TS-SSC 90-043

Fermilab

Fermi National Accelerator Laboratory
Technical Support Engineering
P.O. Box 500 - Batavia, Illinois - 60510

Summary of SSC Collaring Press Finite Element Analyses

Thomas H. Nicol
Technical Support / Engineering
July 2, 1990

INTRODUCTION

The following is a summary of several finite element analyses performed following the failure of the upper main beam on the SSC coil collaring press. The intent of these analyses was to determine the cause of the failure of the center web of the upper longitudinal beam, to determine if other components of the press are near their failure point, and to estimate the effectiveness of planned temporary and permanent reworks and repairs.

Failure occurred in the upper longitudinal beam while collaring a completed long magnet. The mode of failure was buckling of about 3 feet of the center web of the beam. As evidenced by paint flaking off the center web, yielding appears to have occurred at other places in the center web along the length of the same beam as well as in the cross beams where they contact the center web of the longitudinal beam although the latter is to a lesser extent than on the longitudinal beam. Finally, the faceplate of the lower beam appears to be dished in places indicating it too may be close to failure. Failure occurred at a hydraulic pressure of 6,000 psi in the press jacks. This corresponds to 240,000 lb_f acting on each section of the press through two 3 inch tie rods. A section is defined as a single cross beam pair. Sections are spaced on 12 inch centers.

The analyses for the 'as built' press sections were performed at a pressure of 6,000 psi. Analyses for estimating the effectiveness of the temporary fixes were performed at 7,850 psi which is the pressure to which the hydraulic system is limited by safety reliefs. Analyses for estimating the effectiveness of the permanent fixes were performed at 10,000 psi which is the full capacity of the press.

ANALYSIS DESCRIPTIONS

File prefix	Analysis description
UPRPRS_1	Upper cross beam and main beam as built loaded to 6000 psi hydraulic pressure (60% of capacity). This is the point at which the buckling failure occurred in the web of the

upper main beam and at which some deformation was noted in the face plate of the bottom beam

UPRPRS_2	Upper press and main beam with a single row of 1 inch jack bolts installed between the main beam flanges. This is the proposed fix for the upper main beam. The applied load is 7850 psi hydraulic pressure which is the setting of all safety reliefs on the hydraulic system.
UPRPRS_3	Identical to UPRPRS_2 with an additional row of jack bolts. This will determine whether a second row of bolts represents a notable decrease in beam stresses over a single row of bolts.
UPRPRS_4	Upper cross beam and new design for upper main beam loaded to 10000 psi hydraulic pressure (100% of capacity).
UPRPRS_5	Identical to UPRPRS_3 without the main beam center web. This will determine whether one option for fixing the failed section will be effective.
UPRPRS_6	Identical to UPRPRS_4, but with the upper main beam bolted to the cross beam instead of welded. This is the planned attachment scheme for the permanent repair
UPRPRS_7	Upper main beam with grout rather than bolts with the center web removed. This simulates repair of the failed section of the upper beam by grouting rather than through the use of jack bolts.
LWRPRS_1	Lower cross beam and main beam as built loaded to 6000 psi hydraulic pressure (60% of capacity). This is the point at which the buckling failure occurred in the web of the upper main beam and at which some deformation was noted in the face plate of the bottom beam.
LWRPRS_2	Lower cross beam and main beam after filling the lower main beam with epoxy grout. The modulus of the grout is 3.5M psi (EMBECO 885). This is the proposed fix for the lower main beam. The applied load is 7850 psi hydraulic pressure which is the setting of all safety reliefs on the hydraulic system.
LWRPRS_3	Identical to LWRPRS_2 but with the 1/4 inch faceplate of the lower main beam removed. This will give an upper limit on the stresses in the grout in the event that the faceplate fails.

LWRPRS_4	Lower cross beam and new design for lower main beam loaded to 10000 psi hydraulic pressure (100% of capacity).

MAXIMUM STRESS SUMMARY

File prefix	Maximum von Mises stresses Cross beam	Main beam	Compressive stresses Grout / jack bolts
UPRPRS_1	88962	114140	na*
UPRPRS_2	32610	41409	~45000[1]
UPRPRS_3	26385	44392	~30000
UPRPRS_4	37957	21677	na
UPRPRS_5	29090	52614	~40000
UPRPRS_6	37084	23186	na[2]
UPRPRS_7	29737	16329	~4000[3]
LWRPRS_1	48242	84723	na
LWRPRS_2	30656	32129	~2000[4]
LWRPRS_3	29686	31646	~2000
LWRPRS_4	38560	20559	na[5]

Notes:All stresses are in psi.
- *: not applicable
- 1: upper beam temporary rework
- 2: upper beam permanent rework
- 3: upper beam temporary rework of buckled section
- 4: lower beam temporary rework
- 5: lower beam permanent rework

DISCUSSION

From inspection of the failed section of upper beam and from the stresses predicted by these analyses, buckling of the center web of the upper longitudinal beam and yielding of the cross beam webs was caused by compressive stresses in these members considerably above the yield point of the materials. Tensile tests on samples cut from the upper longitudinal beam indicated a yield strength of approximately 42,000 psi. For the 'as built' case, the stresses in upper and lower main and cross beams exceed this value.

The root of the problem lies in the inability of the cross beam and main beam flanges to distribute the applied load over their contact surfaces. This is the result of the low bending stiffness of the flanges when compared to the compressive stiffness of the vertical webs.

Bear in mind that all of these analyses assume elastic material properties. Clearly many of the predicted stresses are beyond the elastic limit of the materials used, particularly in the case of the 'as built' geometries. The actual maximum stresses in these cases would be lower than those predicted here and would be distributed across a larger area due flanges. Rather, the plan is to fill the entire inner volume of this beam with EMBECO 885 grout. This material has a compressive strength of 7,000 psi after 7 days, a compressive modulus of $3.5x10^6$ psi, and an estimated shrinkage of +0.02% (i.e. slight expansion). LWRPRS_2 simulates the addition of this material. The addition of this grout decreases the stresses everywhere in the main and cross beams to values well below their yield strengths. The compressive stress in the grout is below 4,000 psi except in a very small area under the web of the cross beam. LWRPRS_3 is identical to LWRPRS_2, but neglects the front faceplate on the lower beam. This is an attempt to predict the effect on the beams and grout should the faceplate fail. Stresses in the cross beam are well below yield. In the main beam, the stresses directly under the cross beam web are just at the yield point. Peak compressive stresses in the grout increase to approximately 6,000 psi although the compressive stress throughout the bulk of the grout is approximately 2,000 psi. Some local yielding might occur in this configuration. In reality even a failed faceplate would provide some compressive strength. Failure of the main beam or grout would be unlikely.

