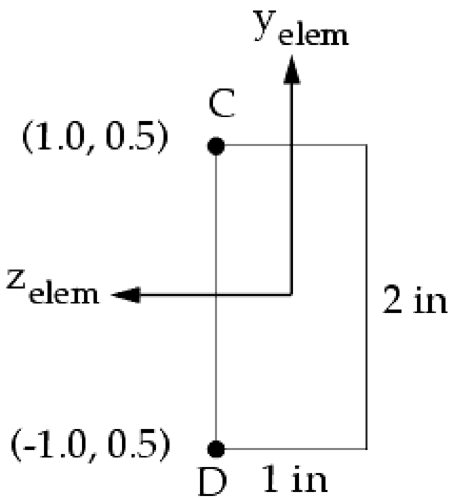
Field	Contents
PID	Property identification number. (Integer > 0)
MID	Material identification number. (Integer > 0)
A	Area of bar cross section. (Real)
I1, I2, I12	Area moments of inertia.
	(Real; $I1 \geq 0.0$
	$I2 \geq 0.0$
	$I1 \cdot I2 > I12^2$)
J	Torsional constant. (Real)
NSM	Nonstructural mass per unit length. (Real)
K1, K2	Area factor for shear. (Real)
Ci, Di, Ei, Fi	Stress recovery coefficients. (Real; Default = 0.0)

For our model, the property ID (PID) is 101, as called out on the CBAR entry. The material ID (MID) is arbitrarily chosen to be 201—this label points to a MAT1 entry. The beam's cross sectional area A is entered in field 4, and the torsional constant J is entered in field 7. The beam has no nonstructural mass (NSM), so column 8 is left blank.

Now you will specify I1 and I2 in fields 5 and 6. Recall that the choice of orientation vector $\vec{v}$ is arbitrary. What is not arbitrary is getting each value of I to match its correct plane. I1 is the moment of inertia for bending in plane 1 (which is the same as bending about the z axis, as it was probably called in your strength of materials class). Similarly, I2 is the moment of inertia for bending in plane 2 (about the y axis). Thus, $I1 = I_Z = 0.667$ in, and $I2 = I_y = 0.1667$in.

As a check for this model, think of plane 1 in this problem as the "stiff plane" (larger value of I) and plane 2 as the "not-as-stiff" plane (smaller value of I).

Stress recovery coefficients are user-selected coordinates located on the bar's element y-z plane at which stresses are calculated by NX Nastran. We will choose the following two points (there is no requirement that all four available points must be used):



Finally, the problem statement requires that we investigate the effect of shear deflection. To add shear deflection to the bar, we include appropriate values of K1 and K2 on the second continuation of the PBAR entry. For a rectangular cross section, K1 = K2 = 5/6.

Leaving K1 and K2 blank results in default values of infinity (i.e., transverse shear flexibility is set equal to zero). This means that no deflection due to shear will occur.

The completed PBAR entry is written as follows (no shear deflection):

1	2	3	4	5	6	7	8	9	10
PBAR	101	201	2.	.667	.1667	.458			
	1.	.5	-1.	.5					

To add shear deflection, a second continuation is added:

PBAR	101	201	2.	.667	.1667	.458			
	1.	.5	-1.	.5					
	.8333	.8333							

In free field format, the PBAR entry is written as follows:

```
PBAR,101,201,2.,.667,.1667,.458
    ,1.,.5,-1.,.5
    ,.8333,.8333
```

1.6 Representing Boundary Conditions

The beam is hinged, so we must constrain GRID points 1 and 4 to represent this behavior. We will use one SPC1 Bulk Data entry for both grid points since the constraints at each end are the same.

The format of the SPC1 entry is as follows:

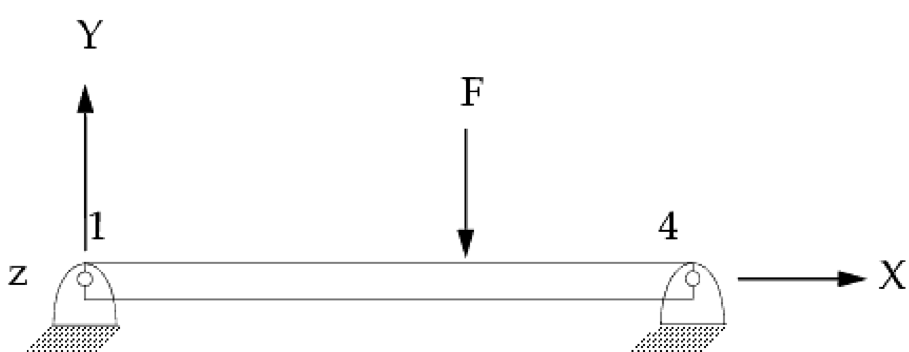
1	2	3	4	5	6	7	8	9	10
SPC1	SID	C	G1	G2	G3	G4	G5	G6	
	G7	G8	G9	-etc.-					

Field	Contents
SID	Identification number of single-point constraint set. (Integer > 0)
C	Component numbers. (Any unique combination of the Integers 1 through 6 with no embedded blanks for grid points. This number must be Integer 0 or blank for scalar points)
Gi	Grid or scalar point identification numbers. (Integer > 0 or “THRU”; for “THRU” option, G1 < G2. NX Nastran allows missing grid points in the sequence G1 through G2)

An SPC set identification number (SID) of 100 is arbitrarily chosen and entered in field 2. To select the SPC, the following Case Control command must be added to the Case Control Section:

```
SPC=100
```

Constraints are applied in the GRID point’s displacement coordinate system—in our problem this is the basic coordinate system. The required components of constraint are shown below:



Grids 1 and 4 cannot translate in the x, y, or z directions (constrain DOFs 1, 2, and 3). Grids 1 and 4 cannot rotate about the x-axis or y-axis (constrain DOFs 4 and 5). Grids 1 and 4 can rotate about the z-axis (leave DOF 6 unconstrained).

Therefore, the required SPC1 entry is written as follows:

SPC1	100	12345	1	4					

Or in free field format we enter:

```
SPC1,100,12345,1,4
```

1.7 Specifying Material Properties

The beam's material is steel, with an elastic modulus of

$0 \times 10^6 \text{ lb/in}$.

Poisson's ratio is 0.3. The format of the MAT1 entry is shown below (we will not use the optional stress limit/margin of safety capability on the MAT1 continuation line).

1	2	3	4	5	6	7	8	9	10
MAT1	MID	E	G	NU	RHO	A	TREF	GE	

Field	Contents
MID	Material identification number. (Integer > 0)
E	Young's modulus. (Real ≥0.0 or blank)
G	Shear modulus. (Real ≥0.0 or blank)
NU	Poisson's ratio. (-1.0 < Real ≤ 0.5 or blank)
RHO	Mass density. (Real)
A	Thermal expansion coefficient. (Real)
TREF	Reference temperature for the calculation of thermal loads, or a temperature-dependent thermal expansion coefficient. (Real; Default = 0.0 if A is specified)
GE	Structural element damping coefficient. (Real)

The material identification number called out on the PBAR entry is 201; this goes in field 2 of the MAT1 entry. Values for RHO, A, TREF, and GE are irrelevant to this problem and are therefore left blank. Thus, the MAT1 entry is written as follows:

MAT1	201	30.E6		.3					

In free field format,

```
MAT1,201,30.E6,,.3
```

1.8 Applying the Loads

The beam is subjected to a single concentrated force of 100 lb_f acting on GRID 3 in the negative Y direction. The FORCE Bulk Data entry is used to apply this load. Its format is described below:

1	2	3	4	5	6	7	8	9	10
FORCE	SID	G	CID	F	N1	N2	N3		

Field **Contents**

SID	Load set identification number. (Integer > 0)
G	Grid point identification number. (Integer > 0)
CID	Coordinate system identification number. (Integer ≥0 ; Default = 0)
F	Scale factor. (Real)
Ni	Components of a vector measured in coordinate system defined by CID. (Real; at least one Ni ≠0.0)

A load set identification number (SID) of 10 is arbitrarily chosen and entered in field 2 of the FORCE entry. To select the load set, the following Case Control command must be added to the Case Control Section:

```
LOAD=10
```

The FORCE entry is written as follows:

FORCE	10	3		-100	0.	1.	0.		

where (0., 1., 0.) is a unit vector in the positive Y direction of the displacement coordinate system.

In free field format, the entry is written as follows.

```
FORCE,10,3,,-100.,0.,1.,0.
```

1.9 Controlling the Analysis Output

The types of analysis quantities to be printed are specified in the Case Control Section. This problem requires displacements and element stresses, so the following commands are needed:

`DISP=ALL`	(prints all GRID point displacements)
`STRESS=ALL`	(prints all element stresses)

In order to help verify the model results, we will also ask for the following output quantities:

`FORCE=ALL`	(prints all element forces)
`SPCF=ALL`	(prints all forces of single point constraint; i.e., reaction forces)

The following command will yield both unsorted and sorted input file listings:

```
ECHO=BOTH
```

TITLE and SUBTITLE headings will appear on each page of the output, and are chosen as follows:

```
TITLE=HINGED BEAM
SUBTITLE=WITH CONCENTRATED FORCE
```

Finally, we select constraint and load sets as follows:

```
SPC=100
LOAD=10
```

The complete Case Control Section is shown below. The commands can be entered in any order after the CEND delimiter.

```
CEND
ECHO=BOTH
DISP=ALL
STRESS=ALL
FORCE=ALL
SPCF=ALL
SPC=100
LOAD=10
TITLE=HINGED
BEAM SUBTITLE=WITH
CONCENTRATED FORCE
```

1.10 Completing the Input File and Running the Model

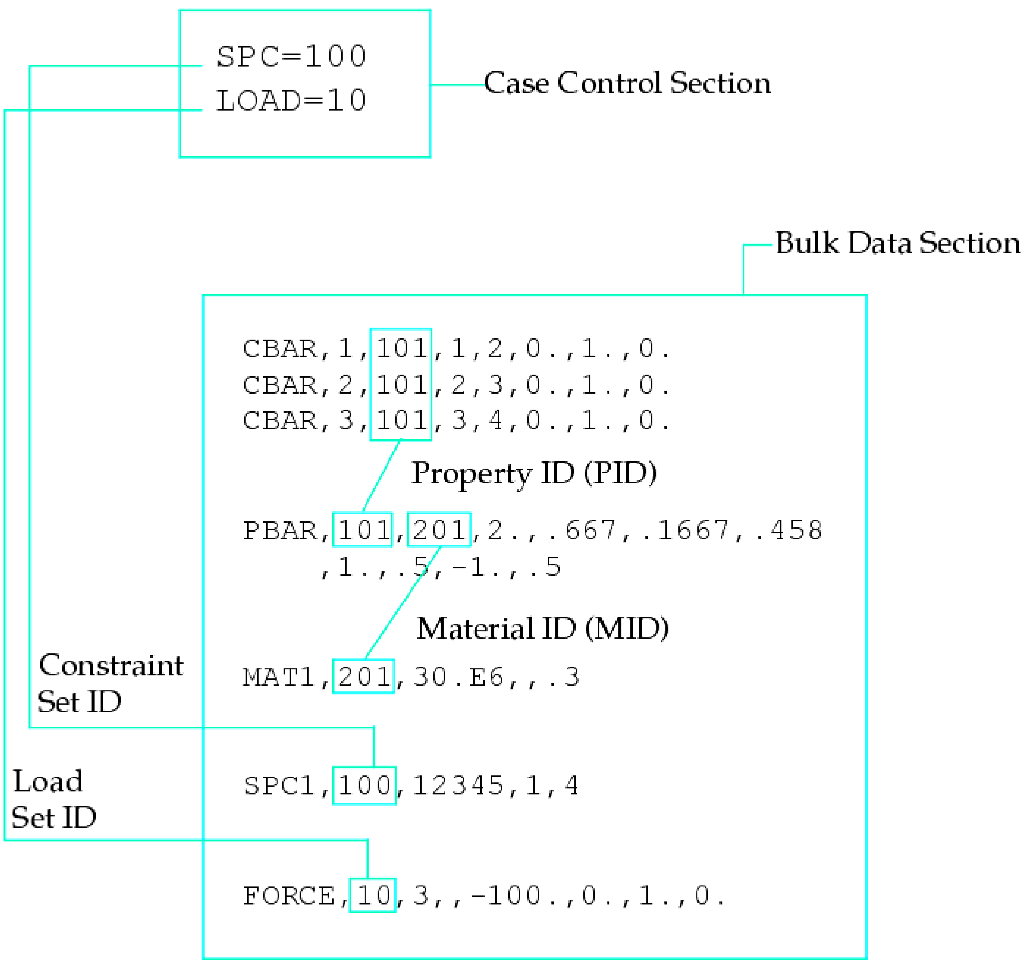
The completed input file (model without shear deflection) is called BASICEX1.DAT, and is shown in Listing 1-1.

```
ID MPM,EXAMPLE1
SOL 101
TIME 100 CEND
ECHO=BOTH
DISP=ALL
STRESS=ALL
FORCE=ALL
SPCF=ALL
SPC=100
LOAD=10
TITLE=HINGED BEAM
SUBTITLE=WITH CONCENTRATED FORCE
$
BEGIN BULK
$      DEFINE GRID POINTS
GRID,1,,0.,0.,0.
GRID,2,,10.,0.,0.
GRID,3,,20.,0.,0.
GRID,4,,30.,0.,0.
$
$      DEFINE CBAR ELEMENTS
CBAR,1,101,1,2,0.,1.,0.
CBAR,2,101,2,3,0.,1.,0.
CBAR,3,101,3,4,0.,1.,0.
$
```

```
$      DEFINE CBAR ELEMENT CROSS SECTIONAL PROPERTIES
PBAR,101,201,2.,.667,.1667,.458
     ,1.,.5,-1.,.5
$
$      DEFINE MATERIAL PROPERTIES
MAT1,201,30.E6,,.3
$
$      DEFINE  SPC CONSTRAINT SET
SPC1,100,12345,1,4
$
$      DEFINE CONCENTRATED
FORCE FORCE,10,3,,-100.,0.,1.,0.
$
ENDDATA
```

Listing 1-1.

It is useful at this point to review "what points to what" in the model. Set and property relationships are summarized in the diagram below:



The job is submitted to NX Nastran with a system command similar to the following:

```
NASTRAN BASICEX1 SCR=YES
```

The details of the command are unique to your system; refer to the NX Nastran Installation and Operations Guide for more information.

1.11 NX Nastran Output

The results of an NX Nastran job are contained in the .f06 file.

The complete .f06 file for this problem (no shear deflection) is shown in Table 1-1.

