GEM TN-93-308
MIT-GEM-SA-01

Axial Support Bar Study

S. J. Myatt
Plasma Fusion Center, Massachusetts Institute of Technology

February 12, 1993

Abstract:

The stress levels in a long thin plate which serves as an axial cold mass support rod on the Gamma Electron Muon (GEM) Detector are the focus of this study. The bar is 45.72 cm (18") wide by 593.75 cm (233.76") long. The nominal tensile load carried by each axial support when the coil is energized is 6.672e6 N, (1.5e6 lbs.). The materials and thicknesses in this study are varied. There are eight bars, located every 45 degrees around the vessel. Only one bar is modeled using ANSYS. A flare of 30 degrees over 120 cm (47.24") of the axial length exists, but is not part of the model. The bars are proposed to be made out of titanium, or Inconel. Several thicknesses are modeled: 3.30 cm, 5.08 cm, and 10.16 cm, (1.3", 2", and 4"). Material properties are take from tables for thinner plates. These date provide an initial estimate of expected stress levels, and allow a determination to be made as to whether or not this bar undergoes plastic deformations. Since the radial displacements are larger than one half the plate thickness, a large deflection solution is required. The applied load, (pulling on the displaced bar), increases the bending stress beyond that which is predicted from conventional beam theory. ANSYS provides a means to run a large deflection problem which automatically updates the stiffness matrix to reflect the deformed shape. In addition, a non-large deflection ANSYS run is made, and the results compared to conventional theory.

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Plasma Fusion Center
Massachusetts Institute of Technology
Cambridge, MA 02139

MIT GEM DETECTOR Memoranda
Approval Sheet

B.A. Smith
Project Engineer

2/12/93
Date

P.H. Titus
Technical Manager

2-12-93
Date

A.M. Dawson
Technical Editor

18 Feb 93
Date

1.0 Abstract

The stress levels in a long thin plate which serves as an axial cold mass support rod on the Gamma Electron Muon (GEM) Detector are the focus of this study. The bar is 45.72 cm (18") wide by 593.75 cm (233.76") long. The nominal tensile load carried by each axial support when the coil is energized is 6.672e6 N, (1.5e6 lbs.). The materials and thicknesses in this study are varied. There are eight bars, located every 45 degrees around the vessel. Only one bar is modeled using ANSYS[1]. A flare of 30 degrees over 120 cm (47.24") of the axial length exists, but is not part of the model. The bars are proposed to be made out of titanium, or Inconel. Several thicknesses are modeled: 3.30 cm, 5.08 cm, and 10.16 cm, (1.3", 2", and 4"). Material properties are taken from tables for thinner plates[2]. These data provide an initial estimate of expected stress levels, and allow a determination to be made as to whether or not this bar undergoes plastic deformations. Since the radial displacements are larger than one half the plate thickness, a large deflection solution is required. The applied load, (pulling on the displaced bar), increases the bending stress beyond that which is predicted from conventional beam theory. ANSYS provides a means to run a large deflection problem which automatically updates the stiffness matrix to reflect the deformed shape. In addition, a non-large deflection ANSYS run is made, and the results compared to conventional theory.

2.0 Conclusions

Stresses for both the titanium and Inconel bars are well below two-thirds yield of the materials selected for all thicknesses evaluated. It is therefore concluded that from a stress standpoint, these bars are of a sufficient design for this loading.

It is also concluded that the membrane effects are significant enough to underestimate noticeably the bending stress when calculated using conventional theories and hand evaluation methods. Such methods would produce more accurate results for bars of greater thickness.

3.0 Analysis Methodology

One end of the bar will be attached to the bobbin, and the other end pulled with a force of 6.672e6 N. The displacement, Δ, of the attached end can be approximated by calculating the thermal contraction of the cold mass under normal operation in a 4K environment. (Radial displacement=$R_m(\alpha)(\Delta T)$=952.5 cm(13.9e-6/K)(292K-4K)=3.81 cm (1.5")). The displacement, including the effect of Lorentz expansion, is found through other finite element analyses to be

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[1] *ANSYS 4.4A1, Swanson Analysis Systems, Incorporated, Houston, PA.*

[2] *Handbook on Materials for Superconducting Machinery, November 75 & January 77, MCIC-HB-04, ARPA Order #2569*

3.5 cm (1.38"). This is modeled as a +Y displacement, radially outward, at the free end.