TEMPORARY REWORK - SUMMARY

In summary, the planned fixes for both longitudinal beams appear to be viable repairs for short term use of the press. The focus of the rework is twofold. First, it must enable operation of the presses to the limits of the safety system. Second, it must ensure that no damage occurs to the cross beams so they may be used as-is in the permanent repair. The effectiveness of these reworks is due not to the strength of the added elements directly, but rather to their ability to distribute the applied load over a larger surface area. Both drastically reduce stresses in the center webs of the cross and main beams and introduce stresses in the added materials within their allowed values. The limits on the hydraulic system prevent pressurization to more than 7,850 psi. The repairs are not likely to be effective for long term use of the press at full hydraulic capacity (10,000 psi).

PERMANENT REPAIR

The permanent repair of the collaring press amounts to replacement of both upper and lower longitudinal beams. The planned replacements are the same width and height as the existing units, but with 2 inch thick flanges and 1 inch thick webs and faceplates. UPRPRS_4 and LWRPRS_4 simulate the addition of these two beams. The only difference between the two analyses is the placement of the vertical restraints which simulate the collaring tooling (the lower mandrel is wider than the upper). For both cases the maximum stress in the redesigned longitudinal beams is between 21,000 and 22,000 psi. In both upper and lower cross beams the maximum stress is approximately 38,000 psi. This latter value is higher than one would like to see, however, this analysis simulates the effect on the beams of 10,000 psi hydraulic pressure. At the current operating maximum (7850 psi) the maximum cross beam stress would be more like 30,000 psi.

Further investigation is warranted to determine if an effective way can be found to strengthen the cross beams during the repair program.

Rather than welding the new upper beam to the cross beam, the plan for the permanent repair is to hang the upper beam from the cross beam with bolts. My initial concern was that any bending in the cross beam would tend to unload the contact surfaces in this scheme. UPRPRS_6 simulates the bolted connection by allowing separation of the contact surfaces. The analysis indicates that the bolted connection is as effective as the welded connection in distributing the applied load across the entire contact surface between the cross beam and main beam flanges (compare with UPRPRS_4).

As with the planned rework for continuation of the 40mm program, the two new beams are effective due to their ability to transfer the applied vertical load over a large surface area. The bending stiffness of the 2 inch flanges is considerably greater than their 'as built' counterparts. Coupled with the compressive stiffness of the 1 inch webs, the high stress concentrations seen at the web crossing points in the existing design are reduced substantially.

There is every reason to believe replacement of the longitudinal beams with the new design will allow the press to be utilized throughout the 50mm coil development program. If strengthening the cross beams is feasible, it could be done as well and would serve as insurance against future deformation of these beam sections.

LIST OF FIGURES

Figure 1: Typical collaring press section

Figure 2: Finite element mesh of upper beam and cross beam

Figure 3: Finite element mesh of lower beam and cross beam

Figure 4: von Mises stress plot of cross beam from analysis UPRPRS_1

Figure 5: von Mises stress plot of longitudinal beam from analysis UPRPRS_1

Figure 6: von Mises stress plot of cross beam from analysis UPRPRS_2

Figure 7: von Mises stress plot of longitudinal beam from analysis UPRPRS_2

Figure 8: compressive stress plot in jack bolts from analysis UPRPRS_2

Figure 9: von Mises stress plot of cross beam from analysis UPRPRS_3

Figure 10: von Mises stress plot of longitudinal beam from analysis UPRPRS_3

Figure 11: compressive stress plot in jack bolts from analysis UPRPRS_3

Figure 12: von Mises stress plot of cross beam from analysis UPRPRS_4

Figure 13: von Mises stress plot of longitudinal beam from analysis UPRPRS_4

Figure 14: von Mises stress plot of cross beam from analysis UPRPRS_5

Figure 15: von Mises stress plot of longitudinal beam from analysis UPRPRS_5

Figure 16: compressive stress plot in jack bolts from analysis UPRPRS_5

Figure 17: von Mises stress plot of cross beam from analysis UPRPRS_6

Figure 18: von Mises stress plot of longitudinal beam from analysis UPRPRS_6

Figure 19: vertical displacement plot of cross beam from analysis UPRPRS_6

Figure 20: vertical displacement plot of longitudinal beam from analysis UPRPRS_6