Table 1-1. Complete .f06 Results File

```
            THIS PROGRAM IS CONFIDENTIAL AND A TRADE SECRET OF.SOFTWARE CORP.  THE RECEIPT OR
   POSSESSION OF THIS PROGRAM DOES NOT CONVEY ANY RIGHTS TO REPRODUCE OR DISCLOSE ITS CONTENTS, OR TO
MANUFACTURE, USE, OR SELL ANYTHING HEREIN, IN WHOLE OR IN PART, WITHOUT THE SPECIFIC WRITTEN CONSENT OF
                          EDS PLM SOLUTIONS SOFTWARE CORPORATION.

                          * * * * * * * * * * * * * * * * * * * *
                          * * * * * * * * * * * * * * * * * * * *
                          * *                                  * *
                          * *        EDS PLM SOLUTIONS         * *
                          * *               CORP               * *
                          * *                                  * *
                          * *        NX  N a s t r a n         * *
                          * *                                  * *
                          * *         VERSION - 1.0            * *     NX Nastran version number
                          * *                                  * *
                          * *          JUL 10, 2003            * *     Installation date
                          * *                                  * *
                          * *                                  * *
                          * *              Intel               * *
                          * *                                  * *
                          * *MODEL PentiumIII/995 (MERCED.scm) * *     Your computer and
                          * *                                  * *     operating system
                          * *  Windows 2000 5.0 (Build 2195)   * *
                          * *                                  * *
                          * *                                  * *
                          * *                                  * *
                          * * * * * * * * * * * * * * * * * * * *
                          * * * * * * * * * * * * * * * * * * * *
```

```
                                                       JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE    1

   N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O
 ID MPM,CH 12 EXAMPLE
 SOL 101
 TIME 100
 CEND
```

```
HINGED BEAM                                                  JULY  10, 2003  NX NASTRAN   9/10/2003   PAGE    2
   WITH CONCENTRATED FORCE
                                      C A S E    C O N T R O L    D E C K    E C H O
               CARD
               COUNT

                1       ECHO=BOTH
                2       DISP=ALL
                3       STRESS=ALL
                4       FORCE=ALL
                5       SPCF=ALL
                6       SPC=100
                7       LOAD=10
                8       TITLE=HINGED BEAM
                9       SUBTITLE=WITH CONCENTRATED FORCE
               10       $
               11       BEGIN BULK
```

```
HINGED BEAM                                                       JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     3
   WITH CONCENTRATED FORCE
                                      I N P U T   B U L K   D A T A   D E C K   E C H O
                             .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                             $     DEFINE GRID POINTS
                             GRID,1,,0.,0.,0.
                             GRID,2,,10.,0.,0.
                             GRID,3,,20.,0.,0.
                             GRID,4,,30.,0.,0.
                             $
                             $     DEFINE CBAR ELEMENTS
                             CBAR,1,101,1,2,0.,1.,0.
                             CBAR,2,101,2,3,0.,1.,0.
                             CBAR,3,101,3,4,0.,1.,0.
                             $
                             $     DEFINE CBAR ELEMENT CROSS SECTIONAL PROPERTIES
                             PBAR,101,201,2.,.667,.1667,.458,,,+PB1
                             +PB1,1.,.5,-1.,.5
                             $
                             $     DEFINE MATERIAL PROPERTIES
                             MAT1,201,30.E6,,.3
                             $
                             $     DEFINE SPC CONSTRAINT SET
                             SPC1,100,12345,1,4
                             $
                             $     DEFINE CONCENTRATED FORCE
                             FORCE,10,3,,-100.,0.,1.,0.
                             $
                             ENDDATA
                             INPUT BULK DATA CARD COUNT =      25
```

```
HINGED BEAM                                                       JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     4
   WITH CONCENTRATED FORCE
                                         S O R T E D   B U L K   D A T A   E C H O
               CARD
               COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                  1-        CBAR    1       101     1       2       0.      1.      0.
                  2-        CBAR    2       101     2       3       0.      1.      0.
                  3-        CBAR    3       101     3       4       0.      1.      0.
                  4-        FORCE   10      3               -100.   0.      1.      0.
                  5-        GRID    1               0.      0.      0.
                  6-        GRID    2               10.     0.      0.
                  7-        GRID    3               20.     0.      0.
                  8-        GRID    4               30.     0.      0.
                  9-        MAT1    201     30.E6           .3
                 10-        PBAR    101     201     2.      .667    .1667   .458                    +PB1
                 11-        +PB1    1.      .5      -1.     .5
                 12-        SPC1    100     12345   1       4
                            ENDDATA
                     TOTAL COUNT=        13
```

```
HINGED BEAM                                                       JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     5
   WITH CONCENTRATED FORCE
USER INFORMATION MESSAGE
ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM WILL BE USED AS REFERENCE LOCATION.
RESULTANTS ABOUT ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM IN SUPERELEMENT BASIC SYSTEM COORDINATES.
                                                  OLOAD    RESULTANT
               T1            T2            T3            R1            R2            R3
       1   0.0000000E+00 -1.0000000E+02  0.0000000E+00  0.0000000E+00  0.0000000E+00 -2.0000000E+03
```

```
HINGED BEAM                                                       JULY 10, 2001  NX NASTRAN   7/10/2003   PAGE     6
   WITH CONCENTRATED FORCE
*** USER INFORMATION MESSAGE 5293 FOR DATA BLOCK KLL

  LOAD SEQ. NO.            EPSILON             EXTERNAL WORK      EPSILONS LARGER THAN 0.001 ARE FLAGGED WITH ASTERISKS
             1         -4.0856207E-17          1.1105558E-01
```

```
HINGED BEAM                                                       JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     7
   WITH CONCENTRATED FORCE
USER INFORMATION MESSAGE
ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM WILL BE USED AS REFERENCE LOCATION.
RESULTANTS ABOUT ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM IN SUPERELEMENT BASIC SYSTEM COORDINATES.

                                                  SPCFORCE RESULTANT

               T1            T2            T3            R1            R2            R3
       1   0.0000000E+00  1.0000000E+02  0.0000000E+00  0.0000000E+00  0.0000000E+00  2.0000000E+03
```

```
HINGED BEAM                                                   JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     8
   WITH CONCENTRATED FORCE
                                        D I S P L A C E M E N T   V E C T O R

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G      0.0            0.0            0.0            0.0            0.0          -2.221112E-04
        2      G      0.0           -1.943473E-03   0.0            0.0            0.0          -1.388195E-04
        3      G      0.0           -2.221112E-03   0.0            0.0            0.0           1.110556E-04
        4      G      0.0            0.0            0.0            0.0            0.0           2.776390E-04
```

```
HINGED BEAM                                                   JULY 10, 2003  NX NASTRAN   7/10/2003   PAGE     9
   WITH CONCENTRATED FORCE
                          F O R C E S   O F   S I N G L E - P O I N T   C O N S T R A I N T

 POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
        1      G      0.0            3.333333E+01   0.0            0.0            0.0            0.0
        4      G      0.0            6.666666E+01   0.0            0.0            0.0            0.0
```

```
HINGED BEAM                                                   JULY 10, 2003  NX NASTRAN   7/10/2003   PAGE    10
   WITH CONCENTRATED FORCE
                            F O R C E S   I N   B A R   E L E M E N T S         ( C B A R )

ELEMENT        BEND-MOMENT END-A            BEND-MOMENT END-B                - SHEAR -               AXIAL
  ID.        PLANE 1       PLANE 2        PLANE 1       PLANE 2        PLANE 1       PLANE 2        FORCE          TORQUE
      1     0.0           0.0            3.333333E+02  0.0           -3.333333E+01  0.0            0.0            0.0
      2     3.333333E+02  0.0            6.666667E+02  0.0           -3.333333E+01  0.0            0.0            0.0
      3     6.666667E+02  0.0            2.034505E-05  0.0            6.666666E+01  0.0            0.0            0.0
```

```
HINGED BEAM                                                   JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE    11
   WITH CONCENTRATED FORCE
```

```
HINGED BEAM                                                   JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE    12
   WITH CONCENTRATED FORCE
                            S T R E S S E S   I N   B A R   E L E M E N T S         ( C B A R )

ELEMENT        SA1            SA2            SA3            SA4           AXIAL          SA-MAX         SA-MIN     M.S.-T
  ID.          SB1            SB2            SB3            SB4           STRESS         SB-MAX         SB-MIN     M.S.-C

     1     0.0            0.0            0.0            0.0            0.0            0.0            0.0
          -4.997502E+02   4.997502E+02   0.0            0.0                           4.997502E+02  -4.997502E+02

     2    -4.997502E+02   4.997502E+02   0.0            0.0            0.0            4.997502E+02  -4.997502E+02
          -9.995003E+02   9.995003E+02   0.0            0.0                           9.995003E+02  -9.995003E+02

     3    -9.995003E+02   9.995003E+02   0.0            0.0            0.0            9.995003E+02  -9.995003E+02
          -3.050233E-05   3.050233E-05   0.0            0.0                           3.050233E-05  -3.050233E-05
```

```
HINGED BEAM                                                   JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE    13
   WITH CONCENTRATED FORCE
```

```
 HINGED BEAM                                                                 JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE    14
    WITH CONCENTRATED FORCE

* * * *  D B D I C T   P R I N T  * * * *      SUBDMAP = PRTSUM  ,  DMAP STATEMENT NO.     13

                                   * * * *  A N A L Y S I S   S U M M A R Y   T A B L E  * * * *

 SEID  PEID PROJ VERS APRCH      SEMG SEMR SEKR SELG SELR MODES DYNRED SOLLIN PVALID SOLNL LOOPID DESIGN CYCLE SENSITIVITY
--------------------------------------------------------------------------------------------------------------------------
    0     0    1    1 '        '    T    T    T    T    T     F      F      T      0     F     -1            0           F

SEID = SUPERELEMENT ID.
PEID = PRIMARY SUPERELEMENT ID OF IMAGE SUPERELEMENT.
PROJ = PROJECT ID NUMBER.
VERS = VERSION ID.
APRCH = BLANK FOR STRUCTURAL ANALYSIS.  HEAT FOR HEAT TRANSFER ANALYSIS.
SEMG = STIFFNESS AND MASS MATRIX GENERATION STEP.
SEMR = MASS MATRIX REDUCTION STEP (INCLUDES EIGENVALUE SOLUTION FOR MODES).
SEKR = STIFFNESS MATRIX REDUCTION STEP.
SELG = LOAD MATRIX GENERATION STEP.
SELR = LOAD MATRIX REDUCTION STEP.
MODES = T (TRUE) IF NORMAL MODES OR BUCKLING MODES CALCULATED.
DYNRED = T (TRUE) MEANS GENERALIZED DYNAMIC AND/OR COMPONENT MODE REDUCTION PERFORMED.
SOLLIN = T (TRUE) IF LINEAR SOLUTION EXISTS IN DATABASE.
PVALID = P-DISTRIBUTION ID OF P-VALUE FOR P-ELEMENTS
LOOPID = THE LAST LOOPID VALUE USED IN THE NONLINEAR ANALYSIS.  USEFUL FOR RESTARTS.
SOLNL = T (TRUE) IF NONLINEAR SOLUTION EXISTS IN DATABASE.
DESIGN CYCLE = THE LAST DESIGN CYCLE (ONLY VALID IN OPTIMIZATION).
SENSITIVITY = SENSITIVITY MATRIX GENERATION FLAG.

                                        * * * END OF JOB * * *
```

1.12 Reviewing the Results

You cannot simply move directly to the displacement and stress results and accept the answers. You are responsible for verifying the correctness of the model. Some common checks are described in this section.

Check for Error Messages, Epsilon, and Reasonable Displacements

No error or warning messages are present in the .f06 (results) file—this is certainly no guarantee of a correct run, but it's a good first step. Also, examine the value of epsilon on page 6 of the output. It is very small (~10^{-16}), showing stable numerical behavior. Next, it is a good policy to check the displacement values, just to verify that they are not absurdly out of line with the physical problem or that a geometric nonlinear analysis is not required. For example, this beam displacing several inches might indicate that a load is orders of magnitude too high, or that a cross sectional property or an elastic modulus has been incorrectly specified. In our case, the lateral displacements (page 8 of the output) are on the order of 10-3 inches, which seems reasonable for this problem.

> **Note**
>
> Suppose you did obtain displacements of several inches—or perhaps into the next city. Shouldn't NX Nastran give some sort of engineering sanity warning? The answer is no, because the program is doing precisely what it was told to do and has no ability to judge what a reasonable displacement is. Recall that our analysis is linear and that the MAT1 material property entry thinks that the elastic modulus E is the material curve. This distinction is shown in Figure 1-5.

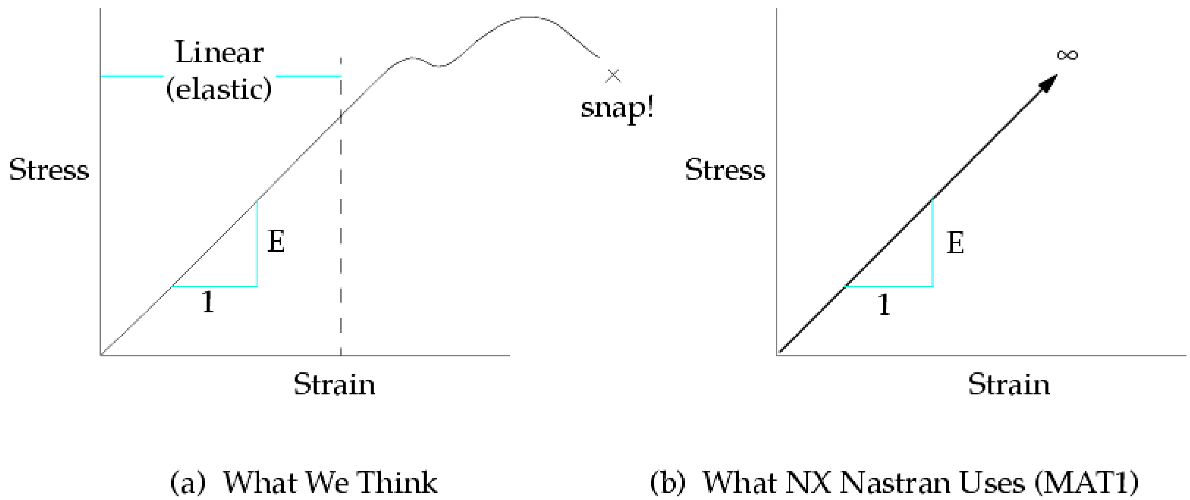


Figure 1-5. Reality versus Modeling

The MAT1 entry states that our material is always elastic and infinitely strong. In reality, we will violate restrictions on small displacements and material linearity given sufficient loading.

Check Reactions

To check static equilibrium, we calculate the reaction forces at the constraints and obtain 33.3 lbs. in the +y direction at grid point 1 and 66.6 lbs. in the +y direction at grid point 4 (Figure 1-7(a)). These values match the forces of single point constraint reported on page 9 of the output (T2 in this table means forces in the Y direction). Thus, the load and resulting reactions make sense.

Check Shear Along the Beam

The shear diagram for the beam is shown in Figure 1-7(b). The output lists the shear forces across each element as -33.3 lbs. for elements 1 and 2 and +66.6 lbs. for element 3.

Note that shear occurs only in plane 1 (the plane of the applied force). The sign convention for CBAR element internal shear forces in Plane 1 ($_{elem}$—y_{elem} plane) is shown in Figure 1-6:

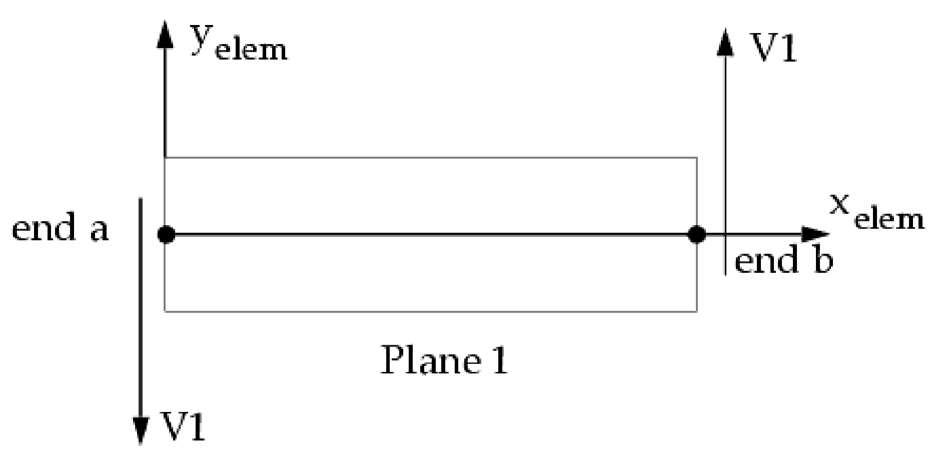


Figure 1-6. CBAR Element Shear Convention (Plane 1)

Thus, the signs make sense with respect to the applied load.

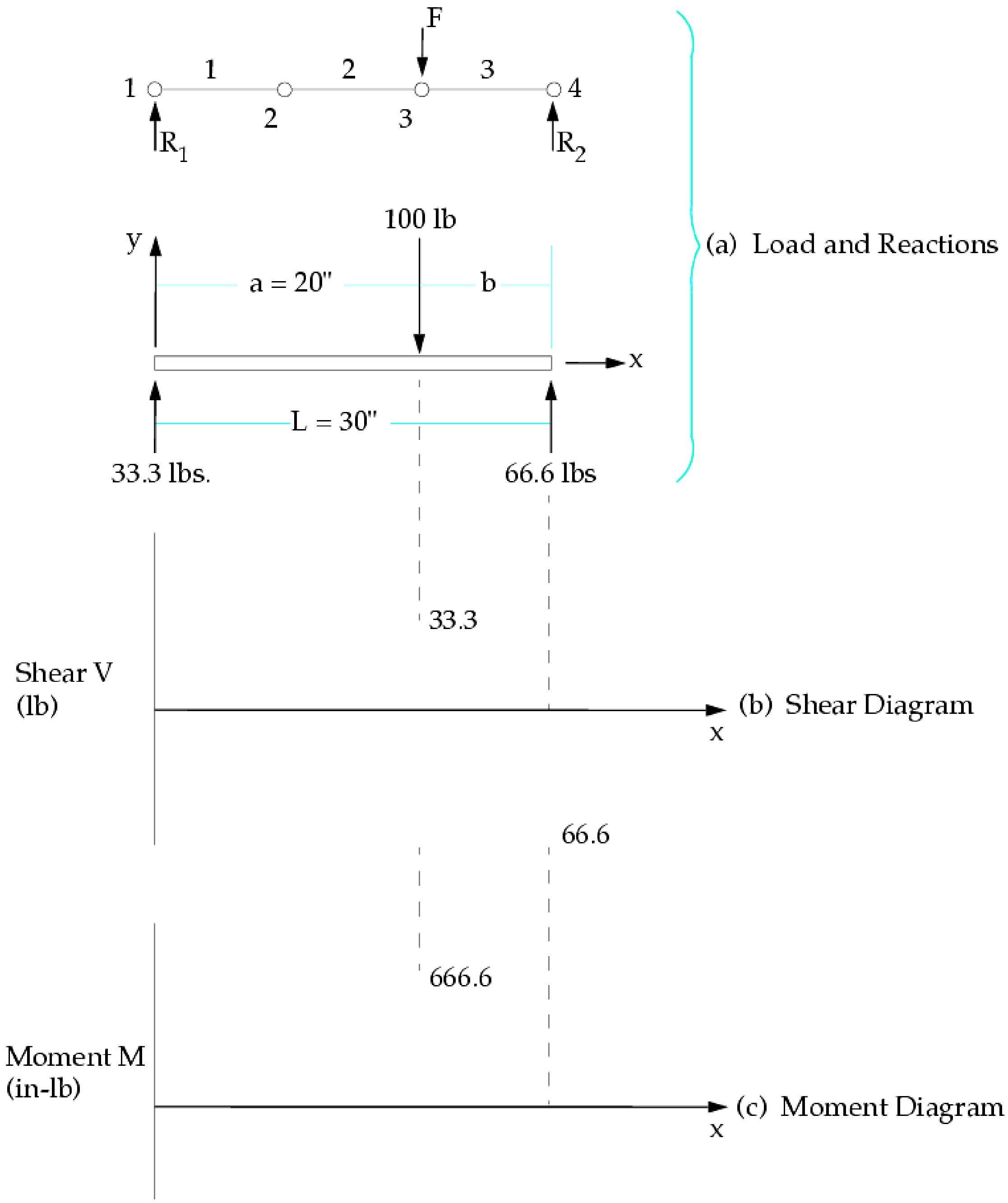


Figure 1-7. Beam Reaction Forces, Shear Diagram, and Moment Diagram

Displacement and Stress Results

The displacement at the point of application of the load (GRID 3) is shown in the results:

$$u_y^3 = -2.221112E\text{-}3 \text{ inch}$$

The deflection is in the -y direction as expected.