A finite element model invoking the large deflection capabilities with stress stiffening is made using geometric parameters. The axial support rod is initially flat. See Figure 4.0-1 for a model plot and boundary condition restraints. Displacements are fixed at the left end. At the free end, an outward radial displacement of 3.50 cm is imposed. Element pressures, which remain normal to the element surface as the structure is displaced, are applied at the free end elements to account for a 6.672 MN pull.

Results from several cases are reported in Table 4.0.1 for the various materials and thicknesses. Cases 1 and 2 are for a titanium bar, 3.30 cm and 5.08 cm thick, respectively. Cases 3 and 4 are for Inconel bars, 5.08 cm and 10.16 cm thick, respectively. Case 5 is the same as Case 4 except that the large deflection key is turned off. This is a conventional analysis that demonstrates the need for the large deflection solution.

4.0 Results

The nominal P/A stress for bar 3.30 cm thick is 6.672e6 N/(0.03302 m)(0.4572 m) = 442 MPa and 288 MPa for a 5.08 cm thick bar. Using conventional beam theories for a cantilever with a specified end displacement, the additional bending stress, $\sigma_b = \Delta 3Et/2L^2$, is much less than the stress calculated using large deflection analysis techniques in ANSYS, as shown in Table 4.0.1. The thinner the bar, the larger the difference between conventional and large deflection bending stresses. The maximum von Mises stress given by ANSYS for a titanium bar 3.30 cm thick, is 507 MPa, and for a 5.08 cm bar, 343 MPa. The maximum stress for the 5.08 cm thick Inconel bar is 361 MPa.

A review of the summary table indicates that the expected stresses from ANSYS would match or approach conventional theory as the thickness of the bar is increased. Case 4, a large deflection analysis of a 10.16 cm thick bar, in comparison to the previous cases, shows that the difference between conventional theory and ANSYS diminishes as the thickness of the plate increases. Note that for a 3.30 cm bar, the bending stress from the conventional theory and large deflection theory differs by a factor of 9. This factor drops to 5 and 2 for a 5.08 cm thick bar and a 10.16 cm thick bar respectively. Case 5 is a non-large deflection analysis. The ANSYS bending stress component, 34 MPa, is closer to the 31 MPa bending stress from conventional theory. However, in comparison to Case 4, the need for a large deflection solution is still evident.

Figures 4.0-2 to 4.0-6 show the stress contours for the various flex bars summarized in Table 4.0.1. All flex bars are restrained at the left end. A typical section plot of the first row of elements from the left is included on Figure 4.0-4. The bending through the thickness is clearly visible.

Table 4.0.1 Summary of Results

Case Number	1	2	3	4	5
Material	Titanium	Titanium	Inconel	Inconel	Inconel, Non-Large Deflection
E GPa (10^6 psi)	133.07 (19.3)	133.07 (19.3)	210.98 (30.6)	210.98 (30.6)	210.98 (30.6)
Thickness cm (in)	3.30 (1.3)	5.08 (2)	5.08 (2)	10.16 (4)	10.16 (4)
ANSYS Max von Mises Stress MPa (ksi)	500 (72.5)	343 (49.7)	361 (52.3)	210 (30.4)	178 (25.8)
2/3 S_y MPa (ksi)	1001 (145.2)	1001 (145.2)	915 (132.7)	915 (132.7)	915 (132.7)
P/A Stress MPa (ksi)	442 (64.1)	288 (41.7)	288 (41.7)	144 (20.9)	144 (20.9)
Bending Stress Conventional Theory MPa (ksi)	7 (.95)	10 (1.5)	16 (2.3)	31 (4.5)	31 (4.5)
Bending Stress ANSYS MPa (ksi)	58 (8.4)	55 (8.0)	73 (10.6)	66 (9.5)	34 (4.9)
File Name (Reference only)	bar10.dat	bar16.dat	bar12.dat	bar15.dat	bar14.dat

Notes: 1. All runs consist of a model of constant length 593.75 cm (233.76") and an offset displacement of 3.5 cm (1.38").