Figure 21: von Mises stress plot of cross beam from analysis UPRPRS_7

Figure 22: von Mises stress plot of longitudinal beam from analysis UPRPRS_7

Figure 23: compressive stress plot in grout from analysis UPRPRS_5

Figure 24: von Mises stress plot of cross beam from analysis LWRPRS_1

Figure 25: von Mises stress plot of longitudinal beam from analysis LWRPRS_1

Figure 26: von Mises stress plot of cross beam from analysis LWRPRS_2

Figure 27: von Mises stress plot of longitudinal beam from analysis LWRPRS_2

Figure 28: compressive stress plot in grout from analysis LWRPRS_2

Figure 29: von Mises stress plot of cross beam from analysis LWRPRS_3

Figure 30: von Mises stress plot of longitudinal beam from analysis LWRPRS_3

Figure 31: compressive stress plot in grout from analysis LWRPRS_3

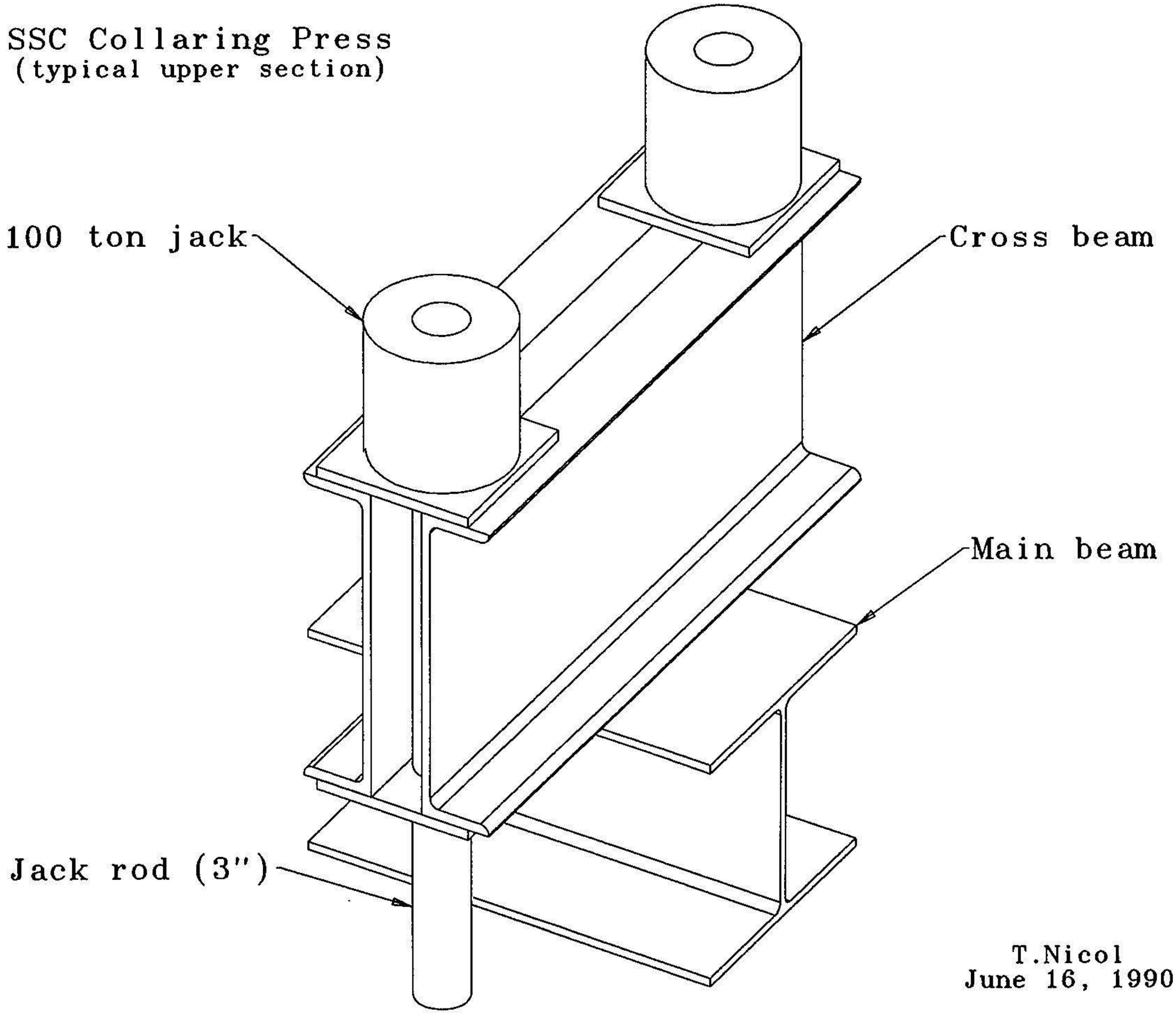
Figure 32: von Mises stress plot of cross beam from analysis LWRPRS_4

Figure 33: von Mises stress plot of longitudinal beam from analysis LWRPRS_4

DISTRIBUTION

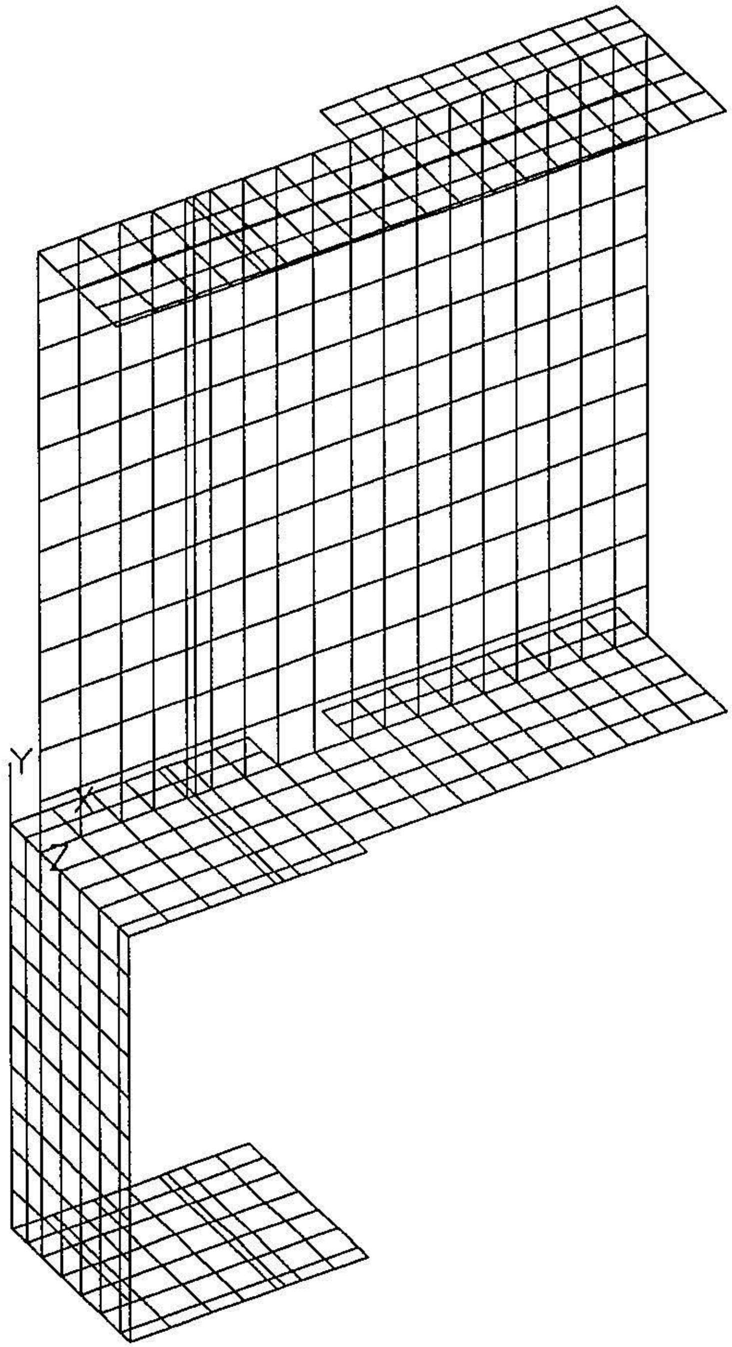
R. Bossert - FNAL
R. Coombes - SSCL
J. Carson - FNAL
J. Jayakumar - SSCL
E. Larson - FNAL
R. Malnar - SSCL
P. Mantsch - FNAL
G. Pewitt - FNAL
W. Robotham - FNAL
R. Rihel - FNAL
P. Sanger - SSCL
J. Strait - FNAL

SSC Collaring Press
(typical upper section)