The CBAR element stresses at the point of application of the load (GRID 3) are reported by end b of CBAR 2 and end a of CBAR 3. Positive stress values indicate tension and negative values indicate compression. The top of the beam is in compression and the bottom of the beam is in tension. Stress recovery point 1 is located on the top of the beam and point 2 is located at the bottom of the beam, as shown in Figure 1-8:

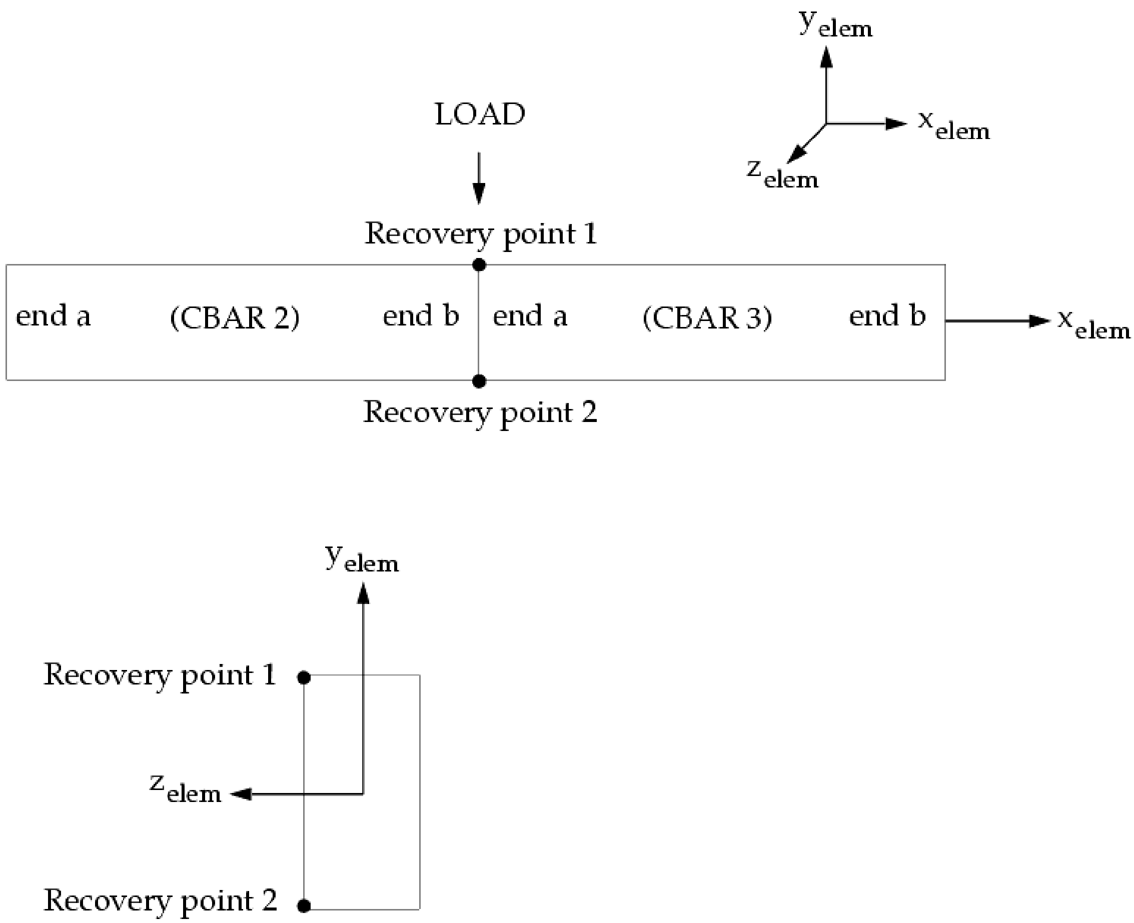


Figure 1-8. Bar Element Output Nomenclature

The NX Nastran CBAR element stress output (Figures 6-7) is interpreted as shown in Figure 1-9:

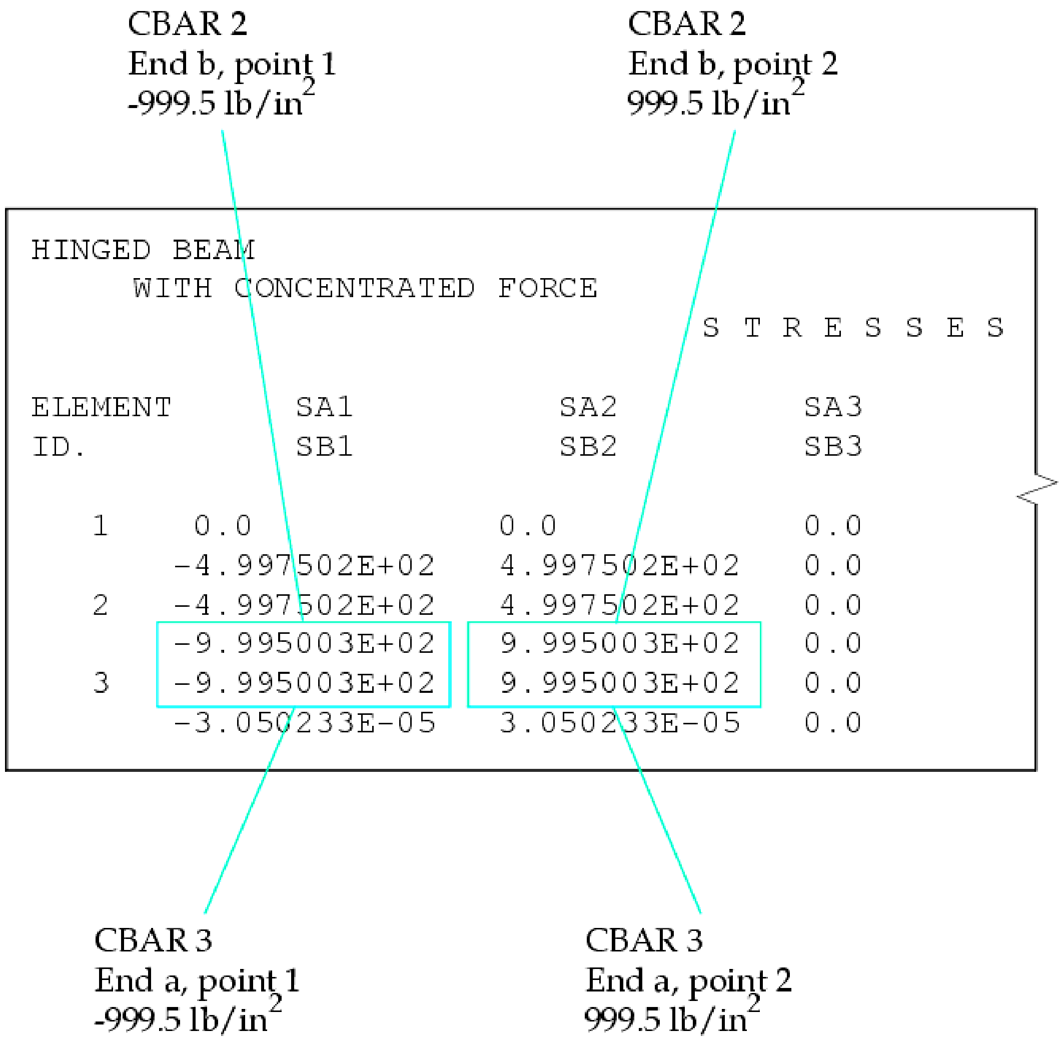
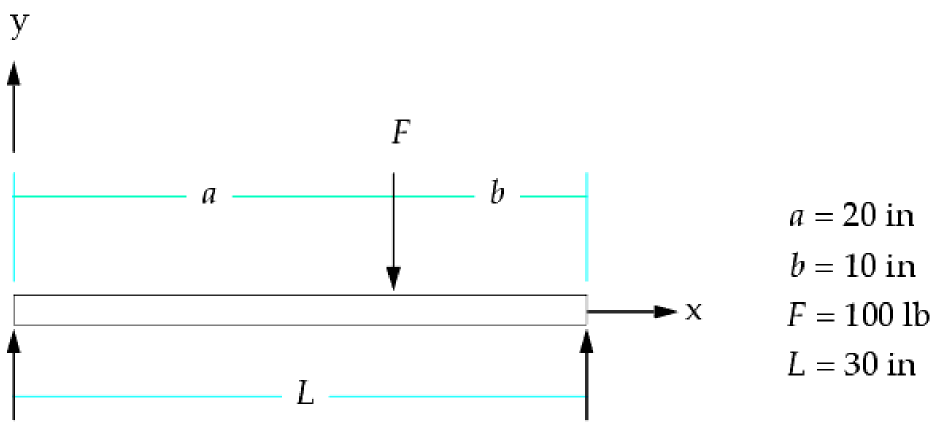


Figure 1-9. Bar Element Stress Output

Therefore, the top surface of the beam (point 1) sees –999.5 lb/in (compression) and the bottom surface sees 999.5 lb/in (tension).

Comparing the Results with Theory

First, the deflection at the point of application of the load will be determined by hand. This calculation does not include shear effects, so it can be directly compared with the NX Nastran results shown in the NX Nastran Output. The deflection due to bending only is calculated as follows:



$$\text{For} \quad x = a, u_y = -\frac{Fa^2b^2}{3EIL} = -\frac{(100\ \text{lb})(20\ \text{in})^2(10\ \text{in})^2}{3(30 \times 10^6\ \text{lb/in}^2)(.667\ \text{in}^4)(30\,\text{in})}$$

$$u_y = -2.22111\ \text{E-3 inch}$$

This value is in exact agreement with the T2 value for GRID 3 on page 8 of the NX Nastran output.

The effect of shear deflection is determined by adding the second continuation of the PBAR entry and rerunning the job. The new Bulk Data Section is shown in Listing1-2.

```
HINGED BEAM                                              JULY 10, 2003   NX NASTRAN   7/10/2003   PAGE     4
     WITH CONCENTRATED FORCE
                                                  S O R T E D   B U L K   D A T A   E C H O
            CARD
            COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                1-        CBAR    1       101     1       2       0.      1.      0.
                2-        CBAR    2       101     2       3       0.      1.      0.
                3-        CBAR    3       101     3       4       0.      1.      0.
                4-        FORCE   10      3               -100.   0.      1.      0.
                5-        GRID    1               0.      0.      0.
                6-        GRID    2               10.     0.      0.
                7-        GRID    3               20.     0.      0.
                8-        GRID    4               30.     0.      0.
                9-        MAT1    201     30.E6           .3
               10-        PBAR    101     201     2.      .667    .1667   .458                    +000001
               11-        ++0000011.      .5      -1.     .5                                      +000002
               12-        ++000002.8333   .8333
               13-        SPC1    100     12345   1       4
                          ENDDATA
                   TOTAL  COUNT=     14
```

Shear Factor K:
K1 = K2 = 5/6 = .8333 for rectangular sections

Shear Factor K: K1 = K2 = 5/6 = .8333 for rectangular sections

Listing 1-2. Shear Factor K on PBAR Entry

The deflection results are given in the output:

```
HINGED BEAM                                          JULY 10, 2003  NX NASTRAN   7/10/2003   PAGE    8
     WITH CONCENTRATED FORCE
                                          D I S P L A C E M E N T   V E C T O R
```

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
1	G	0.0	0.0	0.0	0.0	0.0	-2.221112E-04
2	G	0.0	-1.960807E-03	0.0	0.0	0.0	-1.388195E-04
3	G	0.0	-2.255780E-03	0.0	0.0	0.0	1.110556E-04
4	G	0.0	0.0	0.0	0.0	0.0	2.776390E-04

Comparing deflection at GRID 3 with and without shear, we have:

u_y^3 (without shear) = -2.221112E-3 inch

u_y^3 (with shear) = -2.255780E-3 inch

Thus, adding shear to the model results in about 1.6% greater deflection of GRID 3.

The stresses on the top and bottom surfaces of the beam at the point of application of the load are given by

σ = bending stress = ±Mc/I

where:

M	=	moment at GRID point 3
c	=	distance from neutral axis to outer fiber
I	=	bending moment of inertia in plane 1

From 1-7(c), the moment at GRID 3 is 666.6 in-lb. Thus,

$$\sigma = \pm\frac{(666.6 \text{ in-lb})(1.0 \text{ in})}{(.667 \text{ in}^4)} = \pm 999.4 \text{ lb/in}^2$$

which is in agreement with the NX Nastran results.

Chapter 2: Additional Examples

2.1 Cantilever Beam with a Distributed Load and a Concentrated Moment

This problem uses the same beam as the problem from the previous chapter (i.e., the GRIDs, CBAR elements, and element properties are identical). The loads and constraints have been changed.

Problem Statement

Find the free end deflection of a rectangular cantilever beam subject to a uniform distributed load and a concentrated moment at the free end. The beam's geometry, properties, and loading are shown in Figure 2-1.

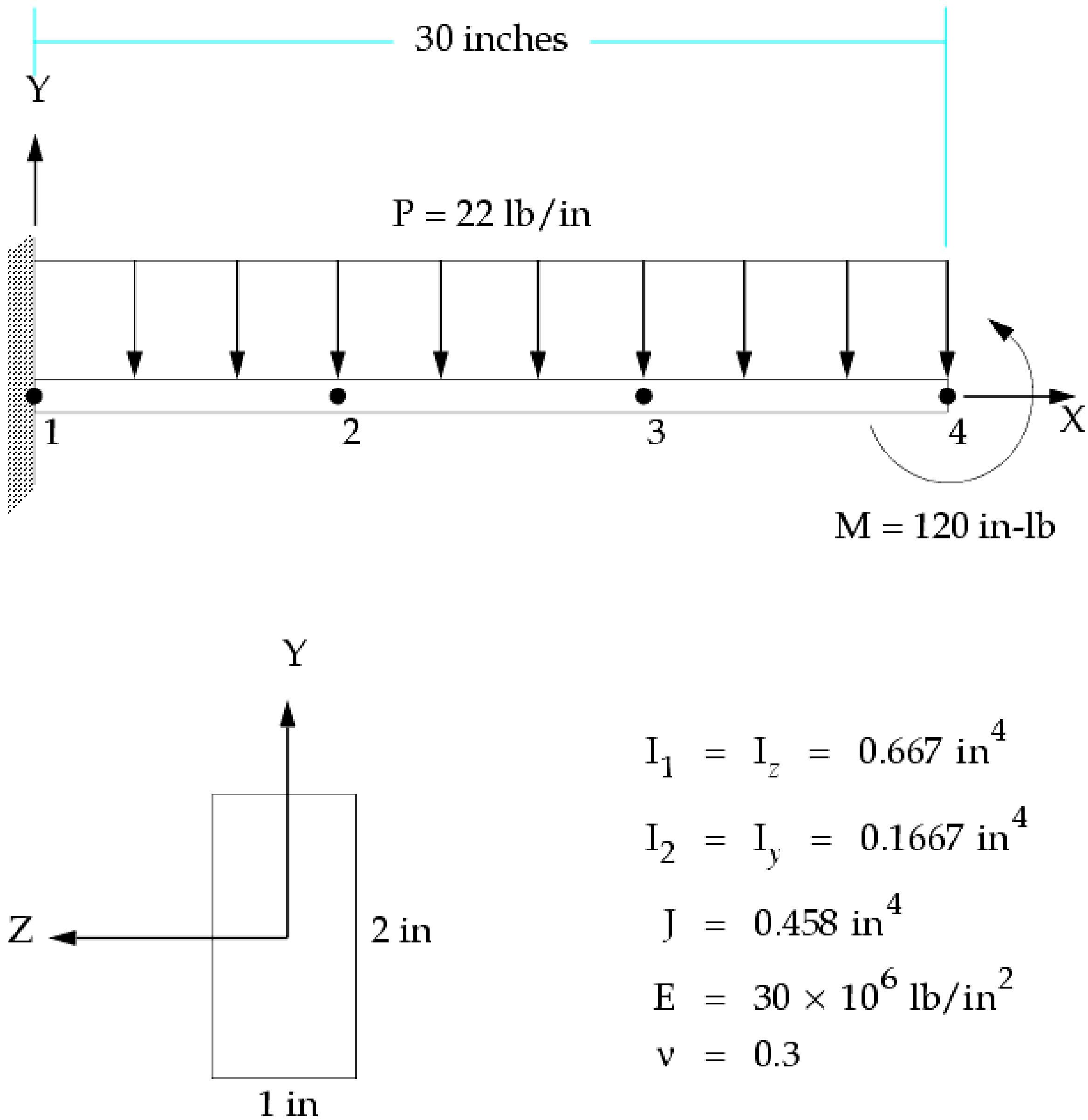


Figure 2-1. Beam Geometry, Properties, and Loads

The Finite Element Model

Applying the Loads

The uniform distributed load is applied to the three CBAR elements using a PLOAD1 entry. One PLOAD1 entry is required for each element. We have chosen fractional scaling, which means that the physical length of the element is normalized to a length of 1.0. Since the distributed load runs the entire length of each element, each PLOAD1 entry will be applied from 0.0 to 1.0. Since the load is uniform, P1 = P2 = 22.0 lb/in.

The concentrated end moment is applied using a MOMENT entry. The direction of the moment (by the right hand rule) is about the +z axis. Thus,

$$\vec{m} = M\vec{N}$$

where M is the magnitude of 120.0 in-lb, and

$$\vec{N}$$

is the vector (0., 0., 1.).

The load set ID is 10, and the loads are selected in the Case Control Section with the Command LOAD = 10.

Applying the Constraints

Grid 1 is fixed in a wall, so all six DOFs (123456) are constrained to zero. This can be done directly on the GRID entry using Field 8 (PS—permanent single point constraints associated with the grid point). No other constraints are required in this model.

Output Requests

The Case Control Command DISP = ALL is required to report displacements. In addition, it is a good idea to look at constraint forces at the wall as part of checking out the model. Thus, we will add the Case Control Command SPCF = ALL.