2. Titanium Modulus of Elasticity and Yield Stress is based on alloy Ti-5Al-2.5Sn at 20K for a plate 0.5 to 1" thick.

3. Inconel Modulus of Elasticity and Yield Stress is based on 718 Nickel-Base Alloy at 4K for a bar up to 1" thick.

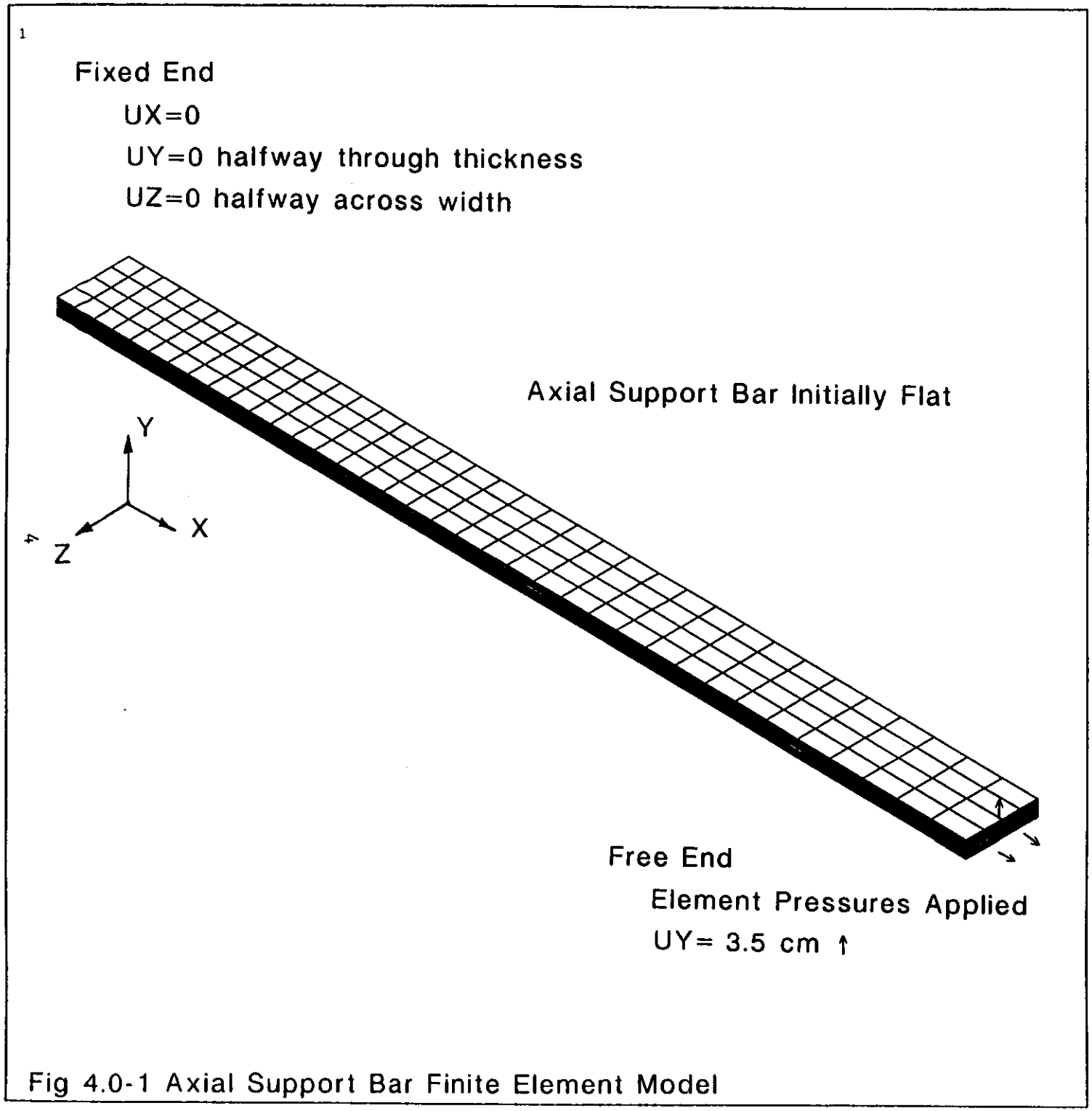
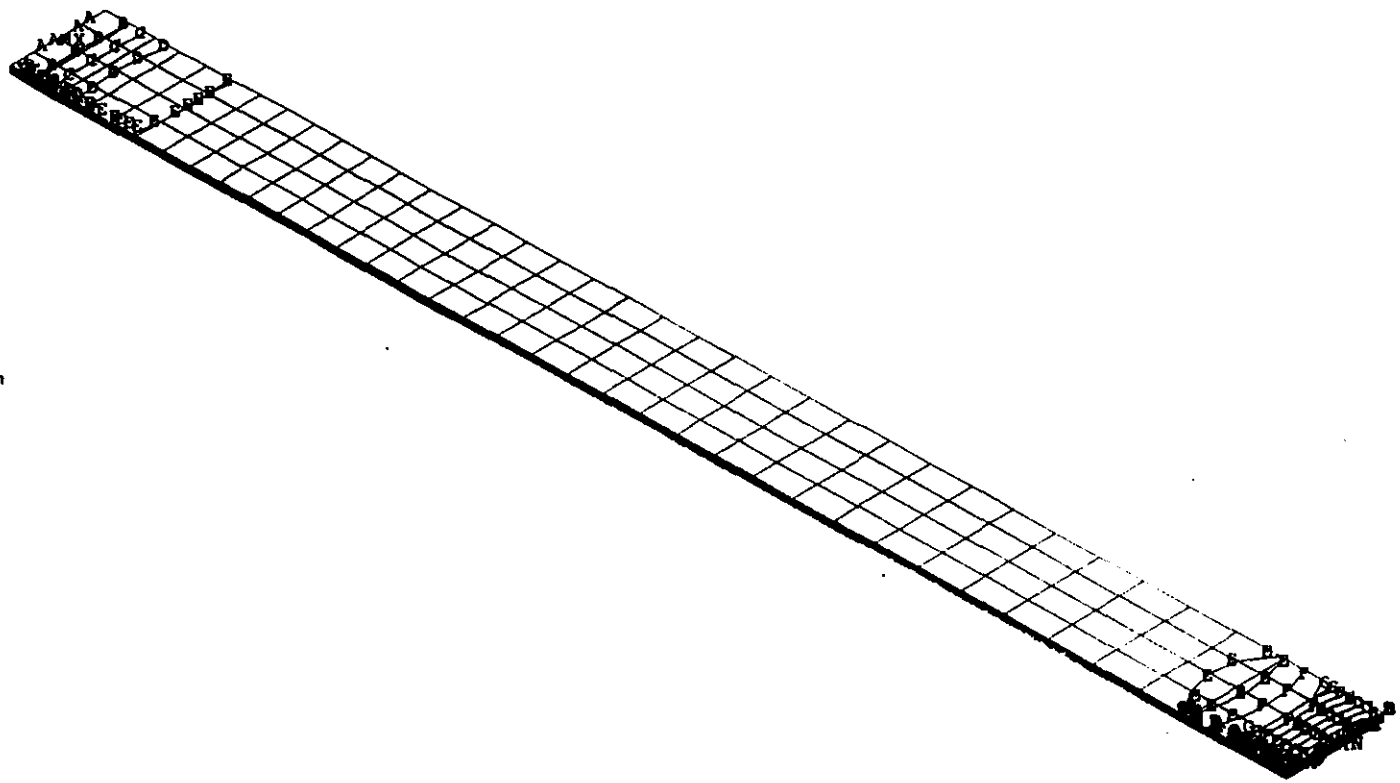