T.Nicol
June 16, 1990

1



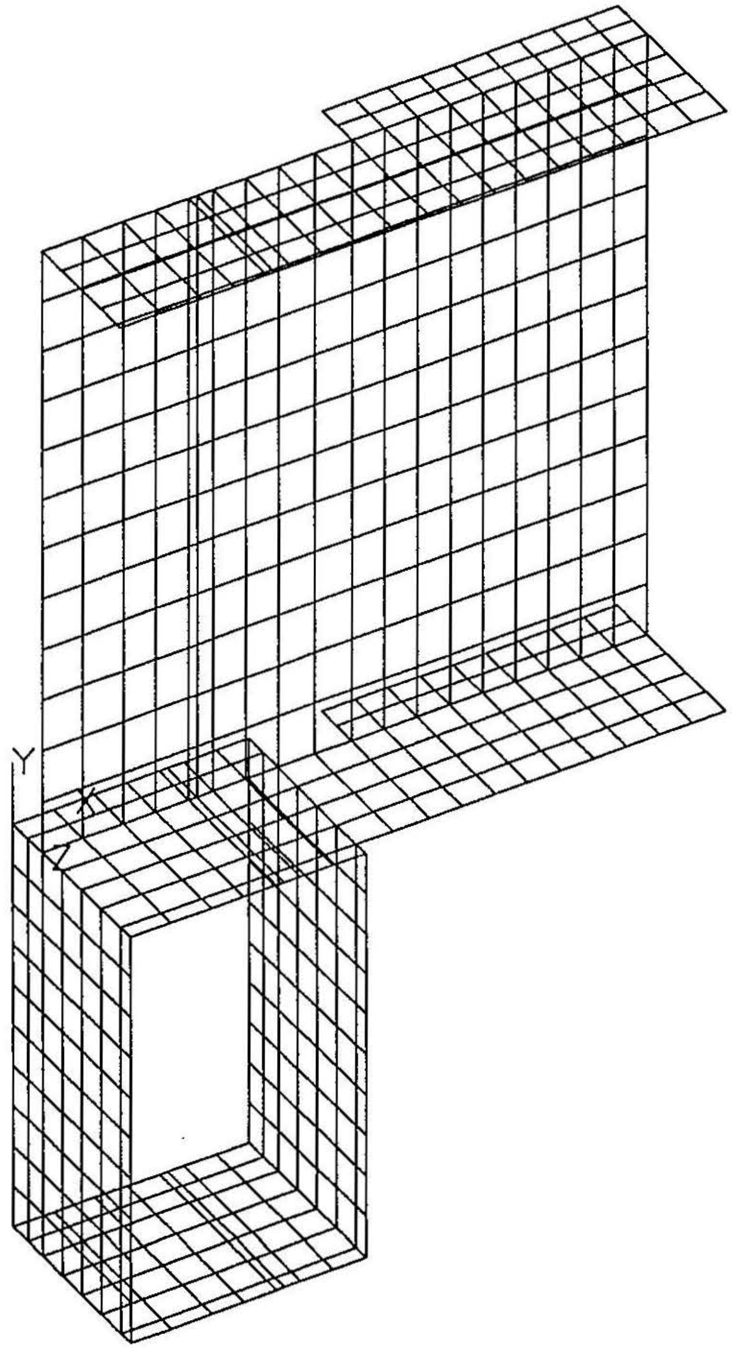
Upper press section finite element mesh

ANSYS 4.4
JUL 2 1990
12:19:00
PLOT NO. 1
PREP7 ELEMENTS
TYPE NUM

XV =−3
YV =4
ZV =5
DIST=18.622
XF =9.25
YF =3
ZF =3

1/4 SYMMETRY ANALYSIS

1

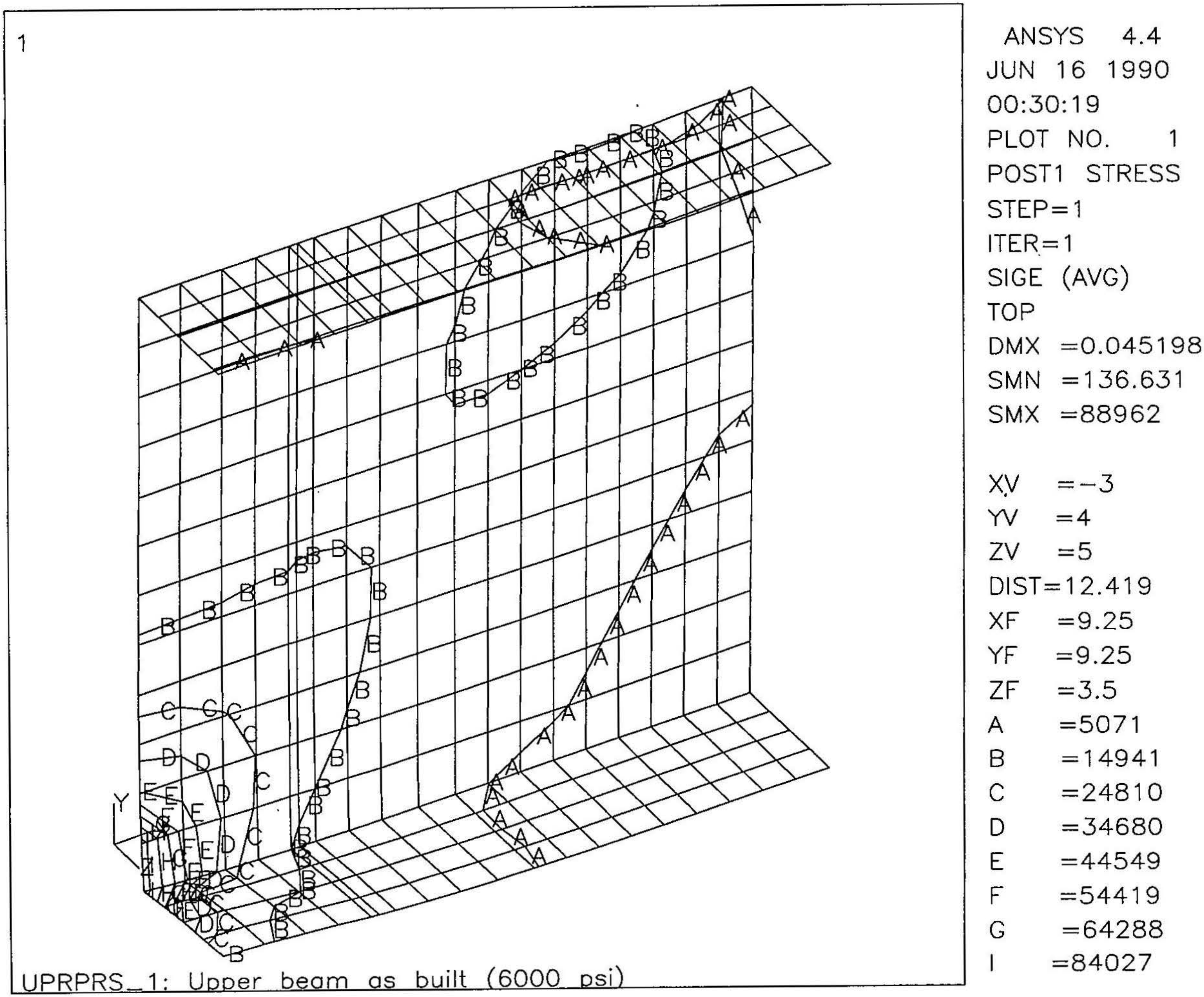