The Input File

The complete input file is shown in Listing 2-1.

```
    ID MPM,EXAMPLE2
SOL 101
TIME 100
CEND
ECHO=BOTH
DISP=ALL
SPCF=ALL
LOAD=10
TITLE=EXAMPLE 2
SUBTITLE=CANTILEVER BEAM
LABEL=DISTRIBUTED LOAD AND END MOMENT
$
BEGIN BULK
$     DEFINE
GRID POINTS
GRID,1,,0.,0.,0.,,123456
GRID,2,,10.,0.,0.
GRID,3,,20.,0.,0.
GRID,4,,30.,0.,0.
$
$     DEFINE CBAR ELEMENTS
CBAR,1,101,1,2,0.,1.,0.
CBAR,2,101,2,3,0.,1.,0.
CBAR,3,101,3,4,0.,1.,0.
$
$     DEFINE CBAR ELEMENT CROSS SECTIONAL PROPERTIES
PBAR,101,201,2.,.667,.1667,.458,,,
```

```
+PB1 +PB1,1.,.5
$
$     DEFINE MATERIAL PROPERTIES
MAT1,201,30.E6,,.3
$
$     DEFINE UNIFORM DISTRIBUTED LOAD
PLOAD1,10,1,FY,FR,0.,-22.,1.,-22.
PLOAD1,10,2,FY,FR,0.,-22.,1.,-22.
PLOAD1,10,3,FY,FR,0.,-22.,1.,-22.
$
$     DEFINE CONCENTRATED MOMENT AT FREE END
MOMENT,10,4,,120.,0.,0.,1.
ENDDATA
```

Listing 2-1.

NX Nastran Results

The NX Nastran results are shown in Table 2-1.

Table 2-1. Cantilever Beam f06 Results File

```
          THIS PROGRAM IS CONFIDENTIAL AND A TRADE SECRET OF EDS PLM SOLUTIONS.  THE RECEIPT OR
     POSSESSION OF THIS PROGRAM DOES NOT CONVEY ANY RIGHTS TO REPRODUCE OR DISCLOSE ITS CONTENTS, OR TO
    MANUFACTURE, USE, OR SELL ANYTHING HEREIN, IN WHOLE OR IN PART, WITHOUT THE SPECIFIC WRITTEN CONSENT
                                   OF EDS PLM SOLUTIONS.


                         * * * * * * * * * * * * * * * * * * * *
                         * * * * * * * * * * * * * * * * * * * *
                         * *                                  * *
                         * *         EDS PLM SOLUTIONS        * *
                         * *               CORP               * *
                         * *                                  * *
                         * *      NX   N a s t r a n          * *
                         * *                                  * *
                         * *         VERSION - 1.0            * *
                         * *                                  * *
                         * *          JUL 10, 2003            * *
                         * *                                  * *
                         * *                                  * *
                         * *              Intel               * *
                         * *                                  * *
                         * *MODEL PentiumIII/995 (MERCED.scm)* *
                         * *                                  * *
                         * *  Windows 2000 5.0 (Build 2195)   * *
                         * *                                  * *
                         * *                                  * *
                         * *                                  * *
                         * * * * * * * * * * * * * * * * * * * *
                         * * * * * * * * * * * * * * * * * * * *
```

```
                                                          JULY  10, 2003   NX NASTRAN   7/10/2003   PAGE     1

     N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O


 ID MPM,EXAMPLE2
 SOL 101
 TIME 100
 CEND
```

```
EXAMPLE 2                                                 JULY  10, 2003   NX NASTRAN   7/10/2003   PAGE     2
 CANTILEVER BEAM
 DISTRIBUTED LOAD AND END MOMENT
                                      C A S E    C O N T R O L    D E C K    E C H O
            CARD
            COUNT
             1        ECHO=BOTH
             2        DISP=ALL
             3        SPCF=ALL
             4        LOAD=10
             5        TITLE=EXAMPLE 2
             6        SUBTITLE=CANTILEVER BEAM
             7        LABEL=DISTRIBUTED LOAD AND END MOMENT
             8        $
             9        BEGIN BULK
```

```
EXAMPLE 2                                                      JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     3
 CANTILEVER BEAM
 DISTRIBUTED LOAD AND END MOMENT
                                        I N P U T   B U L K   D A T A   D E C K   E C H O

                          .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
                           $     DEFINE GRID POINTS
                           GRID,1,,0.,0.,0.,,123456
                           GRID,2,,10.,0.,0.
                           GRID,3,,20.,0.,0.
                              GRID,4,,30.,0.,0.
                           $
                           $     DEFINE CBAR ELEMENTS
                           CBAR,1,101,1,2,0.,1.,0.
                           CBAR,2,101,2,3,0.,1.,0.
                           CBAR,3,101,3,4,0.,1.,0.
                           $
                           $     DEFINE CBAR ELEMENT CROSS SECTIONAL PROPERTIES
                           PBAR,101,201,2.,.667,.1667,.458,,,+PB1
                           +PB1,1.,.5
                           $
                           $     DEFINE MATERIAL PROPERTIES
                           MAT1,201,30.E6,,.3
                           $
                           $     DEFINE UNIFORM DISTRIBUTED LOAD
                           PLOAD1,10,1,FY,FR,0.,-22.,1.,-22.
                           PLOAD1,10,2,FY,FR,0.,-22.,1.,-22.
                           PLOAD1,10,3,FY,FR,0.,-22.,1.,-22.
                           $
                           $     DEFINE CONCENTRATED MOMENT AT FREE END
                           MOMENT,10,4,,120.,0.,0.,1.
                           ENDDATA
                           INPUT BULK DATA CARD COUNT =      26
```

```
EXAMPLE 2                                                      JULY  10, 2003   NX NASTRAN   7/10/2003   PAGE     4
 CANTILEVER BEAM
 DISTRIBUTED LOAD AND END MOMENT
                                           S O R T E D   B U L K   D A T A   E C H O
            CARD
            COUNT        .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
               1-        CBAR    1       101     1       2       0.      1.      0.
               2-        CBAR    2       101     2       3       0.      1.      0.
               3-        CBAR    3       101     3       4       0.      1.      0.
               4-        GRID    1               0.      0.      0.              123456
               5-        GRID    2               10.     0.      0.
               6-        GRID    3               20.     0.      0.
               7-        GRID    4               30.     0.      0.
               8-        MAT1    201     30.E6           .3
               9-        MOMENT  10      4               120.    0.      0.      1.
              10-        PBAR    101     201     2.      .667    .1667   .458                    +PB1
              11-        +PB1    1.      .5
              12-        PLOAD1  10      1       FY      FR      0.      -22.    1.      -22.
              13-        PLOAD1  10      2       FY      FR      0.      -22.    1.      -22.
              14-        PLOAD1  10      3       FY      FR      0.      -22.    1.      -22.
                         ENDDATA
                   TOTAL COUNT=        15
```

```
   EXAMPLE 2                                                      JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     5
    CANTILEVER BEAM
    DISTRIBUTED LOAD AND END MOMENT
 USER INFORMATION MESSAGE
ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM WILL BE USED AS REFERENCE LOCATION.
 RESULTANTS ABOUT ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM IN SUPERELEMENT BASIC SYSTEM COORDINATES.
                                                OLOAD    RESULTANT
             T1             T2             T3             R1             R2             R3
      1   0.0000000E+00 -6.6000000E+02  0.0000000E+00  0.0000000E+00  0.0000000E+00 -9.7800000E+03
```

```
   EXAMPLE 2                                                      JULY  10, 2003 NX NASTRAN   7/10/2003   PAGE     6
    CANTILEVER BEAM
    DISTRIBUTED LOAD AND END MOMENT
*** USER INFORMATION MESSAGE 5293 FOR DATA BLOCK KLL
   LOAD SEQ. NO.             EPSILON              EXTERNAL WORK      EPSILONS LARGER THAN 0.001 ARE FLAGGED WITH ASTERISKS
               1         -7.7706584E-17          1.4106205E+01
```

```
   EXAMPLE 2                                                                   JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     7
    CANTILEVER BEAM
    DISTRIBUTED LOAD AND END MOMENT
 USER INFORMATION MESSAGE
ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM WILL BE USED AS REFERENCE LOCATION.
 RESULTANTS ABOUT ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM IN SUPERELEMENT BASIC SYSTEM COORDINATES.
                                                 SPCFORCE RESULTANT
              T1             T2             T3             R1             R2             R3
  1   0.0000000E+00  6.6000000E+02  0.0000000E+00  0.0000000E+00  0.0000000E+00  9.7800000E+03
```

```
 EXAMPLE 2                                                                   JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     8
  CANTILEVER BEAM
  DISTRIBUTED LOAD AND END MOMENT

                                             D I S P L A C E M E N T   V E C T O R

  POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
         1      G      0.0            0.0            0.0            0.0            0.0            0.0
         2      G      0.0           -1.939863E-02   0.0            0.0            0.0           -3.421623E-03
         3      G      0.0           -6.110278E-02   0.0            0.0            0.0           -4.644345E-03
         4      G      0.0           -1.086207E-01   0.0            0.0            0.0           -4.767616E-03
```

```
EXAMPLE 2                                                                   JULY 10, 2003  NX NASTRAN   7/10/2003   PAGE     9
 CANTILEVER BEAM
 DISTRIBUTED LOAD AND END MOMENT

                              F O R C E S   O F   S I N G L E - P O I N T   C O N S T R A I N T

  POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
         1      G      0.0            6.600000E+02   0.0            0.0            0.0            9.780000E+03
```

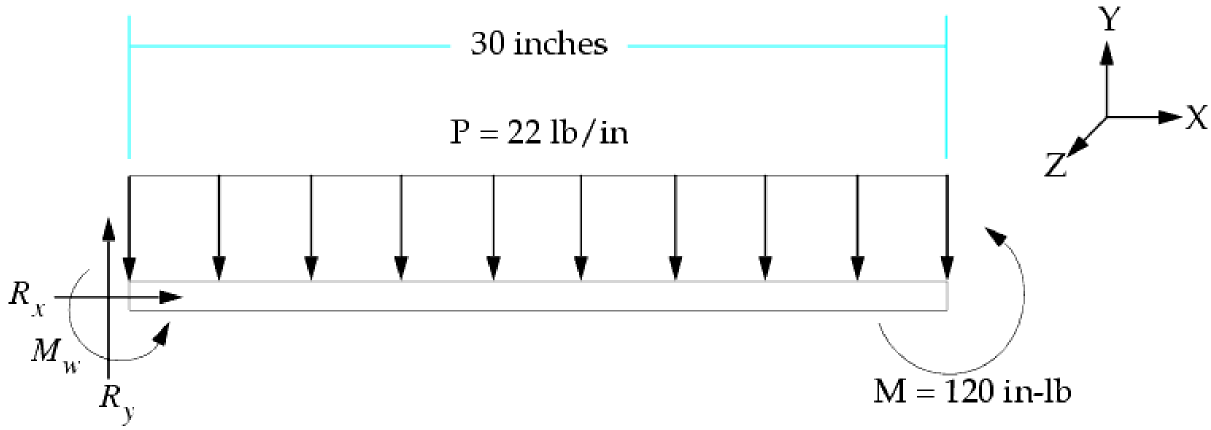
```
 EXAMPLE 2                                                                   JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE    10
  CANTILEVER BEAM
  DISTRIBUTED LOAD AND END MOMENT
```

```
   EXAMPLE 2                                                                   JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE    11
    CANTILEVER BEAM
    DISTRIBUTED LOAD AND END MOMENT
* * * *  D B D I C T   P R I N T  * * * *      SUBDMAP = PRTSUM  ,  DMAP STATEMENT NO.     13
                                      * * * *  A N A L Y S I S   S U M M A R Y   T A B L E  * * * *
 SEID  PEID PROJ VERS APRCH      SEMG SEMR SEKR SELG SELR MODES DYNRED SOLLIN PVALID SOLNL LOOPID DESIGN CYCLE SENSITIVITY
-------------------------------------------------------------------------------------------------------------------------
    0     0    1    1 '        '    T    T    T    T    T     F      F      T      0     F     -1            0           F
SEID = SUPERELEMENT ID.
PEID = PRIMARY SUPERELEMENT ID OF IMAGE SUPERELEMENT.
PROJ = PROJECT ID NUMBER.
VERS = VERSION ID.
APRCH = BLANK FOR STRUCTURAL ANALYSIS.  HEAT FOR HEAT TRANSFER ANALYSIS.
SEMG = STIFFNESS AND MASS MATRIX GENERATION STEP.
SEMR = MASS MATRIX REDUCTION STEP (INCLUDES EIGENVALUE SOLUTION FOR MODES).
SEKR = STIFFNESS MATRIX REDUCTION STEP.
SELG = LOAD MATRIX GENERATION STEP.
SELR = LOAD MATRIX REDUCTION STEP.
MODES = T (TRUE) IF NORMAL MODES OR BUCKLING MODES CALCULATED.
DYNRED = T (TRUE) MEANS GENERALIZED DYNAMIC AND/OR COMPONENT MODE REDUCTION PERFORMED.
SOLLIN = T (TRUE) IF LINEAR SOLUTION EXISTS IN DATABASE.
PVALID = P-DISTRIBUTION ID OF P-VALUE FOR P-ELEMENTS
LOOPID = THE LAST LOOPID VALUE USED IN THE NONLINEAR ANALYSIS.  USEFUL FOR RESTARTS.
SOLNL = T (TRUE) IF NONLINEAR SOLUTION EXISTS IN DATABASE.
DESIGN CYCLE = THE LAST DESIGN CYCLE (ONLY VALID IN OPTIMIZATION).
SENSITIVITY = SENSITIVITY MATRIX GENERATION FLAG.

                                        * * * END OF JOB * * *
```

Reviewing the Results

First, we review the .f06 output file for any warning or error messages. None are present in this file. Next, look at epsilon on page 6 of the output. Its value of -7.77E-17 is indeed very small, showing no evidence of numerical difficulties. Finally, we review the reaction forces (forces of single point constraint, or SPC forces) at the wall. As a check, a free body diagram of the structure is used to solve for reaction forces as follows:



Solving for the reactions at the wall, we obtain:

Forces in x: $\overset{+}{\rightarrow} \sum F_x = 0 = R_x$

$$\boxed{R_x = 0}$$

Forces in y: $+\uparrow \sum F_y = 0 = R_y - (22 \text{ lb/in})(30 \text{ in})$

$$\boxed{R_y = 660 \text{ lbs}}$$

Moment at wall: $+ \sum M_{wall} = M_w + 120 \text{ in-lb} - (660\text{lbs})(15 \text{ in})$

$$\boxed{M_w = 9780 \text{ in-lb}}$$

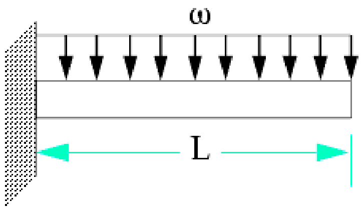
The SPC forces are listed on page 9 of the NX Nastran results. The T2 reaction (force at grid point 1 in the y direction) is +660 lbs. The R3 reaction (moment about the z axis) is +9780 lb. Thus, we can be confident that the loads were applied correctly, and at least the static equilibrium of the problem makes sense.

The displacement results are shown on page 8 of the .f06 file. Note that all displacements at the wall (GRID 1) are exactly zero, as they should be. The free end deflection in the y direction (T2 of GRID 4) is -1.086207E-1 in.

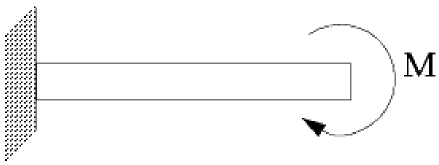
As a final observation, note that there is no axial shortening of the beam as it deflects downward (all T1s are exactly zero). This is a consequence of the simplifying small displacement assumptions built into slender beam theory and beam elements when used in linear analysis. If the load on the beam is such that large displacement occurs, nonlinear analysis must be used to update the element matrices as the structure deforms. The shortening terms will then be part of the solution.

Comparison with Theory

The theory solution to this problem is as follows:



$$\text{Maximum deflection} = \frac{\omega L^4}{8EI}$$



$$\text{Maximum deflection} = \frac{ML^2}{2EI}$$

Using superposition, the net deflection at free end is given by:

$$-\left(\frac{ML^2}{2EI} + \frac{\omega L^4}{8EI}\right) = -\frac{L^2}{2EI}\left(M + \frac{\omega L^2}{4}\right) = -0.10862 \text{ inches}$$

Thus, we are in exact agreement with the NX Nastran result.

It should be noted that simple beam bending problems such as this give exact answers, even with one element. This is a very special case and is by no means typical of real world problems.

2.2 Rectangular Plate (fixed-hinged-hinged-free) with a Uniform Lateral Pressure Load

Problem Statement

Create an NX Nastran model to analyze the thin rectangular plate shown in Figure 2-2. The plate is subject to a uniform pressure load of 0.25 lb/in^2 in the -z direction. Find the maximum deflection of the plate.