Fig 4.0-1 Axial Support Bar Finite Element Model

1

Large Displacement Analysis

Element Pressures



ANSYS 4.4A1

OCT 14 1992

13:37:57

PLOT NO. 2

POST1 STRESS

STEP=1

ITER=20

SIGE (AVG)

DMX =1.583

SMN =54945

SMX =72521 psi

MAX von Mises = 500 MPa

XV =1

YV =1

ZV =1

DIST=97.913

XF =116.88

YF =0.65

ZF =-9

PRECISE HIDDEN

A =55922

B =57875

C =59827

D =61780

E =63733

F =65686

G =67639

H =69591

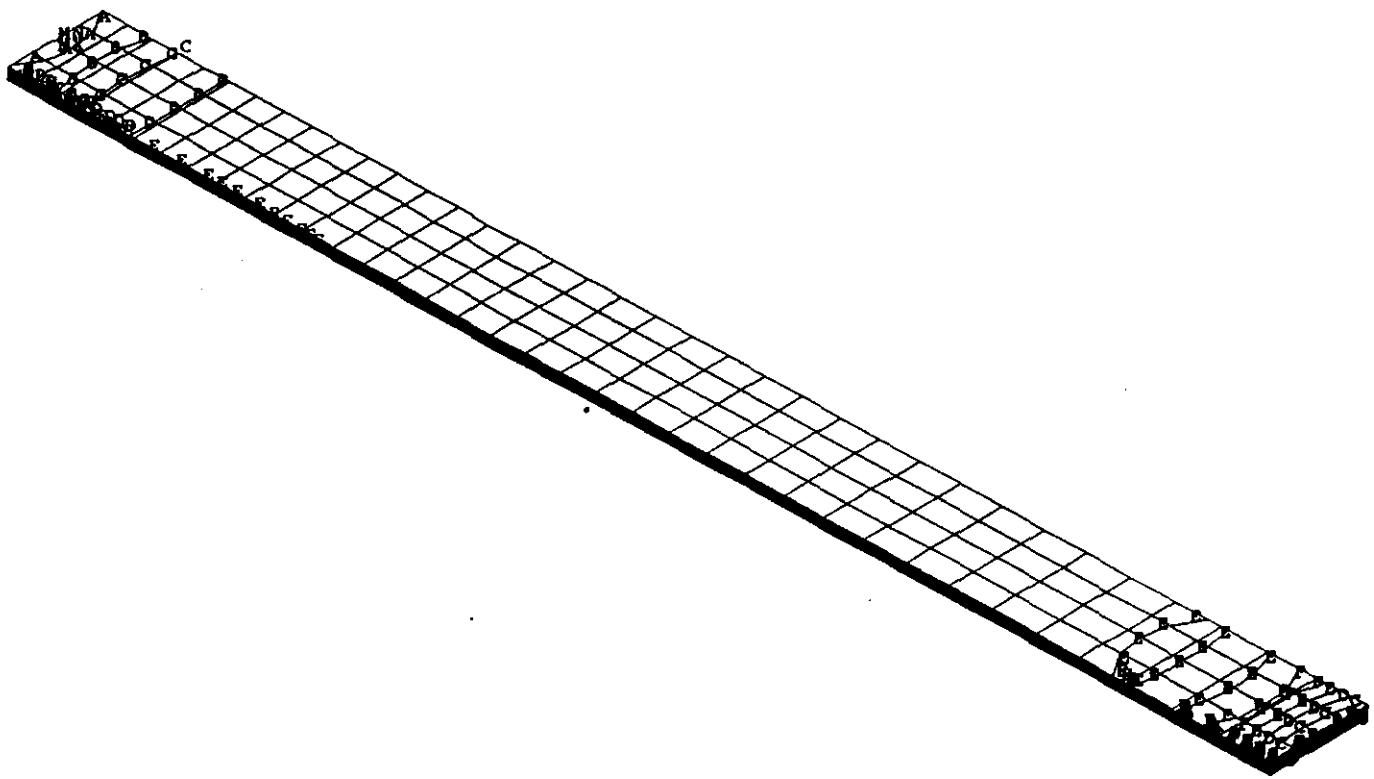
I =71544

Fig 4.0-2 Stress Contour Plot for Titanium Bar 3.30 cm Thick (CASE 1)