ANSYS 4.4
JUL 2 1990
12:21:43
PLOT NO. 1
PREP7 ELEMENTS
TYPE NUM

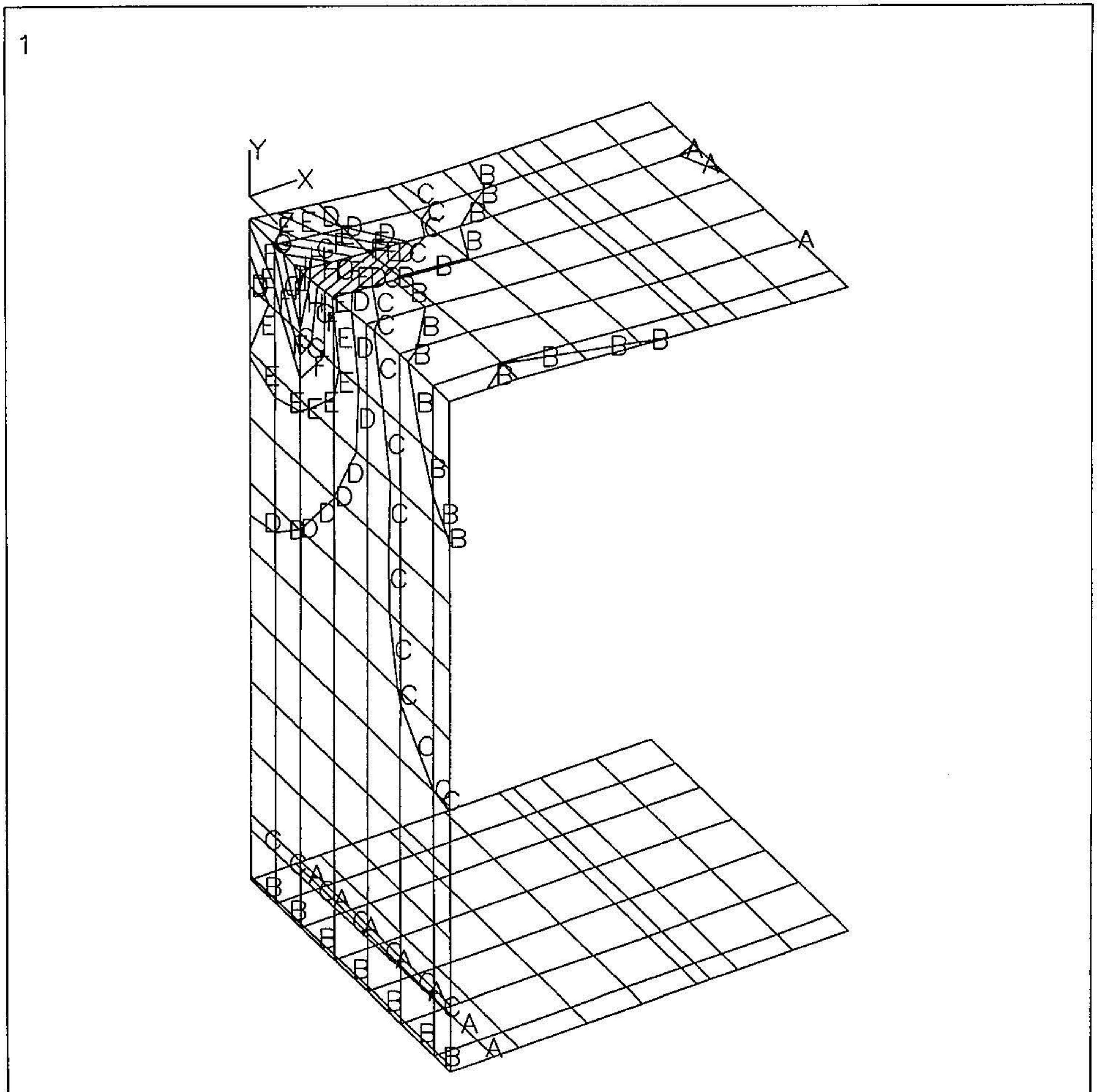
XV =-3
YV =4
ZV =5
DIST=18.622
XF =9.25
YF =3
ZF =3

1/4 SYMMETRY ANALYSIS

Lower press section finite element mesh



UPRPRS_1: Upper beam as built (6000 psi)