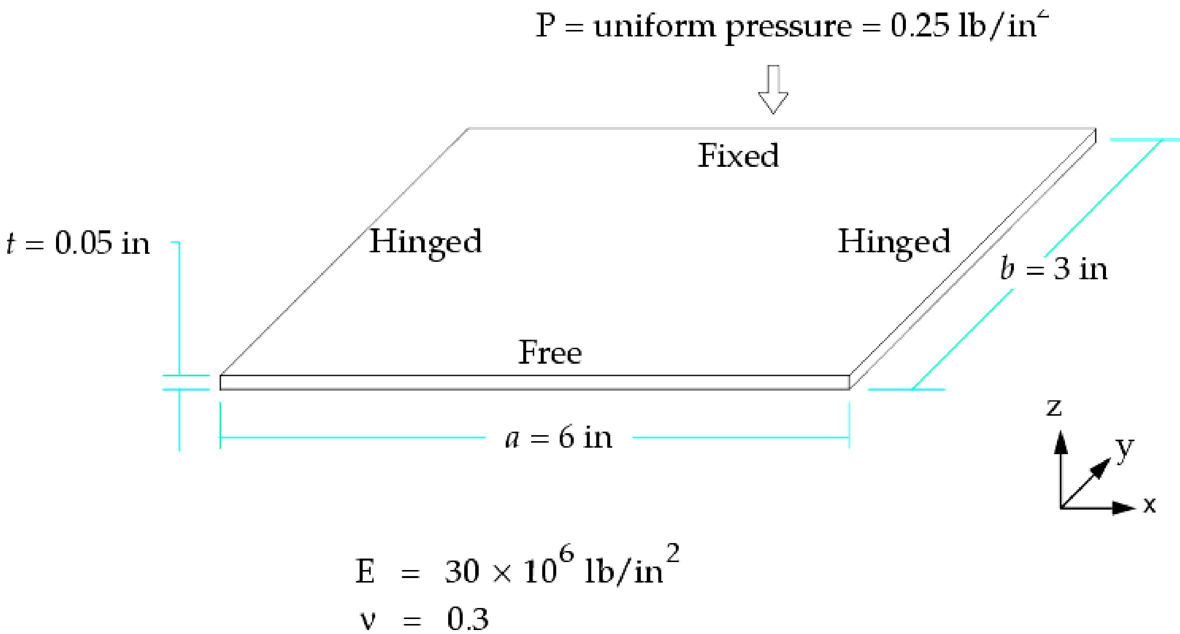


Figure 2-2. Plate Geometry, Boundary Conditions, and Load

The Finite Element Model

Designing the Model

First, we need to examine the structure to verify that it can reasonably qualify as a thin plate. The thickness is 1/60 of the next largest dimension (3 inches), which is satisfactory.

Next, we observe by inspection that the maximum deflection, regardless of the actual value, should occur at the center of the free edge. Thus, it will be helpful to locate a grid point there to recover the maximum displacement.

As a matter of good practice, we wish to design a model with the fewest elements that will do the job. In our case, doing the job means good displacement accuracy. The model shown in Figure 2-3 contains 20 GRID points and 12 CQUAD4 elements, which we hope will yield reasonable displacement results. If we have reason to question the accuracy of the solution, we can always rerun the model with a finer mesh.

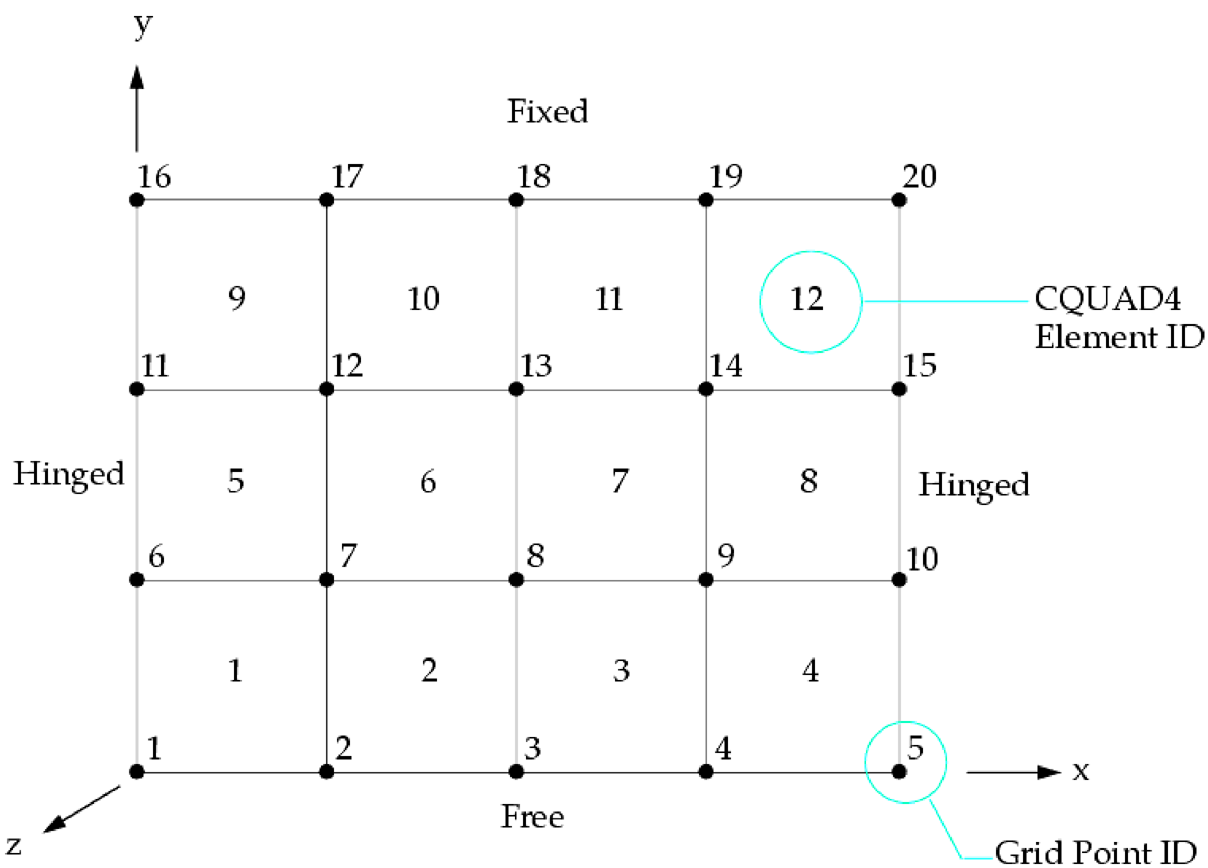


Figure 2-3. Plate Finite Element Model

Applying the Load

The uniform pressure load is applied to all plate elements using the PLOAD2 entry. Only one PLOAD2 entry is required by using the "THRU" feature (elements 1 THRU 12). The positive normal to each plate element (as dictated by the GRID point ordering sequence) is in the negative z axis direction, which is the same direction as the pressure load. Therefore, the value of pressure in Field 3 of the PLOAD2 entry is positive.

Applying the Constraints

SPC1 entries are used to model the structure's constraints. The SPC1 entries have a set ID of 10, which is selected by the Case Control command SPC = 100. The constraints on the structure are shown in Figure 2-4.

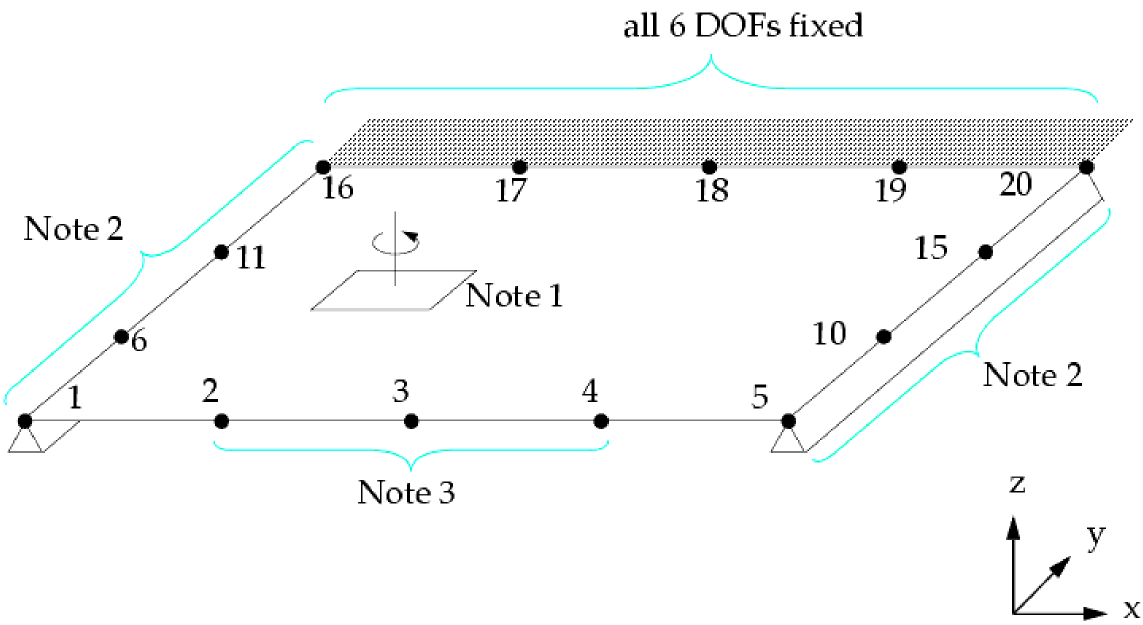


Figure 2-4. Constraints on the Plate Structure

> **Note**
>
> 1. The out-of-plane rotational DOF (degree of freedom 6) is constrained for all grids in the model. This is a requirement of a CQUAD4 flat plate element, and has nothing to do with this specific problem.
>
> 2. Grids 16 and 20, shared with the fixed edge, are fixed—the greater constraint governs. For the remaining grids:
>
> 3. Displacements Allowed: Rotation about y-axis (DOF 5)
>
> 4. Displacements Not Allowed: Rotation about x-axis (DOF 4) Translation in x, y, or z (DOFs 1, 2, 3)
>
> 5. The non-corner grids of the free edge have no additional constraints.

The SPC1 entries are written as follows:

Format:

1	2	3	4	5	6	7	8	9	10
SPC1	SID	C	G1	G2	G3	G4	G5	G6	
	G7	G8	G9	-etc.-					

Alternate Format:

SPC1	SID	C	G1	“THRU”	G2				

Out-of-plane Rotations:

SPC1	100	6	1	THRU	20				

Hinged Edges:

spc1	100	1234	1	6	11	5	10	15	

Fixed Edge:

Note that some constraints are redundantly specified. For example, GRID 17 is constrained in all 6 DOFs with the fixed edge SPC1, and again in DOF 6 with the out-of-plane rotational constraint. This is perfectly acceptable, and keeps the constraint bookkeeping a little tidier.

SPC1	100	123456	16	THRU	20				

Output Requests

The problem statement requires displacements. As a matter of good practice, we will also request SPC forces to check the model's reactions. Thus, the following output requests are included in the Case Control Section:

```
DISP=ALL SPCF=ALL
```

The Input File

The complete input file is shown in Listing 2-2.

```
 ID MPM,EXAMPLE3
SOL 101
TIME 100
CEND
SPCF=ALL
DISP=ALL
TITLE=PLATE EXAMPLE
SUBTITLE=FIXED-HINGED-HINGED-FREE
LABEL=UNIFORM LATERAL PRESSURE LOAD (0.25 lb/in**2)
SPC=100
ECHO=BOTH
LOAD=5
$
BEGIN BULK
$ DEFINE GRID POINTS
GRID,1,,0.,0.,0.
GRID,2,,1.5,0.,0.
GRID,3,,3.0,0.,0.
GRID,4,,4.5,0.,0.
GRID,5,,6.0,0.,0.
GRID,6,,0.,1.,0.
GRID,7,,1.5,1.,0.
GRID,8,,3.0,1.,0.
GRID,9,,4.5,1.,0.
GRID,10,,6.0,1.,0.
GRID,11,,0.,2.,0.
GRID,12,,1.5,2.,0.
GRID,13,,3.0,2.,0.
GRID,14,,4.5,2.,0.
```

```
GRID,15,,6.0,2.,0.
GRID,16,,0.,3.,0.
GRID,17,,1.5,3.,0.
GRID,18,,3.0,3.,0.
GRID,19,,4.5,3.,0.
GRID,20,,6.0,3.,0.
$
$ DEFINE PLATE ELEMENTS
CQUAD4,1,101,1,6,7,2
CQUAD4,2,101,2,7,8,3
CQUAD4,3,101,3,8,9,4
CQUAD4,4,101,4,9,10,5
CQUAD4,5,101,6,11,12,7
CQUAD4,6,101,7,12,13,8
CQUAD4,7,101,8,13,14,9
CQUAD4,8,101,9,14,15,10
CQUAD4,9,101,11,16,17,12
CQUAD4,10,101,12,17,18,13
CQUAD4,11,101,13,18,19,14
CQUAD4,12,101,14,19,20,15
$
$ DEFINE PRESSURE LOAD ON PLATES
PLOAD2,5,0.25,1,THRU,12
$ DEFINE PROPERTIES OF PLATE ELEMENTS
PSHELL,101,105,.05,105,,105
MAT1,105,30.E6,,0.3
$
$ DEFINE FIXED EDGE
SPC1,100,123456,16,THRU,20
$
$ DEFINE HINGED EDGES
SPC1,100,1234,1,6,11,5,10,15
$
$ CONSTRAIN OUT-OF-PLANE ROTATION FOR ALL GRIDS
SPC1,100,6,1,THRU,20
ENDDATA
```

Listing 2-2.

NX Nastran Results

The NX Nastran results are shown in Table 2-2.