1

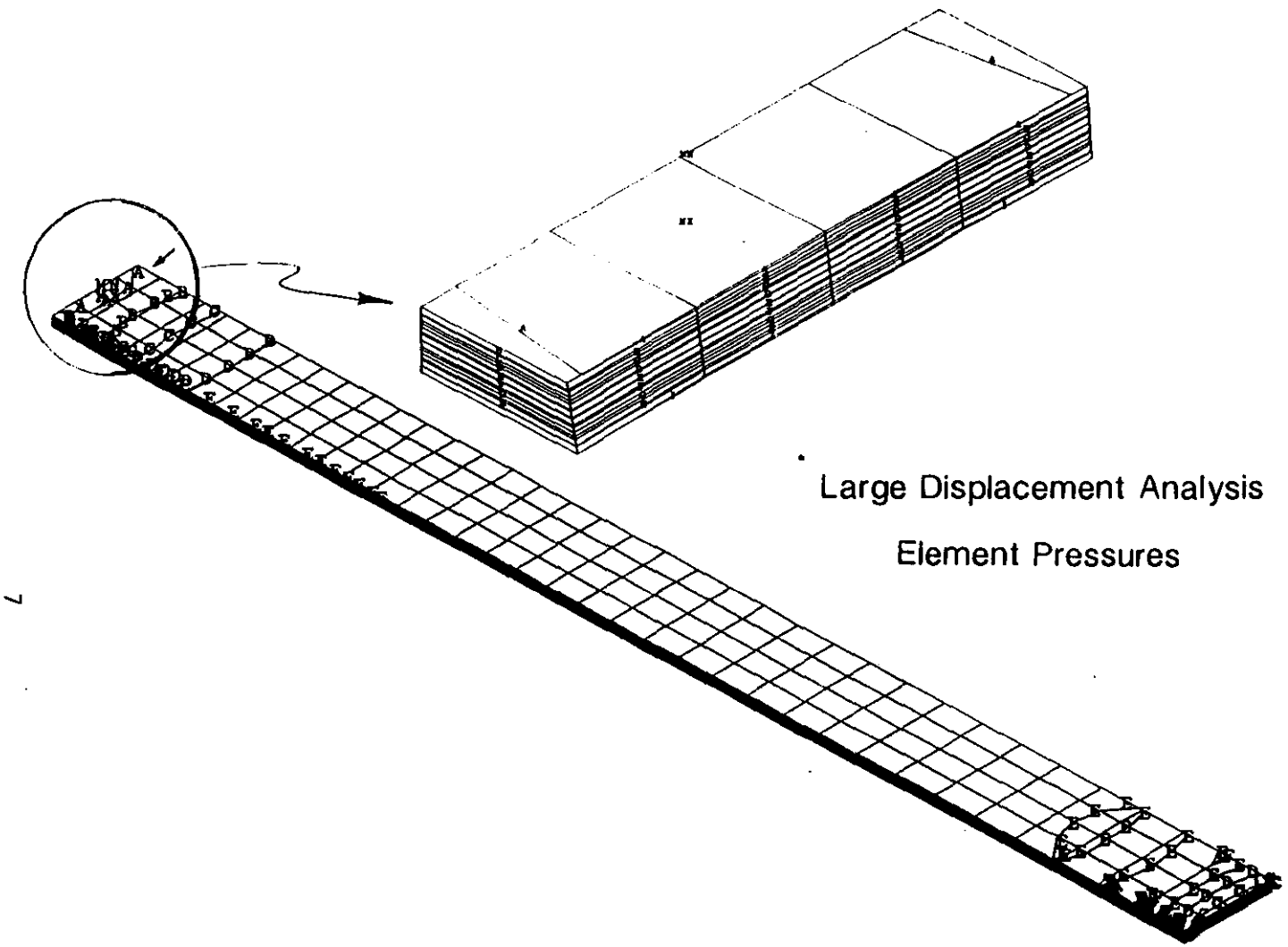
Large Displacement Analysis

Element Pressures



ANSYS 4.4A1
NOV 5 1992
13:10:45
PLOT NO. 1
POST1 STRESS
STEP=1
ITER=20
SIGE (AVG)
DMX =1.47
SMN =33848
SMX =49671 psi
MAX von Mises = 343 MPa
XV =1
YV =1
ZV =1
DIST=97.913
XF =116.88
YF =1
ZF =-9
PRECISE HIDDEN
A =34727
B =36485
C =38243
D =40001
E =41760
F =43518
G =45276
H =47034
I =48792

Fig 4.0-3 Stress Contour Plot for Titanium Bar 5.08 cm Thick (CASE 2)



ANSYS 4.4A1
OCT 27 1992
10:44:43
PLOT NO. 1
POST1 STRESS
STEP=1
ITER=20
SIGE (AVG)
DMX =1.417
SMN =31404
SMX =52260 psi
MAX von Mises = 361 MPa
XV =1
YV =1
ZV =1
DIST=97.913
XF =116.88
YF =1
ZF =-9
PRECISE HIDDEN
A =32563
B =34880
C =37198
D =39515
E =41832
F =44150
G =46467
H =48784
I =51102