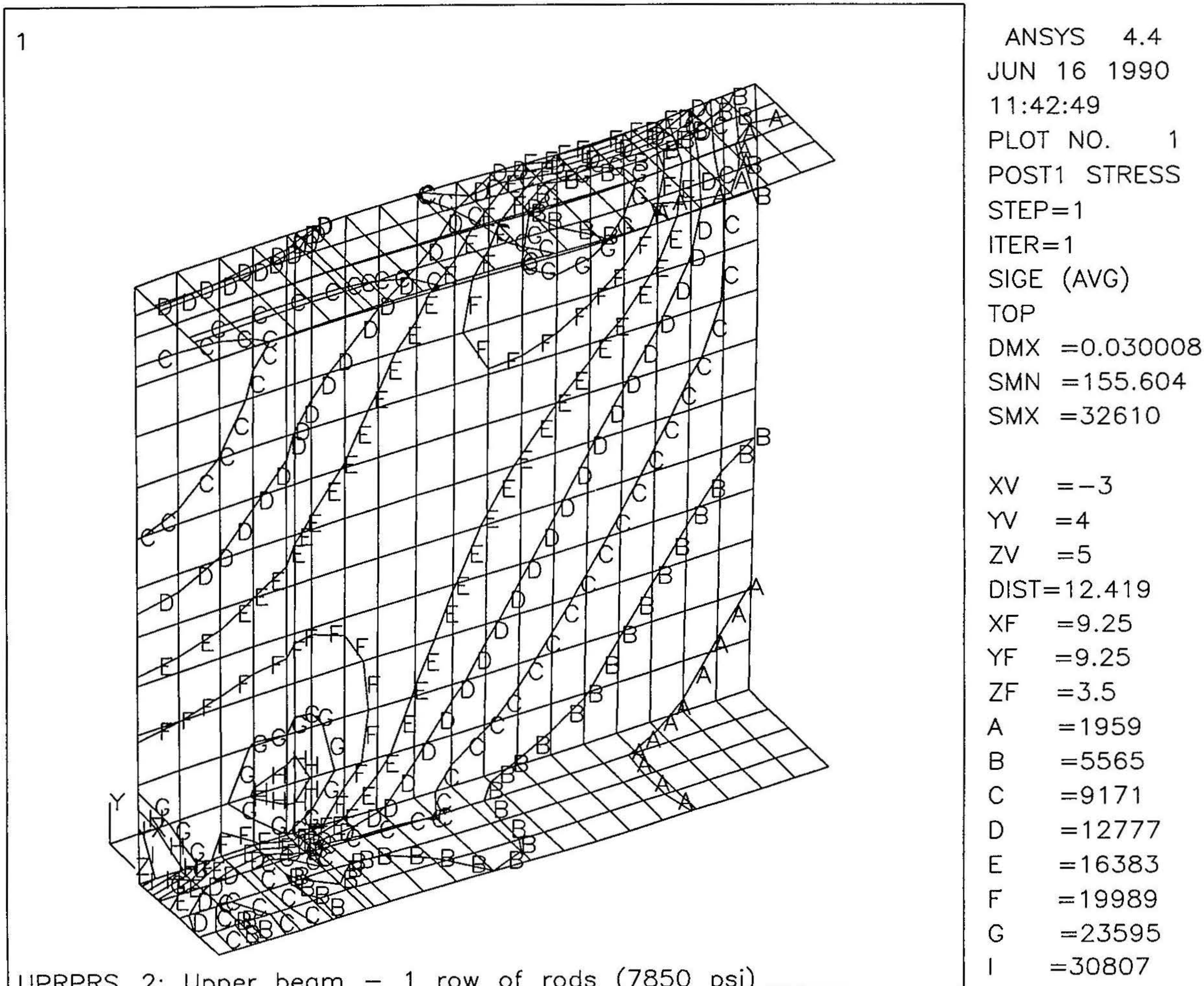


UPRPRS_1: Upper beam as built (6000 psi)

ANSYS 4.4
JUN 16 1990
00:30:31
PLOT NO. 2
POST1 STRESS
STEP=1
ITER=1
SIGE (AVG)
TOP
DMX =0.036611
SMN =8.891
SMX =114140

XV =-3
YV =4
ZV =5
DIST=8.431
XF =3.625
YF =-6.25
ZF =3
A =6349
B =19031
C =31712
D =44393
E =57074
F =69756
G =82437
I =107799

FIGURE 5



UPRPRS_2: Upper beam – 1 row of rods (7850 psi)