Table 2-2. Rectangular Plate f06 Results File

```
        THIS PROGRAM IS CONFIDENTIAL AND A TRADE SECRET OF EDS PLM SOLUTIONS CORP.  THE RECEIPT OR
     POSSESSION OF THIS PROGRAM DOES NOT CONVEY ANY RIGHTS TO REPRODUCE OR DISCLOSE ITS CONTENTS, OR TO
    MANUFACTURE, USE, OR SELL ANYTHING HEREIN, IN WHOLE OR IN PART, WITHOUT THE SPECIFIC WRITTEN CONSENT
                                    OF EDS PLM SOLUTIONS.

                      * * * * * * * * * * * * * * * * * * * *
                      * * * * * * * * * * * * * * * * * * * *
                      * *                                 * *
                      * *         EDS PLM SOLUTIONS       * *
                      * *              CORP               * *
                      * *                                 * *
                      * *       NX     N a s t r a n      * *
                      * *                                 * *
                      * *         VERSION - 1.0           * *
                      * *                                 * *
                      * *          JUL:10, 2003           * *
                      * *                                 * *
                      * *                                 * *
                      * *              Intel              * *
                      * *                                 * *
                      * *MODEL PentiumIII/995 (MERCED.scm)* *
                      * *                                 * *
                      * *  Windows 2000 5.0 (Build 2195)  * *
                      * *                                 * *
                      * *                                 * *
                      * *                                 * *
                      * * * * * * * * * * * * * * * * * * * *
                      * * * * * * * * * * * * * * * * * * * *
```

```
                                                     JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE    1

   N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O
 ID MPM,EXAMPLE3
 SOL 101
 TIME 100
 CEND
```

```
 PLATE EXAMPLE                                          JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     2
  FIXED-HINGED-HINGED-FREE
  UNIFORM LATERAL PRESSURE LOAD (0.25 LB/IN**2)
                                  C A S E    C O N T R O L    D E C K    E C H O
               CARD
               COUNT
                1      SPCF=ALL
                2      DISP=ALL
                3      TITLE=PLATE EXAMPLE
                4      SUBTITLE=FIXED-HINGED-HINGED-FREE
                5      LABEL=UNIFORM LATERAL PRESSURE LOAD (0.25 LB/IN**2)
                6      SPC=100
                7      ECHO=BOTH
                8      LOAD=5
                9      $
               10      BEGIN BULK
```

```
PLATE EXAMPLE                                                    JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     3
   FIXED-HINGED-HINGED-FREE
  UNIFORM LATERAL PRESSURE LOAD (0.25 LB/IN**2)
                                        I N P U T   B U L K   D A T A   D E C K   E C H O
                            .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
                            $     DEFINE GRID POINTS
                            GRID,1,,0.,0.,0.
                            GRID,2,,1.5,0.,0.
                            GRID,3,,3.0,0.,0.
                            GRID,4,,4.5,0.,0.
                            GRID,5,,6.0,0.,0.
                            GRID,6,,0.,1.,0.
                            GRID,7,,1.5,1.,0.
                            GRID,8,,3.0,1.,0.
                            GRID,9,,4.5,1.,0.
                            GRID,10,,6.0,1.,0.
                            GRID,11,,0.,2.,0.
                            GRID,12,,1.5,2.,0.
                            GRID,13,,3.0,2.,0.
                            GRID,14,,4.5,2.,0.
                            GRID,15,,6.0,2.,0.
                            GRID,16,,0.,3.,0.
                            GRID,17,,1.5,3.,0.
                            GRID,18,,3.0,3.,0.
                            GRID,19,,4.5,3.,0.
                            GRID,20,,6.0,3.,0.
                            $
                            $     DEFINE PLATE ELEMENTS
                            CQUAD4,1,101,1,6,7,2
                            CQUAD4,2,101,2,7,8,3
                            CQUAD4,3,101,3,8,9,4
                            CQUAD4,4,101,4,9,10,5
                            CQUAD4,5,101,6,11,12,7
                            CQUAD4,6,101,7,12,13,8
                            CQUAD4,7,101,8,13,14,9
                            CQUAD4,8,101,9,14,15,10
                            CQUAD4,9,101,11,16,17,12
                            CQUAD4,10,101,12,17,18,13
                            CQUAD4,11,101,13,18,19,14
                            CQUAD4,12,101,14,19,20,15
                            $
                            $     DEFINE PRESSURE LOAD ON PLATES
                            PLOAD2,5,0.25,1,THRU,12
                            $     DEFINE PROPERTIES OF PLATE ELEMENTS
                            PSHELL,101,105,.05,105,,105
                            MAT1,105,30.E6,,0.3
                            $
                            $     DEFINE FIXED EDGE
                            SPC1,100,123456,16,THRU,20
                            $
                            $     DEFINE HINGED EDGES
                            SPC1,100,1234,1,6,11,5,10,15
                            $
                            $     CONSTRAIN OUT-OF-PLANE ROTATION FOR ALL GRIDS
                            SPC1,100,6,1,THRU,20
                            ENDDATA
                            INPUT BULK DATA CARD COUNT =      51
```

```
 PLATE EXAMPLE                                                                    JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     4
    FIXED-HINGED-HINGED-FREE
 UNIFORM LATERAL PRESSURE LOAD (0.25 LB/IN**2)
                                                  S O R T E D   B U L K   D A T A   E C H O
                CARD
                COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                   1-        CQUAD4  1       101     1       6       7       2
                   2-        CQUAD4  2       101     2       7       8       3
                   3-        CQUAD4  3       101     3       8       9       4
                   4-        CQUAD4  4       101     4       9       10      5
                   5-        CQUAD4  5       101     6       11      12      7
                   6-        CQUAD4  6       101     7       12      13      8
                   7-        CQUAD4  7       101     8       13      14      9
                   8-        CQUAD4  8       101     9       14      15      10
                   9-        CQUAD4  9       101     11      16      17      12
                  10-        CQUAD4  10      101     12      17      18      13
                  11-        CQUAD4  11      101     13      18      19      14
                  12-        CQUAD4  12      101     14      19      20      15
                  13-        GRID    1               0.      0.      0.
                  14-        GRID    2               1.5     0.      0.
                  15-        GRID    3               3.0     0.      0.
                  16-        GRID    4               4.5     0.      0.
                  17-        GRID    5               6.0     0.      0.
                  18-        GRID    6               0.      1.      0.
                  19-        GRID    7               1.5     1.      0.
                  20-        GRID    8               3.0     1.      0.
                  21-        GRID    9               4.5     1.      0.
                  22-        GRID    10              6.0     1.      0.
                  23-        GRID    11              0.      2.      0.
                  24-        GRID    12              1.5     2.      0.
                  25-        GRID    13              3.0     2.      0.
                  26-        GRID    14              4.5     2.      0.
                  27-        GRID    15              6.0     2.      0.
                  28-        GRID    16              0.      3.      0.
                  29-        GRID    17              1.5     3.      0.
                  30-        GRID    18              3.0     3.      0.
                  31-        GRID    19              4.5     3.      0.
                  32-        GRID    20              6.0     3.      0.
                  33-        MAT1    105     30.E6           0.3
                  34-        PLOAD2  5       0.25    1       THRU    12
                  35-        PSHELL  101     105     .05     105             105
                  36-        SPC1    100     6       1       THRU    20
                  37-        SPC1    100     1234    1       6       11      5       10      15
                  38-        SPC1    100     123456  16      THRU    20
                             ENDDATA
                      TOTAL COUNT=        39

 PLATE EXAMPLE                                                                    JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     5
    FIXED-HINGED-HINGED-FREE
   UNIFORM LATERAL PRESSURE LOAD (0.25 LB/IN**2)
 USER INFORMATION MESSAGE
ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM WILL BE USED AS REFERENCE LOCATION.
 RESULTANTS ABOUT ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM IN SUPERELEMENT BASIC SYSTEM COORDINATES.

                                                    OLOAD    RESULTANT

                T1              T2              T3              R1              R2              R3

        1    0.0000000E+00   0.0000000E+00 -4.5000000E+00 -6.7500000E+00   1.3500000E+01   0.0000000E+00

   PLATE EXAMPLE                                                                  JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     6
      FIXED-HINGED-HINGED-FREE
     UNIFORM LATERAL PRESSURE LOAD (0.25 LB/IN**2)
 *** USER INFORMATION MESSAGE 5293 FOR DATA BLOCK KLL

     LOAD SEQ. NO.             EPSILON              EXTERNAL WORK      EPSILONS LARGER THAN 0.001 ARE FLAGGED WITH ASTERISKS

                 1          1.8446709E-15          2.1564697E-03
```

```
 PLATE EXAMPLE                                                            JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     7
    FIXED-HINGED-HINGED-FREE
   UNIFORM LATERAL PRESSURE LOAD (0.25 LB/IN**2)
USER INFORMATION MESSAGE
ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM WILL BE USED AS REFERENCE LOCATION.
RESULTANTS ABOUT ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM IN SUPERELEMENT BASIC SYSTEM COORDINATES.

                                                  SPCFORCE RESULTANT

              T1             T2             T3             R1             R2             R3

       1   0.0000000E+00  0.0000000E+00  4.5000000E+00  6.7500000E+00 -1.3500000E+01  0.0000000E+00
```

```
PLATE EXAMPLE                                                            JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     8
   FIXED-HINGED-HINGED-FREE
  UNIFORM LATERAL PRESSURE LOAD (0.25 LB/IN**2)
                                             D I S P L A C E M E N T   V E C T O R

     POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
            1      G      0.0            0.0            0.0            0.0            2.010781E-03   0.0
            2      G      0.0            0.0           -2.627660E-03   1.125413E-03   1.375545E-03   0.0
            3      G      0.0            0.0           -3.678445E-03   1.583532E-03  -1.514721E-21   0.0
            4      G      0.0            0.0           -2.627660E-03   1.125413E-03  -1.375545E-03   0.0
            5      G      0.0            0.0            0.0            0.0           -2.010781E-03   0.0
            6      G      0.0            0.0            0.0            0.0            1.188741E-03   0.0
            7      G      0.0            0.0           -1.544730E-03   1.037140E-03   7.948730E-04   0.0
            8      G      0.0            0.0           -2.149283E-03   1.469851E-03  -2.318725E-21   0.0
            9      G      0.0            0.0           -1.544730E-03   1.037140E-03  -7.948730E-04   0.0
           10      G      0.0            0.0            0.0            0.0           -1.188741E-03   0.0
           11      G      0.0            0.0            0.0            0.0            4.129650E-04   0.0
           12      G      0.0            0.0           -5.316482E-04   9.315911E-04   2.673020E-04   0.0
           13      G      0.0            0.0           -7.322498E-04   1.282421E-03   1.553187E-21   0.0
           14      G      0.0            0.0           -5.316482E-04   9.315911E-04  -2.673020E-04   0.0
           15      G      0.0            0.0            0.0            0.0           -4.129650E-04   0.0
           16      G      0.0            0.0            0.0            0.0            0.0            0.0
           17      G      0.0            0.0            0.0            0.0            0.0            0.0
           18      G      0.0            0.0            0.0            0.0            0.0            0.0
           19      G      0.0            0.0            0.0            0.0            0.0            0.0
           20      G      0.0            0.0            0.0            0.0            0.0            0.0
```

```
PLATE EXAMPLE                                                            JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     9
   FIXED-HINGED-HINGED-FREE
  UNIFORM LATERAL PRESSURE LOAD (0.25 LB/IN**2)
                             F O R C E S   O F   S I N G L E - P O I N T   C O N S T R A I N T

     POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
            1      G      0.0            0.0            3.572939E-01  -9.891411E-02   0.0            0.0
            5      G      0.0            0.0            3.572939E-01  -9.891411E-02   0.0            0.0
            6      G      0.0            0.0            4.663838E-01  -4.931600E-02   0.0            0.0
           10      G      0.0            0.0            4.663838E-01  -4.931600E-02   0.0            0.0
           11      G      0.0            0.0            3.687456E-01   2.768068E-01   0.0            0.0
           15      G      0.0            0.0            3.687456E-01   2.768068E-01   0.0            0.0
           16      G      0.0            0.0           -4.810094E-01   1.029394E-01   2.657713E-02   0.0
           17      G      0.0            0.0            9.980871E-01  -7.319196E-01  -5.360183E-03   0.0
           18      G      0.0            0.0            1.080998E+00  -1.002403E+00   0.0            0.0
           19      G      0.0            0.0            9.980871E-01  -7.319196E-01   5.360183E-03   0.0
           20      G      0.0            0.0           -4.810094E-01   1.029394E-01  -2.657713E-02   0.0
```

```
 PLATE EXAMPLE                                                  JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE    11
   FIXED-HINGED-HINGED-FREE
  UNIFORM LATERAL PRESSURE LOAD (0.25 LB/IN**2)
* * * *  D B D I C T   P R I N T  * * * *      SUBDMAP = PRTSUM  ,  DMAP STATEMENT NO.     13

                                    * * * *  A N A L Y S I S  S U M M A R Y  T A B L E  * * * *

 SEID  PEID PROJ VERS APRCH      SEMG SEMR SEKR SELG SELR MODES DYNRED SOLLIN PVALID SOLNL LOOPID DESIGN CYCLE SENSITIVITY
 -----------------------------------------------------------------------------------------------------------------------
    0     0    1    1 '        '    T    T    T    T    T     F      F      T      0     F     -1            0           F

0SEID = SUPERELEMENT ID.
 PEID = PRIMARY SUPERELEMENT ID OF IMAGE SUPERELEMENT.
 PROJ = PROJECT ID NUMBER.
 VERS = VERSION ID.
 APRCH = BLANK FOR STRUCTURAL ANALYSIS.  HEAT FOR HEAT TRANSFER ANALYSIS.
 SEMG = STIFFNESS AND MASS MATRIX GENERATION STEP.
 SEMR = MASS MATRIX REDUCTION STEP (INCLUDES EIGENVALUE SOLUTION FOR MODES).
 SEKR = STIFFNESS MATRIX REDUCTION STEP.
 SELG = LOAD MATRIX GENERATION STEP.
 SELR = LOAD MATRIX REDUCTION STEP.
 MODES = T (TRUE) IF NORMAL MODES OR BUCKLING MODES CALCULATED.
 DYNRED = T (TRUE) MEANS GENERALIZED DYNAMIC AND/OR COMPONENT MODE REDUCTION PERFORMED.
 SOLLIN = T (TRUE) IF LINEAR SOLUTION EXISTS IN DATABASE.
 PVALID = P-DISTRIBUTION ID OF P-VALUE FOR P-ELEMENTS
 LOOPID = THE LAST LOOPID VALUE USED IN THE NONLINEAR ANALYSIS.  USEFUL FOR RESTARTS.
 SOLNL = T (TRUE) IF NONLINEAR SOLUTION EXISTS IN DATABASE.
 DESIGN CYCLE = THE LAST DESIGN CYCLE (ONLY VALID IN OPTIMIZATION).
 SENSITIVITY = SENSITIVITY MATRIX GENERATION FLAG.

                                        * * * END OF JOB * * *
```

Reviewing the Results

The value of epsilon, listed on page 6 of the output, is small, indicating a numerically well-behaved problem. A plot of the deformed plate is shown in Figure 2-5. As expected, the maximum displacement (-3.678445E-3 inches) occurs at grid point 3 in the -T3 direction. This deflection is approximately one-fourteenth the thickness of the plate, and is therefore a fairly reasonable “small” displacement.

It is also useful to check the applied loads against the reaction forces. We have:

Total Lateral Applied Force = (0.25 lb/in^2)(3 in)(6 in) = 4.5 lbs

which is in agreement with the T3 direction SPCFORCE resultant listed on page 7 of the output. Note that the SPCFORCE is positive, and the applied load is in the negative z (-T3) direction.

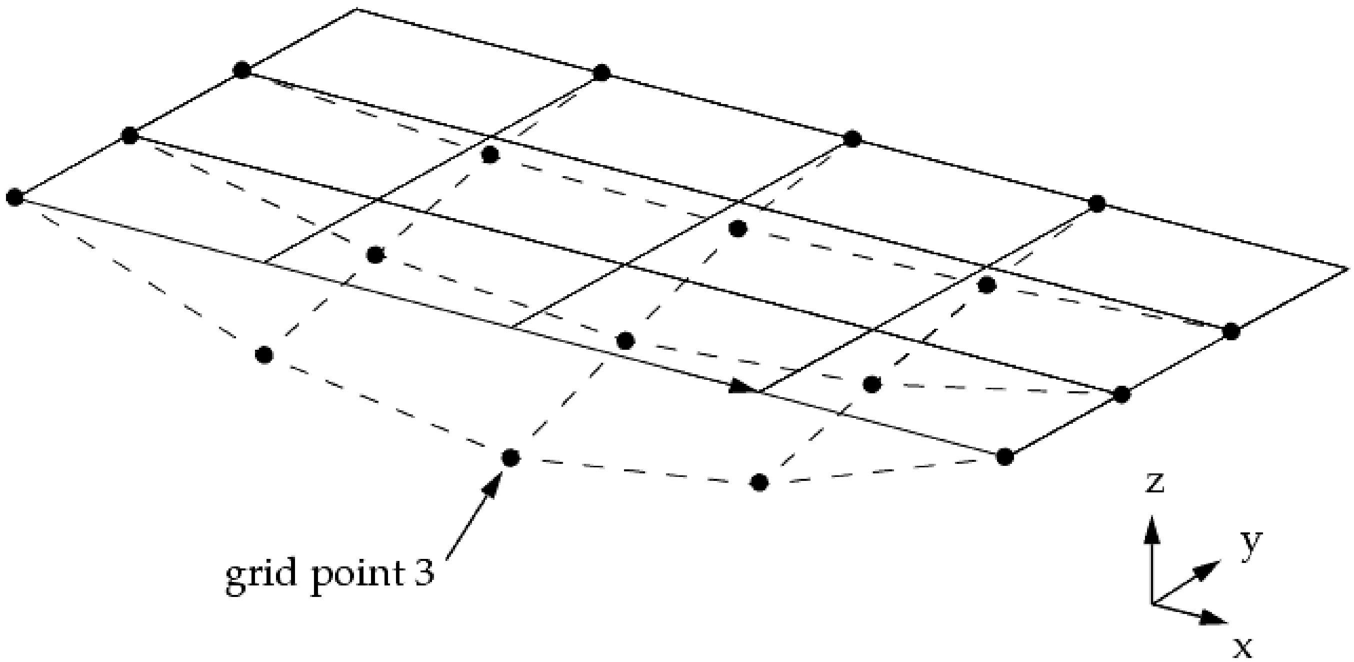


Figure 2-5. Deformed Shape

Comparison with Theory

Article 46 of Timoshenko, Theory of Plates and Shells, 2nd ed., gives the analytical solution for the maximum deflection of a fixed-hinged-hinged-free plate with a uniform lateral load as:

W_{max} = ($0.582\ qb^4$ / D) (for b/a = 1/2)

where:

q = lateral pressure = 0.25 lb/in^2

D =

$$\frac{Et^3}{12(1-\nu^2)} = \frac{(30 \times 10^6\ \mathrm{lb/in}^2)(0.5\ \mathrm{in})^3}{12(1-0.3^2)} = 343.407$$

Therefore, the maximum deflection is:

$$W_{max} = \frac{.0582(0.25\ \mathrm{lb/in}^2)(3\ \mathrm{in})^4}{343.407\ \mathrm{in\text{-}lb}} = 3.43193\mathrm{E\text{-}3\ in}$$

The NX Nastran solution at grid point 3 is:

W_{max} = 3.678445E-3 in

The NX Nastran result (which includes transverse shear) is 7.2% greater than the theory solution. The theory solution does not account for transverse shear deflection. Rerunning the model without shear (by eliminating MID3 in field 7of the PSHELL entry) gives a deflection of:

W_{max} (no shear) = 3.664290E-3 in

Thus, for this thin plate, adding shear deflection results in less than half a percent difference in the total deflection.

2.3 Gear Tooth with Solid Elements

In this problem we create a very simple CHEXA solid element model of a gear tooth. In addition, NX Nastran's subcase feature is used to apply two load cases in a single run.

Problem Statement

Two spur gears are in contact as shown in Figure 2-6. The gears are either aligned or misaligned. In the aligned case, a distributed load of 600 N/mm exists across the line of contact between two teeth. The line of contact is located at a radius of 99.6 mm from the gear's center. In the misaligned case, a concentrated load of 6000 N acts at a single point of contact at the edge of a tooth. The gear teeth are 10 mm wide and 23.5 mm high (from base to tip). The gear's material properties are:

E = 2.0 x 10^5 MPa

v = 0.3

The goal is to obtain a rough estimate of a gear tooth's peak von Mises stress for each load case. von Mises stress, a commonly used quantity in finite element stress analysis, is given by:

$$\sigma_{von} = \frac{1}{\sqrt{2}}[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{yz})^2 + 6(\tau_{zx})^2 + 6(\tau_{xy})^2]^{1/2}$$

Equation 2-1.

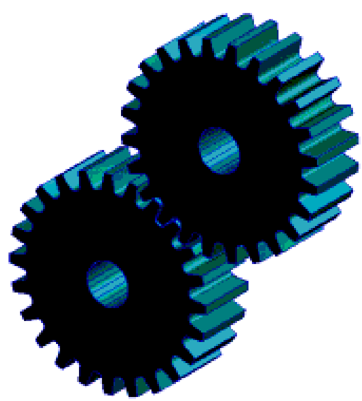


Figure 2-6. Spur Gears

The Finite Element Model

A single gear tooth is modeled using two CHEXA solid elements with midside grid points as shown in Figure 2-7. Midside grid points are useful when the shape of a structure is complex or when bending effects are important.

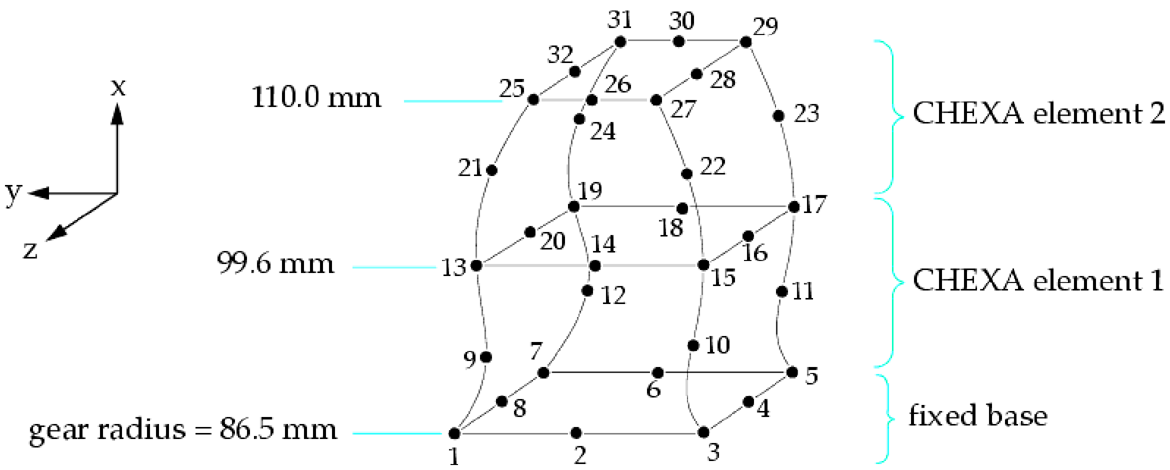


Figure 2-7. Finite Element Model of a Single Gear Tooth

Applying the Loads

Subcase 1 represents aligned gear teeth and uses the distributed load shown in Figure 2-8. The total applied load is given by:

Total Load = Distributed Load · Width of Gear Tooth = 600 N/mm · 10 mm = 6000 N

In order to approximate the “contact patch” of mating gear teeth, we distribute the total force of 6000 N across the line of contact with 1000 N on each corner grid (grid points 15 and 17) and 4000 N on the center grid (grid point 16). A load set identification number of 41 (arbitrarily chosen) is given to the three FORCE Bulk Data entries of subcase 1.