Fig 4.0-4 Stress Contour Plot for Inconel Bar 5.08 cm Thick (CASE 3)

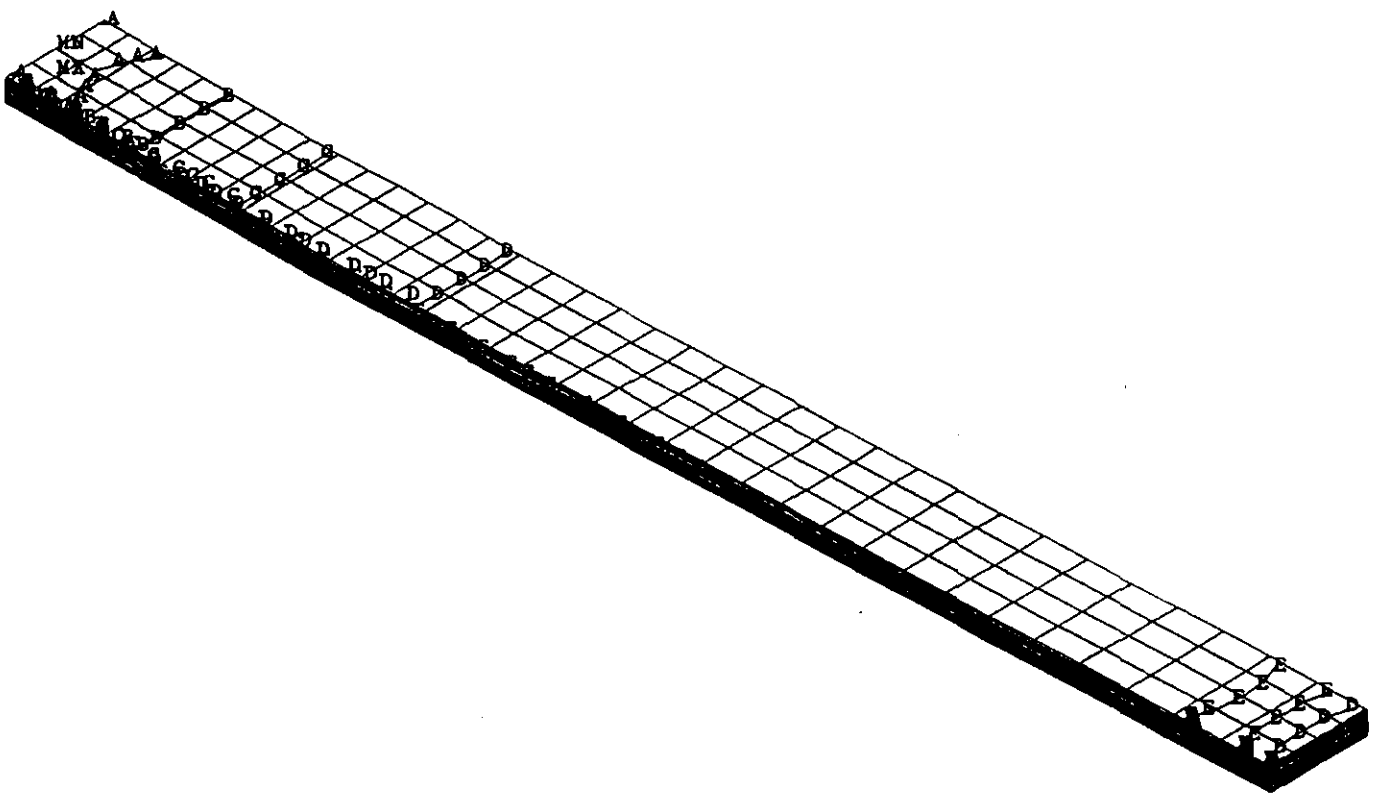
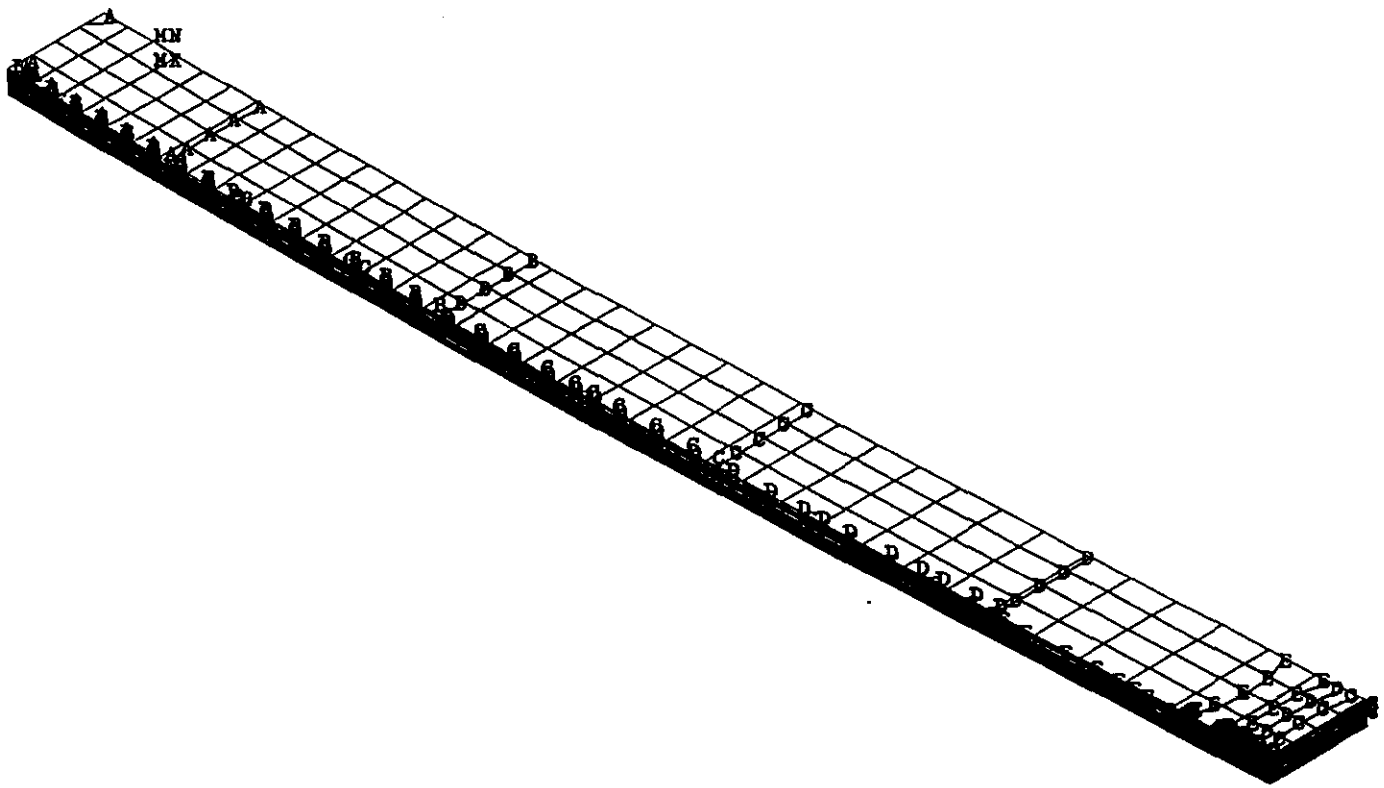


Fig 4.0-5 Stress Contour Plot for Inconel Bar 10.16 cm Thick (CASE 4)

1

Conventional Analysis

Element Pressures



ANSYS 4.4A1
OCT 23 1992
14:32:50
PLOT NO. 1
POST1 STRESS
STEP=1
ITER=20
SIGE (AVG)
DMX =1.391
SMN =16257
SMNB=15930
SMX =25420
SMXB=25753 psi
MAX von Mises = 178 MPa
XV =1
YV =1
ZV =1
DIST=97.913
XF =116.88
YF =2
ZF =-9
PRECISE HIDDEN
A =16766
B =17784
C =18802
D =19820
E =20838
F =21857
G =22875
H =23893
I =24911

Fig 4.0-6 Stress Contour Plot for Inconel Bar 10.16 cm Thick (CASE 5)