FIGURE 6

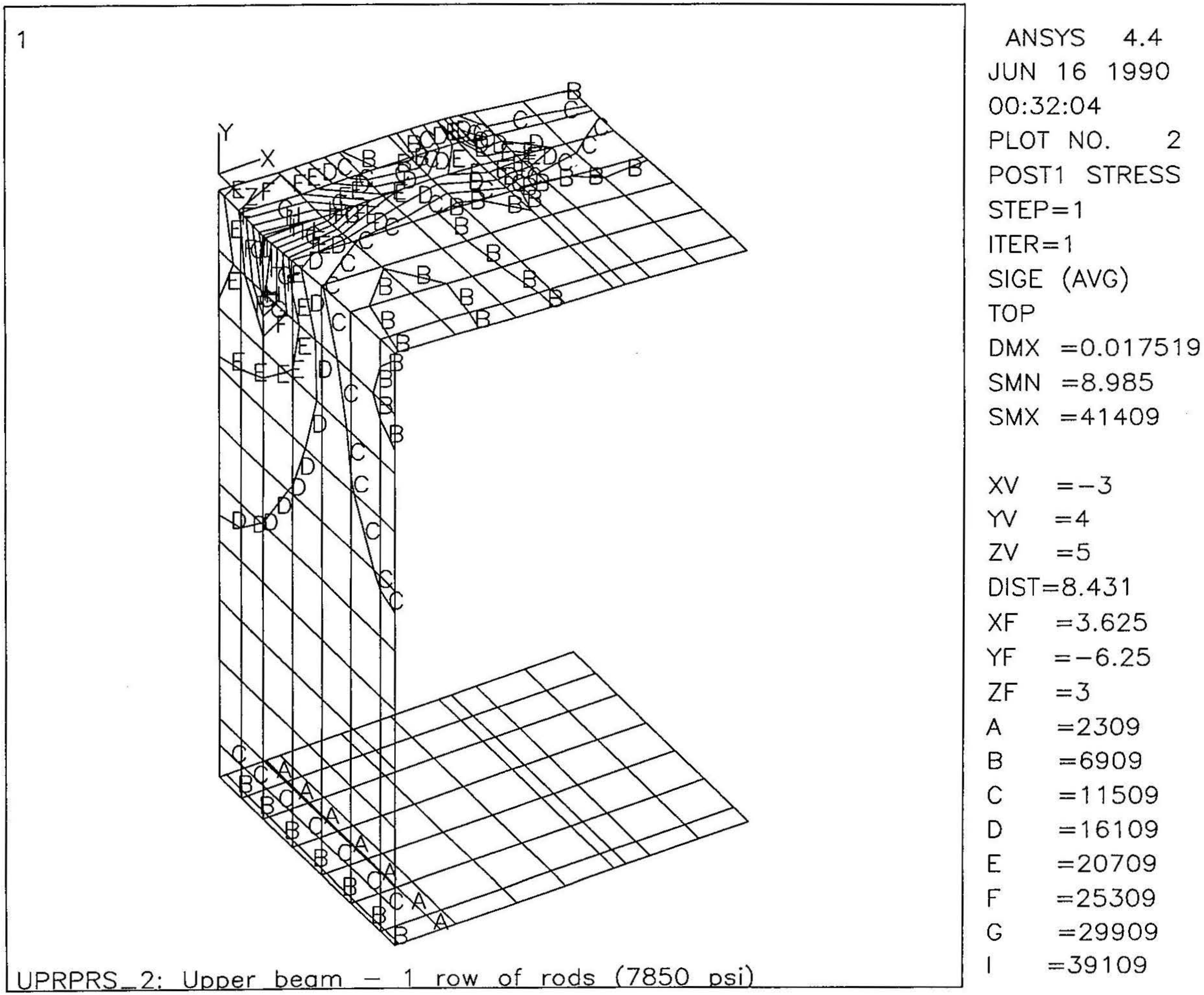
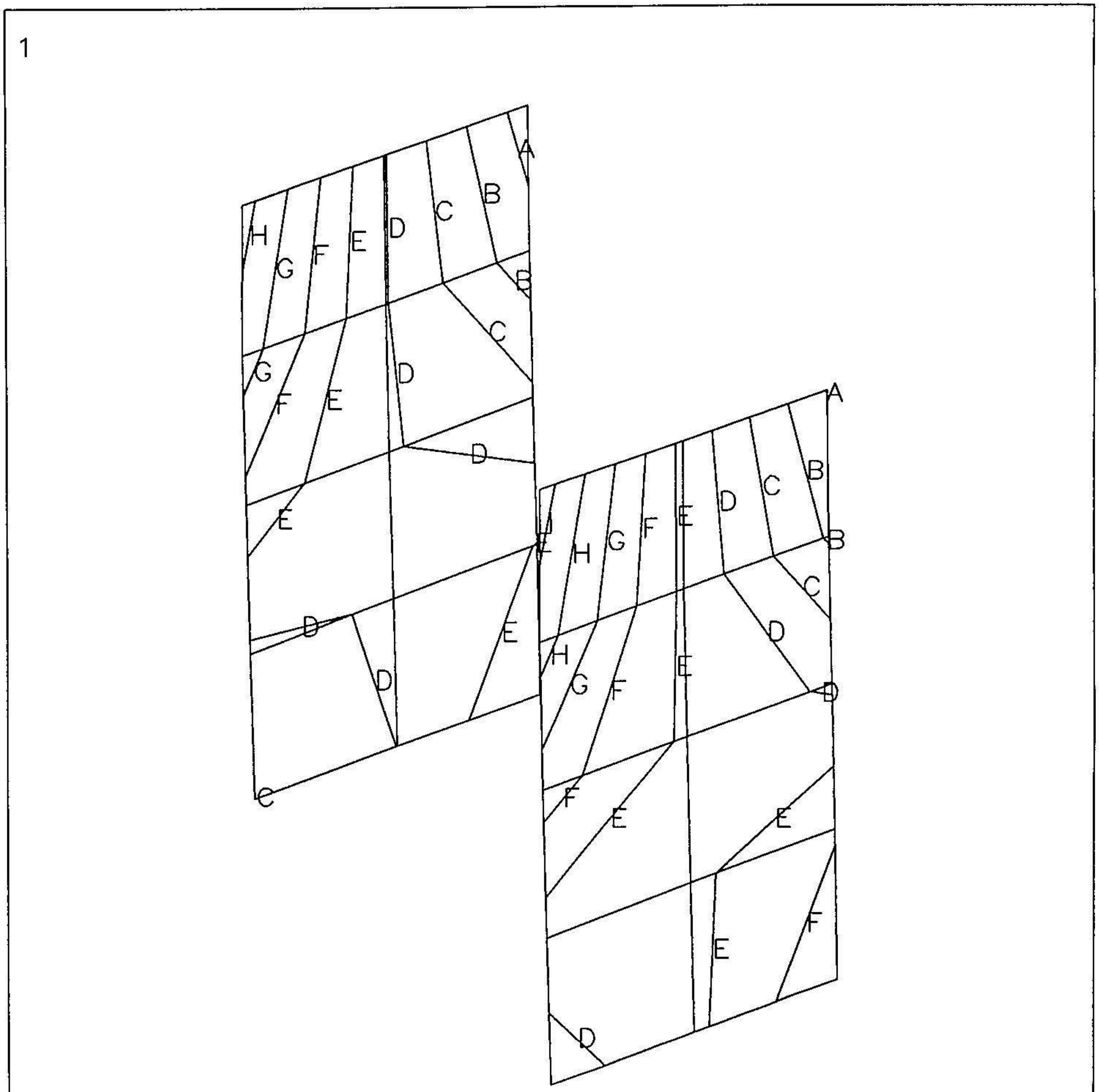

1
Y
X
ANSYS 4.4
JUN 16 1990
00:32:04
PLOT NO. 2
POST1 STRESS
STEP=1
ITER=1
SIGE (AVG)
TOP
DMX =0.017519
SMN =8.985
SMX =41409
XV =-3
YV =4
ZV =5
DIST=8.431
XF =3.625
YF =-6.25
ZF =3
A =2309
B =6909
C =11509
D =16109
E =20709
F =25309
G =29909
I =39109
UPRPRS_2: Upper beam - 1 row of rods (7850 psi)