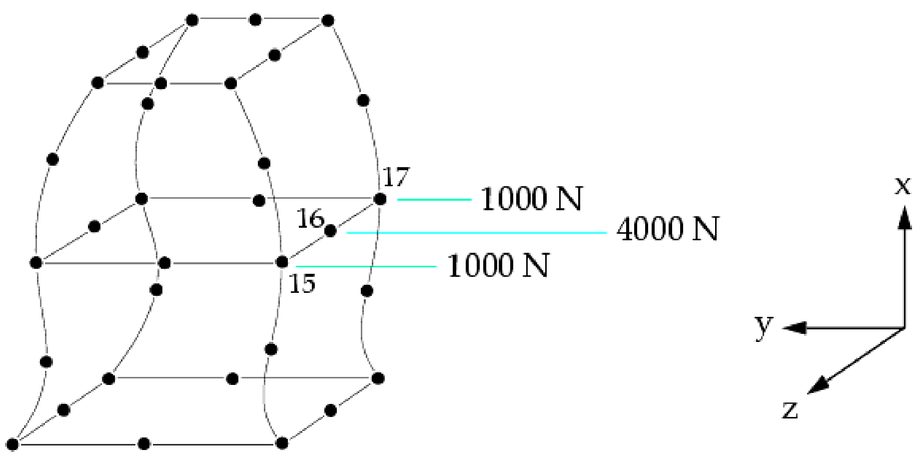


Figure 2-8. Gears in Alignment (Distributed Load)

Subcase 2 represents misaligned gear teeth and uses a single concentrated force of 6000 N as shown in Figure 2-9. A load set identification number of 42 is given to the single FORCE entry of subcase 2. Note that the total applied force (i.e., force transmitted from one tooth to the next) is the same in both subcases.

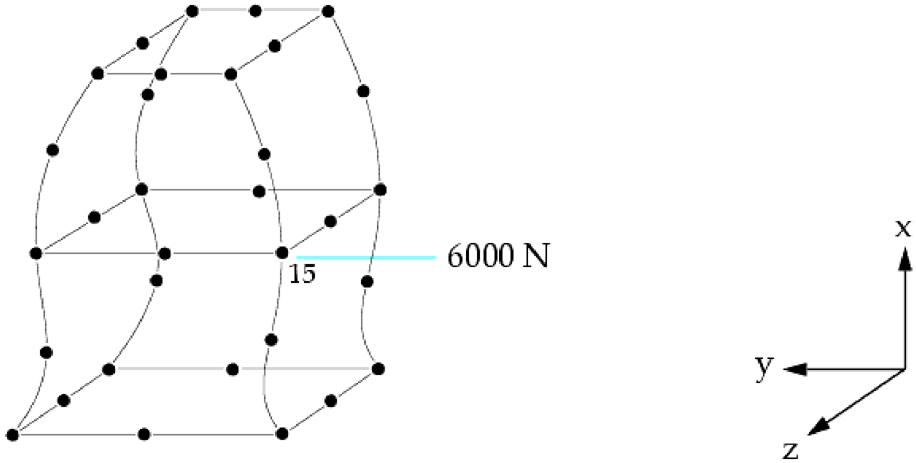


Figure 2-9. Gears Misaligned (Concentrated Load)

Applying the Constraints

The base of the tooth is assumed to be fixed as shown in Figure 2-7. Consequently, grid points 1 through 8 are constrained to zero displacement in their translational DOFs (1, 2, and 3). Recall that solid elements have only translational DOFs and no rotational DOFs. Since each grid point starts out with all six DOFs, the remaining “unattached” rotational DOFs must be constrained to prevent numerical singularities. Thus, all grid points in the model (1 through 32) are constrained in DOFs 4, 5, and 6. The constraints are applied using SPC1 Bulk Data entries.

Output Requests

Stress output is selected with the Case Control command STRESS = ALL. Note that this command appears above the subcase level and therefore applies to both subcases.

The Input File

The complete input file is shown in Listing 2-3.

```
 ID SOLID, ELEMENT MODEL
SOL 101
TIME 100
CEND
TITLE = GEAR TOOTH EXAMPLE
STRESS = ALL
SPC = 30
SUBCASE 1
    LOAD = 41
    SUBTITLE = GEAR TOOTH UNDER 600 N/mm LINE LOAD
SUBCASE 2
    LOAD = 42
    SUBTITLE = GEAR TOOTH UNDER 6000 N CONCENTRATED LOAD
BEGIN BULK
GRID,  1,   ,   86.5,   12.7,   5.0
GRID,  2,   ,   86.5,   0.0,    5.0
GRID,  3,   ,   86.5,  -12.7,   5.0
GRID,  4,   ,   86.5,  -12.7,   0.0
```

```
GRID,  5,   ,   86.5,  -12.7,  -5.0
GRID,  6,   ,   86.5,   0.0,   -5.0
GRID,  7,   ,   86.5,   12.7,  -5.0
GRID,  8,   ,   86.5,   12.7,   0.0
GRID,  9,   ,   93.0,   8.7,    5.0
GRID, 10,   ,   93.0,  -8.7,    5.0
GRID, 11,   ,   93.0,  -8.7,   -5.0
GRID, 12,   ,   93.0,   8.7,   -5.0
GRID, 13,   ,   99.6,   7.8,    5.0
GRID, 14,   ,  100.0,   0.0,    5.0
GRID, 15,   ,   99.6,  -7.8,    5.0
GRID, 16,   ,   99.6,  -7.8,    0.0
GRID, 17,   ,   99.6,  -7.8,   -5.0
GRID, 18,   ,  100.0,   0.0,   -5.0
GRID, 19,   ,   99.6,   7.8,   -5.0
GRID, 20,   ,   99.6,   7.8,    0.0
GRID, 21,   ,  105.0,   5.7,    5.0
GRID, 22,   ,  105.0,  -5.7,    5.0
GRID, 23,   ,  105.0,  -5.7,   -5.0
GRID, 24,   ,  105.0,   5.7,   -5.0
GRID, 25,   ,  110.0,   3.5,    5.0
GRID, 26,   ,  110.0,   0.0,    5.0
GRID, 27,   ,  110.0,  -3.5,    5.0
GRID, 28,   ,  110.0,  -3.5,    0.0
GRID, 29,   ,  110.0,  -3.5,   -5.0
GRID, 30,   ,  110.0,   0.0,   -5.0
GRID, 31,   ,  110.0,   3.5,   -5.0
GRID, 32,   ,  110.0,   3.5,    0.0
$
CHEXA,  1,  10,  3,  5,  7,  1,  15,  17,
     , 19,  13,  4,  6,  8,  2,  10,  11,
     , 12,   9,    16,    18,    20,    14
$
CHEXA, 2,    10,   15,   17,   19,   13,   27,    29,
      ,31,   25,   16,   18,   20,   14,   22,    23,
      ,24,   21,   28,   30,   32,   26
$
PSOLID, 10,  20
MAT1,   20,  2.+5,   ,  0.3
SPC1,   30,  456,      1,   THRU,     32
SPC1,   30,  123,      1,   THRU,      8
$    DISTRIBUTED LOAD FOR SUBCASE 1
FORCE,  41,    15,    ,      1000.,    0.,  1.,  0.
FORCE,  41,    16,    ,      4000.,    0., 1., 0.
FORCE,  41,    17,    ,      1000.,    0., 1., 0.
$    CONCENTRATED LOAD FOR SUBCASE 2
FORCE,  42,    15,    ,      6000.,   0., 1., 0.
ENDDATA
```

Listing 2-3. Gear Tooth Input File

NX Nastran Results

The NX Nastran results are shown in Table 2-3.

Table 2-3. Gear Tooth f06 Results File

```
       THIS PROGRAM IS CONFIDENTIAL AND A TRADE SECRET OF EDS PLM SOLUTIONS CORP.  THE RECEIPT OR
    POSSESSION OF THIS PROGRAM DOES NOT CONVEY ANY RIGHTS TO REPRODUCE OR DISCLOSE ITS CONTENTS, OR TO
   MANUFACTURE, USE, OR SELL ANYTHING HEREIN, IN WHOLE OR IN PART, WITHOUT THE SPECIFIC WRITTEN CONSENT
                              OF EDS PLM SOLUTIONS CORPORATION.

                          * * * * * * * * * * * * * * * * * * * *
                          * * * * * * * * * * * * * * * * * * * *
                          * *                                 * *
                          * *         EDS PLM SOLUTIONS       * *
                          * *              CORP               * *
                          * *                                 * *
                          * *         NX  N a s t r a n       * *
                          * *                                 * *
                          * *        VERSION - 1.0            * *
                          * *                                 * *
                          * *         JUL 10, 2003            * *
                          * *                                 * *
                          * *                                 * *
                          * *             Intel               * *
                          * *                                 * *
                          * *MODEL PentiumIII/995 (MERCED.scm)* *
                          * *                                 * *
                          * *  Windows 2000 5.0 (Build 2195)  * *
                          * *                                 * *
                          * *                                 * *
                          * *                                 * *
                          * * * * * * * * * * * * * * * * * * * *
                          * * * * * * * * * * * * * * * * * * * *
```

```
                                                          JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     1

   N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O
 ID   SOLID, ELEMENT MODEL
 SOL  101
 TIME 100
 CEND
```

```
 GEAR TOOTH EXAMPLE                                         JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     2

                                      C A S E    C O N T R O L    D E C K    E C H O
                CARD
                COUNT
                 1      TITLE        = GEAR TOOTH EXAMPLE
                 2      STRESS       = ALL
                 3      SPC          = 30
                 4      SUBCASE 1
                 5         LOAD      = 41
                 6         SUBTITLE  = GEAR TOOTH UNDER 600 N/MM LINE LOAD
                 7      SUBCASE 2
                 8         LOAD      = 42
                 9         SUBTITLE  = GEAR TOOTH UNDER 6000 N CONCENTRATED LOAD
                10      BEGIN BULK
                             INPUT BULK DATA CARD COUNT =      52
```

```
 GEAR TOOTH EXAMPLE                                                  JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     3

                                          S O R T E D   B U L K   D A T A   E C H O
                CARD
                COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
                   1-        CHEXA   1       10      3       5       7       1       15      17      +000001
                   2-        ++00000119      13      4       6       8       2       10      11      +000002
                   3-        ++00000212      9       16      18      20      14                      +000003
                   4-        CHEXA   2       10      15      17      19      13      27      29      +000004
                   5-        ++00000431      25      16      18      20      14      22      23      +000005
                   6-        ++00000524      21      28      30      32      26                      +000006
                   7-        FORCE   41      15              1000.   0.      1.      0.
                   8-        FORCE   41      16              4000.   0.      1.      0.
                   9-        FORCE   41      17              1000.   0.      1.      0.
                  10-        FORCE   42      15              6000.   0.      1.      0.
                  11-        GRID    1               86.5    12.7    5.0
                  12-        GRID    2               86.5    0.0     5.0
                  13-        GRID    3               86.5    -12.7   5.0
                  14-        GRID    4               86.5    -12.7   0.0
                  15-        GRID    5               86.5    -12.7   -5.0
                  16-        GRID    6               86.5    0.0     -5.0
                  17-        GRID    7               86.5    12.7    -5.0
                  18-        GRID    8               86.5    12.7    0.0
                  19-        GRID    9               93.0    8.7     5.0
                  20-        GRID    10              93.0    -8.7    5.0
                  21-        GRID    11              93.0    -8.7    -5.0
                  22-        GRID    12              93.0    8.7     -5.0
                  23-        GRID    13              99.6    7.8     5.0
                  24-        GRID    14              100.0   0.0     5.0
                  25-        GRID    15              99.6    -7.8    5.0
                  26-        GRID    16              99.6    -7.8    0.0
                  27-        GRID    17              99.6    -7.8    -5.0
                  28-        GRID    18              100.0   0.0     -5.0
                  29-        GRID    19              99.6    7.8     -5.0
                  30-        GRID    20              99.6    7.8     0.0
                  31-        GRID    21              105.0   5.7     5.0
                  32-        GRID    22              105.0   -5.7    5.0
                  33-        GRID    23              105.0   -5.7    -5.0
                  34-        GRID    24              105.0   5.7     -5.0
                  35-        GRID    25              110.0   3.5     5.0
                  36-        GRID    26              110.0   0.0     5.0
                  37-        GRID    27              110.0   -3.5    5.0
                  38-        GRID    28              110.0   -3.5    0.0
                  39-        GRID    29              110.0   -3.5    -5.0
                  40-        GRID    30              110.0   0.0     -5.0
                  41-        GRID    31              110.0   3.5     -5.0
                  42-        GRID    32              110.0   3.5     0.0
                  43-        MAT1    20      2.+5            0.3
                  44-        PSOLID  10      20
                  45-        SPC1    30      123     1       THRU    8
                  46-        SPC1    30      456     1       THRU    32
                             ENDDATA
                     TOTAL COUNT=        47

   GEAR TOOTH EXAMPLE                                                  JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     4

 USER INFORMATION MESSAGE
 ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM WILL BE USED AS REFERENCE LOCATION.
  RESULTANTS ABOUT ORIGIN OF SUPERELEMENT BASIC COORDINATE SYSTEM IN SUPERELEMENT BASIC SYSTEM COORDINATES.
                                                  OLOAD    RESULTANT

               T1             T2             T3             R1             R2             R3
      1   0.0000000E+00  6.0000000E+03  0.0000000E+00  0.0000000E+00  0.0000000E+00  5.9760000E+05
      2   0.0000000E+00  6.0000000E+03  0.0000000E+00 -3.0000000E+04  0.0000000E+00  5.9760000E+05

   GEAR TOOTH EXAMPLE                                                  JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     5
                                                                                                      SUBCASE 1

 *** USER INFORMATION MESSAGE 5293 FOR DATA BLOCK KLL
   LOAD SEQ. NO.            EPSILON              EXTERNAL WORK      EPSILONS LARGER THAN 0.001 ARE FLAGGED WITH ASTERISKS
                1         8.1898186E-16         3.3558350E+01
                2         1.3675490E-16         8.0560677E+01
```

```
   GEAR TOOTH EXAMPLE                                                  JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     6
      GEAR TOOTH UNDER 600 N/MM LINE LOAD
                                                                                                                SUBCASE 1
                      S T R E S S E S   I N   H E X A H E D R O N   S O L I D   E L E M E N T S   ( H E X A )

0                CORNER        ------CENTER AND CORNER POINT STRESSES---------       DIR.  COSINES       MEAN
  ELEMENT-ID    GRID-ID       NORMAL              SHEAR             PRINCIPAL       -A-  -B-  -C-     PRESSURE       VON MISES
          1         0GRID CS 20 GP

               CENTER  X   3.259422E+00  XY   3.291709E+01   A   3.381539E+01  LX 0.73-0.68 0.00  -1.145106E+00    5.718108E+01
                       Y  -1.645274E+00  YZ  -1.774964E-15   B  -3.220124E+01  LY 0.68 0.73 0.00
                       Z   1.821169E+00  ZX   1.720846E-15   C   1.821169E+00  LZ 0.00 0.00-1.00

                    3  X   9.586081E+01  XY   1.681114E+01   A   1.038217E+02  LX 0.94-0.33-0.01  -5.882202E+01    6.854695E+01
                       Y   3.988232E+01  YZ   2.886330E+00   B   2.943023E+01  LY 0.24 0.70-0.67
                       Z   4.072294E+01  ZX  -1.569083E+01   C   4.321412E+01  LZ-0.22-0.63-0.74

                    5  X   9.586081E+01  XY   1.681114E+01   A   1.038217E+02  LX 0.94-0.33 0.01  -5.882202E+01    6.854695E+01
                       Y   3.988232E+01  YZ  -2.886330E+00   B   2.943023E+01  LY 0.24 0.70 0.67
                       Z   4.072294E+01  ZX   1.569083E+01   C   4.321412E+01  LZ 0.22 0.63-0.74

                    7  X  -1.049563E+02  XY   3.525449E+01   A  -2.709955E+01  LX 0.43 0.90-0.06   6.616337E+01    8.762088E+01
                       Y  -4.772841E+01  YZ  -2.680735E+00   B  -1.233072E+02  LY 0.80-0.41-0.44
                       Z  -4.580541E+01  ZX  -1.339709E+01   C  -4.808340E+01  LZ-0.42 0.14-0.89

                    1  X  -1.049563E+02  XY   3.525449E+01   A  -2.709955E+01  LX 0.43 0.90 0.06   6.616337E+01    8.762088E+01
                       Y  -4.772841E+01  YZ   2.680735E+00   B  -1.233072E+02  LY 0.80-0.41 0.44
                       Z  -4.580541E+01  ZX   1.339709E+01   C  -4.808340E+01  LZ 0.42-0.14-0.89

                   15  X   3.247527E+01  XY   6.892332E+01   A   6.460156E+01  LX 0.90-0.39 0.18   2.277133E+01    1.725774E+02
                       Y  -1.019971E+02  YZ   3.051623E-01   B  -1.312817E+02  LY 0.37 0.92 0.12
                       Z   1.207883E+00  ZX   1.500595E+01   C  -1.633868E+00  LZ 0.22 0.04-0.98

                   17  X   3.247527E+01  XY   6.892332E+01   A   6.460156E+01  LX 0.90-0.39-0.18   2.277133E+01    1.725774E+02
                       Y  -1.019971E+02  YZ  -3.051623E-01   B  -1.312817E+02  LY 0.37 0.92-0.12
                       Z   1.207883E+00  ZX  -1.500595E+01   C  -1.633868E+00  LZ-0.22-0.04-0.98

                   19  X  -4.222647E+01  XY   1.067942E+01   A  -9.214685E+00  LX 0.36 0.93 0.06   2.293951E+01    3.672278E+01
                       Y  -1.417941E+01  YZ  -8.758508E-01   B  -4.735876E+01  LY 0.66-0.30 0.68
                       Z  -1.241265E+01  ZX   7.411705E+00   C  -1.224508E+01  LZ 0.66-0.20-0.73

                   13  X  -4.222647E+01  XY   1.067942E+01   A  -9.214685E+00  LX 0.36 0.93-0.06   2.293951E+01    3.672278E+01
                       Y  -1.417941E+01  YZ   8.758508E-01   B  -4.735876E+01  LY 0.66-0.30-0.68
                       Z  -1.241265E+01  ZX  -7.411705E+00   C  -1.224508E+01  LZ-0.66 0.20-0.73

          2         0GRID CS 20 GP

               CENTER  X   4.882296E+00  XY  -4.862728E-01   A   4.904797E+00  LX 1.00 0.05 0.00  -7.478473E-01    9.708314E+00
                       Y  -5.604282E+00  YZ   8.803369E-16   B  -5.626782E+00  LY-0.05 1.00 0.00
                       Z   2.965527E+00  ZX   3.146788E-15   C   2.965527E+00  LZ 0.00 0.00-1.00

                   15  X  -6.527560E-01  XY  -3.658327E+01   A   1.337905E+01  LX 0.92 0.33-0.23   3.386906E+01    1.117319E+02
                       Y  -9.447928E+01  YZ  -3.515887E+00   B  -1.073635E+02  LY-0.30 0.94 0.1
                       Z  -6.475166E+00  ZX  -6.853597E+00   C  -7.622752E+00  LZ-0.26 0.06-0.96
```

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   GEAR TOOTH EXAMPLE                                                         JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     7
      GEAR TOOTH UNDER 600 N/MM LINE LOAD
                                                                                                                   SUBCASE 1
                         S T R E S S E S   I N   H E X A H E D R O N   S O L I D   E L E M E N T S   ( H E X A )

               CORNER        ------CENTER AND CORNER POINT STRESSES---------       DIR.  COSINES       MEAN
  ELEMENT-ID    GRID-ID       NORMAL              SHEAR             PRINCIPAL       -A-  -B-  -C-     PRESSURE       VON MISES
                   17  X  -6.527560E-01  XY  -3.658327E+01   A   1.337905E+01  LX 0.92 0.33 0.23   3.386906E+01    1.117319E+02
                       Y  -9.447928E+01  YZ   3.515887E+00   B  -1.073635E+02  LY-0.30 0.94-0.14
                       Z  -6.475166E+00  ZX   6.853597E+00   C  -7.622752E+00  LZ 0.26-0.06-0.96

                   19  X  -1.064864E+01  XY   3.353643E+01   A   2.346755E+01  LX 0.69-0.69 0.20   8.570051E+00    5.989574E+01
                       Y  -1.259695E+01  YZ   5.501396E+00   B  -4.522928E+01  LY 0.68 0.72 0.14
                       Z  -2.464565E+00  ZX   3.459682E+00   C  -3.948429E+00  LZ 0.24-0.04-0.97

                   13  X  -1.064864E+01  XY   3.353643E+01   A   2.346755E+01  LX 0.69-0.69-0.20   8.570051E+00    5.989574E+01
                       Y  -1.259695E+01  YZ  -5.501396E+00   B  -4.522928E+01  LY 0.68 0.72-0.14
                       Z  -2.464565E+00  ZX  -3.459682E+00   C  -3.948429E+00  LZ-0.24 0.04-0.97

                   27  X  -4.605958E+00  XY   1.404592E+01   A   3.862373E+01  LX 0.31 0.95 0.01  -1.087944E+01    4.297141E+01
                       Y   3.401790E+01  YZ   1.107342E+00   B  -9.173705E+00  LY 0.95-0.31 0.03
                       Z   3.226375E+00  ZX   3.496277E-01   C   3.188291E+00  LZ 0.03 0.00-1.00

                   29  X  -4.605958E+00  XY   1.404592E+01   A   3.862373E+01  LX 0.31 0.95-0.01  -1.087944E+01    4.297141E+01
                       Y   3.401790E+01  YZ  -1.107342E+00   B  -9.173705E+00  LY 0.95-0.31-0.03
                       Z   3.226375E+00  ZX  -3.496277E-01   C   3.188291E+00  LZ-0.03 0.00-1.00

                   31  X  -3.306385E+01  XY  -1.294417E+01   A  -1.647081E+01  LX-0.24 0.44-0.87   3.483593E+01    4.006144E+01
                       Y  -5.363751E+01  YZ  -4.772546E+00   B  -6.081178E+01  LY-0.04 0.89 0.46
                       Z  -1.780642E+01  ZX  -4.617607E+00   C  -2.722520E+01  LZ 0.97 0.15-0.19

                   25  X  -3.306385E+01  XY  -1.294417E+01   A  -1.647081E+01  LX 0.24 0.44-0.87   3.483593E+01    4.006144E+01
                       Y  -5.363751E+01  YZ   4.772546E+00   B  -6.081178E+01  LY 0.04 0.89 0.46
                       Z  -1.780642E+01  ZX   4.617607E+00   C  -2.722520E+01  LZ 0.97-0.15 0.19
```

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 GEAR TOOTH EXAMPLE                                                   JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     8
    GEAR TOOTH UNDER 6000 N CONCENTRATED LOAD
                                                                                                           SUBCASE 2
                S T R E S S E S   I N   H E X A H E D R O N   S O L I D   E L E M E N T S   ( H E X A )

              CORNER        ------CENTER AND CORNER POINT STRESSES---------       DIR.  COSINES       MEAN
 ELEMENT-ID    GRID-ID        NORMAL              SHEAR             PRINCIPAL       -A-  -B-  -C-      PRESSURE        VON MISES
      1            0GRID CS 20 GP

              CENTER  X   4.571454E+00  XY   3.291783E+01   A   3.922741E+01  LX 0.69 0.70 0.20  -1.679391E+00    5.933091E+01
                      Y   7.224079E+00  YZ   5.886761E+00   B  -2.786473E+01  LY 0.72-0.69-0.07
                      Z  -6.757360E+00  ZX  -7.090083E-02   C  -6.324505E+00  LZ 0.09 0.19-0.98

                   3  X   1.985495E+01  XY   1.187322E+01   A   2.949835E+01  LX 0.86-0.44-0.26  -1.143677E+01    4.453531E+01
                      Y   6.537606E+00  YZ  -1.615572E+01   B  -1.800151E+01  LY 0.09 0.63-0.77
                      Z   7.917767E+00  ZX   1.433615E+01   C   2.281349E+01  LZ 0.50 0.64 0.58

                   5  X   1.661192E+02  XY   2.175381E+01   A   1.814674E+02  LX 0.94-0.31-0.11  -1.037578E+02    1.308156E+02
                      Y   7.332195E+01  YZ  -2.795475E+01   B   3.062253E+01  LY 0.11 0.63-0.77
                      Z   7.183234E+01  ZX   3.914438E+01   C   9.918353E+01  LZ 0.31 0.72 0.63

                   7  X  -1.487215E+02  XY   8.178657E+00   A  -4.295859E+01  LX-0.28 0.92-0.26   9.001753E+01    1.143501E+02
                      Y  -5.901127E+01  YZ   1.136970E+01   B  -1.654868E+02  LY 0.45-0.11-0.88
                      Z  -6.231984E+01  ZX  -3.968795E+01   C  -6.160725E+01  LZ 0.84 0.37 0.39

                   1  X  -6.489181E+01  XY   6.221058E+01   A   1.336910E+01  LX 0.62 0.76 0.17   4.375712E+01    1.177515E+02
                      Y  -3.608615E+01  YZ   1.234834E+01   B  -1.189491E+02  LY 0.78-0.61-0.14
                      Z  -3.029339E+01  ZX  -1.599290E+01   C  -2.569135E+01  LZ-0.01 0.22-0.97

                  15  X  -9.783761E+00  XY   2.190359E+02   A   1.531718E+02  LX 0.70-0.36 0.62   1.437844E+02    6.305996E+02
                      Y  -4.481931E+02  YZ   1.083072E+02   B  -5.499730E+02  LY 0.37 0.92 0.12
                      Z   2.662374E+01  ZX   5.490842E+01   C  -3.455194E+01  LZ 0.62-0.14-0.78

                  17  X   5.878865E+01  XY  -7.572263E+01   A   2.186662E+02  LX-0.44 0.77 0.47  -9.227718E+01    1.919590E+02
                      Y   1.483216E+02  YZ  -6.093703E+01   B   1.170096E+01  LY 0.81 0.56-0.17
                      Z   6.972133E+01  ZX   2.121105E+01   C   4.646441E+01  LZ-0.39 0.31-0.86

                  19  X  -4.857354E+01  XY   1.472993E+01   A   5.522838E+01  LX-0.18 0.80-0.58   1.066104E+01    1.095192E+02
                      Y  -1.509605E+01  YZ   3.695835E+01   B  -7.084710E+01  LY 0.43-0.47-0.77
                      Z   3.168645E+01  ZX  -2.810862E+01   C  -1.636441E+01  LZ 0.89 0.39 0.26

                  13  X  -4.758395E+01  XY   1.283193E+00   A   1.204274E+01  LX-0.61 0.23-0.76   5.867738E+01    1.085369E+02
                      Y  -1.016174E+02  YZ  -1.684200E+01   B  -1.072945E+02  LY-0.12 0.92 0.38
                      Z  -2.683081E+01  ZX  -4.637775E+01   C  -8.078040E+01  LZ 0.78 0.33-0.53

      2            0GRID CS 20 GP

              CENTER  X   4.884711E+00  XY  -4.864016E-01   A   5.807430E+00  LX-0.41-0.03-0.91  -2.043858E+00    9.684574E+00
                      Y   2.091794E+00  YZ   4.776686E+00   B  -4.381088E+00  LY 0.74-0.59-0.32
                      Z  -8.449320E-01  ZX  -3.765759E-02   C   4.705231E+00  LZ 0.53 0.80-0.27

                  15  X  -2.824835E+01  XY  -1.569827E+02   A   7.118480E+01  LX-0.41 0.35-0.84   1.191875E+02    4.959504E+02
                      Y  -3.729666E+02  YZ   8.750310E+01   B  -4.484842E+02  LY 0.31 0.92 0.23
                      Z   4.365232E+01  ZX   9.658312E+00   C   1.973675E+01  LZ 0.85-0.17-0.49
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 GEAR TOOTH EXAMPLE                                               JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE     9
    GEAR TOOTH UNDER 6000 N CONCENTRATED LOAD
                                                                                                          SUBCASE 2
                       S T R E S S E S   I N   H E X A H E D R O N   S O L I D   E L E M E N T S   ( H E X A )

             CORNER        ------CENTER AND CORNER POINT STRESSES---------       DIR.  COSINES       MEAN
ELEMENT-ID   GRID-ID       NORMAL              SHEAR             PRINCIPAL       -A-  -B-  -C-     PRESSURE       VON MISES
                 17  X   3.985225E+01  XY   8.883585E+01   A   1.923506E+02  LX 0.45 0.70-0.56  -7.316022E+01    2.038985E+02
                     Y   1.231419E+02  YZ  -6.007481E+01   B  -4.303396E+01  LY 0.84-0.54 0.00
                     Z   5.648651E+01  ZX   2.036191E+01   C   7.016407E+01  LZ-0.30-0.47-0.83

                 19  X   2.995373E+00  XY  -4.761217E+01   A   1.047138E+02  LX-0.38 0.68-0.63  -2.687507E+01    1.271617E+02
                     Y   1.995684E+01  YZ   4.607714E+01   B  -4.112845E+01  LY 0.60 0.70 0.39
                     Z   5.767300E+01  ZX  -1.472099E+01   C   1.703989E+01  LZ 0.70-0.22-0.67

                 13  X  -3.080114E+01  XY   1.097670E+02   A   4.568690E+01  LX 0.81-0.55-0.21   6.197749E+01    2.154415E+02
                     Y  -1.260158E+02  YZ  -1.312900E+01   B  -1.981381E+02  LY 0.54 0.84-0.11
                     Z  -2.911551E+01  ZX  -1.319591E+01   C  -3.348130E+01  LZ-0.24 0.02-0.97

                 27  X   1.384408E+01  XY   6.899274E+01   A   2.069963E+02  LX 0.34 0.06-0.94  -5.168850E+01    2.342441E+02
                     Y   1.735428E+02  YZ  -4.039832E+01   B  -4.009761E+01  LY 0.92 0.17 0.35
                     Z  -3.232135E+01  ZX  -1.512994E+01   C  -1.183315E+01  LZ-0.18 0.98 0.00

                 29  X   4.168195E+01  XY  -3.819234E+01   A   8.848639E+01  LX-0.62 0.35-0.70  -2.957272E+01    9.502836E+01
                     Y   3.132346E+01  YZ   3.619569E+01   B  -2.005870E+01  LY 0.67 0.70-0.25
                     Z   1.571276E+01  ZX  -8.393348E+00   C   2.029048E+01  LZ 0.41-0.63-0.67

                 31  X   8.506835E+01  XY   1.017675E+01   A   1.344014E+02  LX 0.19-0.08-0.98  -8.568668E+01    8.255613E+01
                     Y   1.283673E+02  YZ  -1.923362E+01   B   3.914836E+01  LY 0.96 0.22 0.17
                     Z   4.362441E+01  ZX   1.647656E+00   C   8.351028E+01  LZ-0.20 0.97-0.12

                 25  X  -1.289453E+02  XY  -3.887628E+01   A  -4.716179E+01  LX 0.29 0.76 0.58   1.001211E+02    1.037033E+02
                     Y  -1.184131E+02  YZ   1.273300E+00   B  -1.650881E+02  LY-0.14 0.64-0.76
                     Z  -5.300490E+01  ZX   1.947105E+01   C  -8.811346E+01  LZ 0.95-0.14-0.29
```

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GEAR TOOTH EXAMPLE                                               JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE    10
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 GEAR TOOTH EXAMPLE                                               JULY  10, 2003  NX NASTRAN   7/10/2003   PAGE    11


* * * *  D B D I C T   P R I N T  * * * *     SUBDMAP = PRTSUM  ,  DMAP STATEMENT NO.     13

                                 * * * *  A N A L Y S I S   S U M M A R Y   T A B L E  * * * *

SEID  PEID PROJ VERS APRCH      SEMG SEMR SEKR SELG SELR MODES DYNRED SOLLIN PVALID SOLNL LOOPID DESIGN CYCLE SENSITIVITY
--------------------------------------------------------------------------------------------------------------------------
   0     0    1    1 '        '    T    T    T    T    T     F      F      T      0     F     -1            0           F

SEID = SUPERELEMENT ID.
PEID = PRIMARY SUPERELEMENT ID OF IMAGE SUPERELEMENT.
PROJ = PROJECT ID NUMBER.
VERS = VERSION ID.
APRCH = BLANK FOR STRUCTURAL ANALYSIS.  HEAT FOR HEAT TRANSFER ANALYSIS.
SEMG = STIFFNESS AND MASS MATRIX GENERATION STEP.
SEMR = MASS MATRIX REDUCTION STEP (INCLUDES EIGENVALUE SOLUTION FOR MODES).
SEKR = STIFFNESS MATRIX REDUCTION STEP.
SELG = LOAD MATRIX GENERATION STEP.
SELR = LOAD MATRIX REDUCTION STEP.
MODES = T (TRUE) IF NORMAL MODES OR BUCKLING MODES CALCULATED.
DYNRED = T (TRUE) MEANS GENERALIZED DYNAMIC AND/OR COMPONENT MODE REDUCTION PERFORMED.
SOLLIN = T (TRUE) IF LINEAR SOLUTION EXISTS IN DATABASE.
PVALID = P-DISTRIBUTION ID OF P-VALUE FOR P-ELEMENTS
LOOPID = THE LAST LOOPID VALUE USED IN THE NONLINEAR ANALYSIS.  USEFUL FOR RESTARTS.
SOLNL = T (TRUE) IF NONLINEAR SOLUTION EXISTS IN DATABASE.
DESIGN CYCLE = THE LAST DESIGN CYCLE (ONLY VALID IN OPTIMIZATION).
SENSITIVITY = SENSITIVITY MATRIX GENERATION FLAG.

                                        * * * END OF JOB * * *
```

Stress Results

First we examine the output for error or warning messages—none are present—and find epsilon, which is reported for each subcase (page 5 of the output). Epsilon is very small in both cases.

CHEXA stress results are reported at each element's center and corner grid points. Stresses at midside grid points are not available. For gear teeth in alignment (subcase 1), the peak von Mises stress is 1.73E2 MPa at grid points 15 and 17 of CHEXA element 1 (page 6 of the output shown in Table 2-3.) For misaligned gear teeth (subcase 2), the peak von Mises stress is 6.31E2 MPa at grid point 15 (see output).

Observe that for both subcases the von Mises stresses at grid points shared by two adjacent elements differ. Solid element stresses are calculated inside the element and are interpolated in toward the element's center and extrapolated outward to its corners. The numerical discrepancy between shared grid points is due to interpolation and extrapolation differences between adjoining elements in regions where high stress gradients exists (which is often the case in a model with an inadequate number of elements). This discrepancy between neighboring element stresses can be reduced by refining the element mesh.

Note also that solid elements result in a considerable volume of printed output. If printed output is desired for larger solid element models, you may want to be somewhat selective in requesting output using the Case Control Section of the input file.

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