FIGURE 7

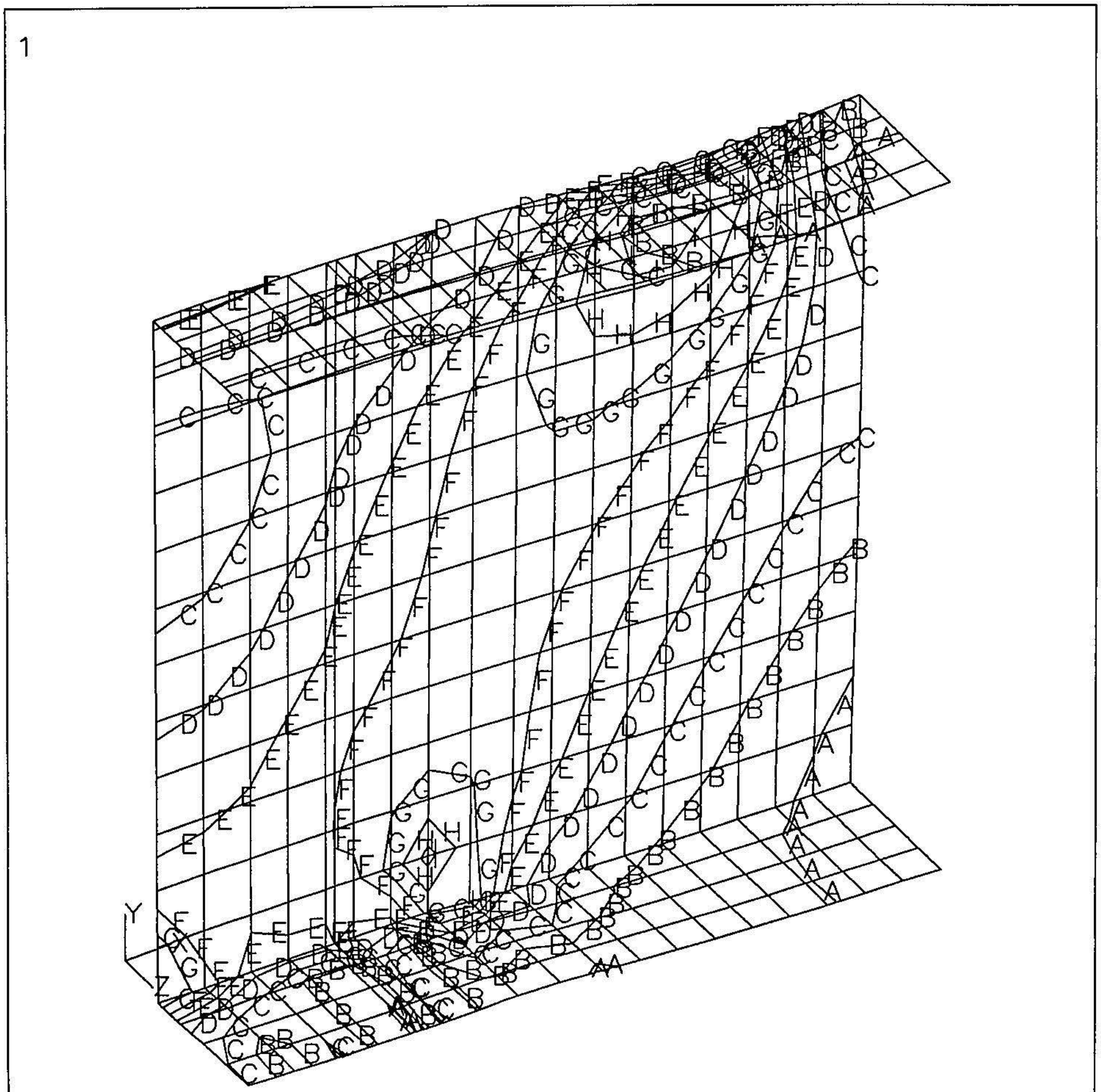


UPRPRS_2: Upper beam – 1 row of rods (7850 psi)

ANSYS 4.4
JUN 16 1990
09:17:18
PLOT NO. 3
POST1 STRESS
STEP=1
ITER=1
SY (AVG)
MIDDLE
S GLOBAL
DMX =0.00901
SMN =-59679
SMX =-30483

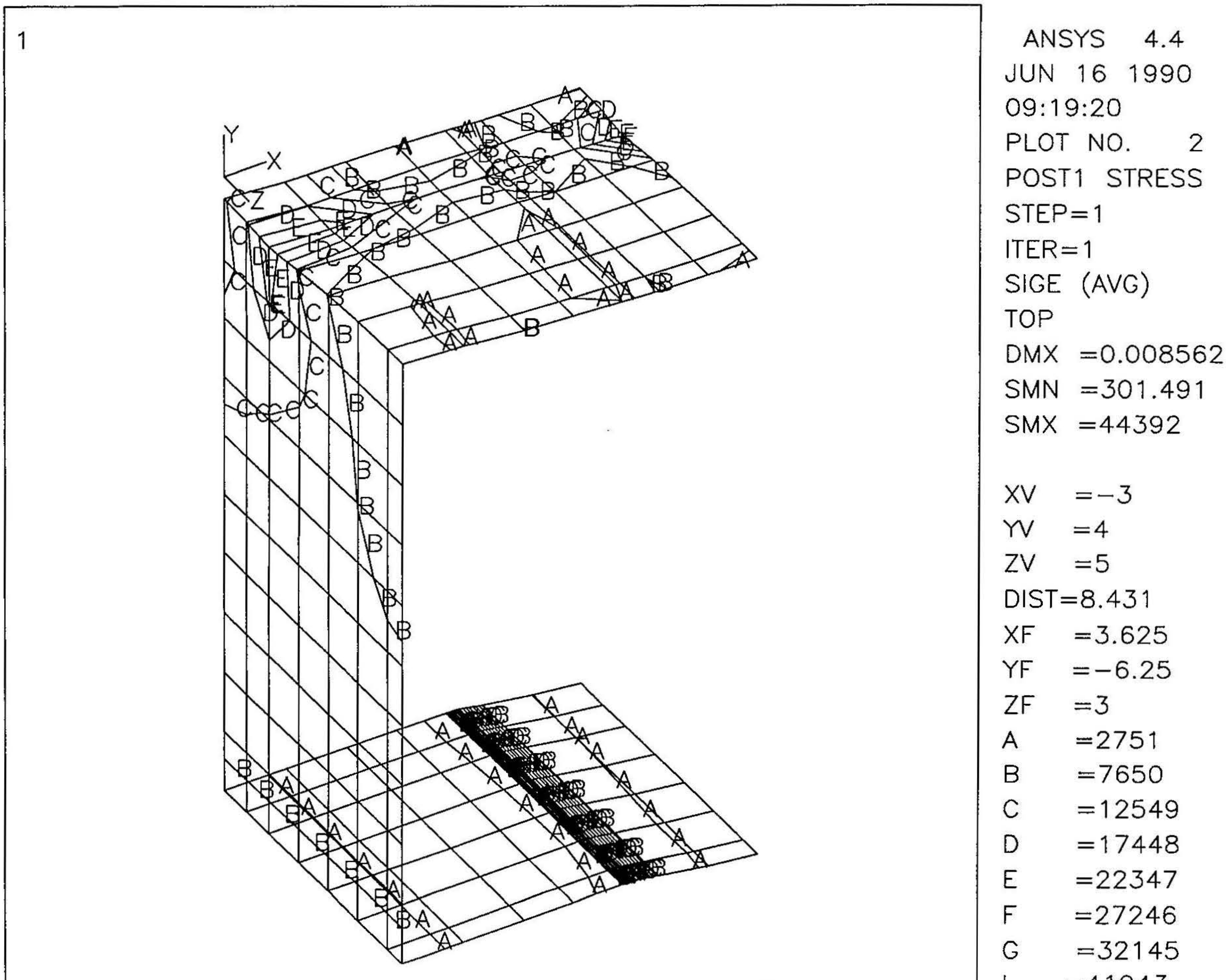
XV =-3
YV =4
ZV =5
DIST=3.295
XF =3.5
YF =-6.25
ZF =1.75
A =-58057
B =-54813
C =-51569
E =-45081
F =-41837
G =-38593
I =-32105

FIGURE 8



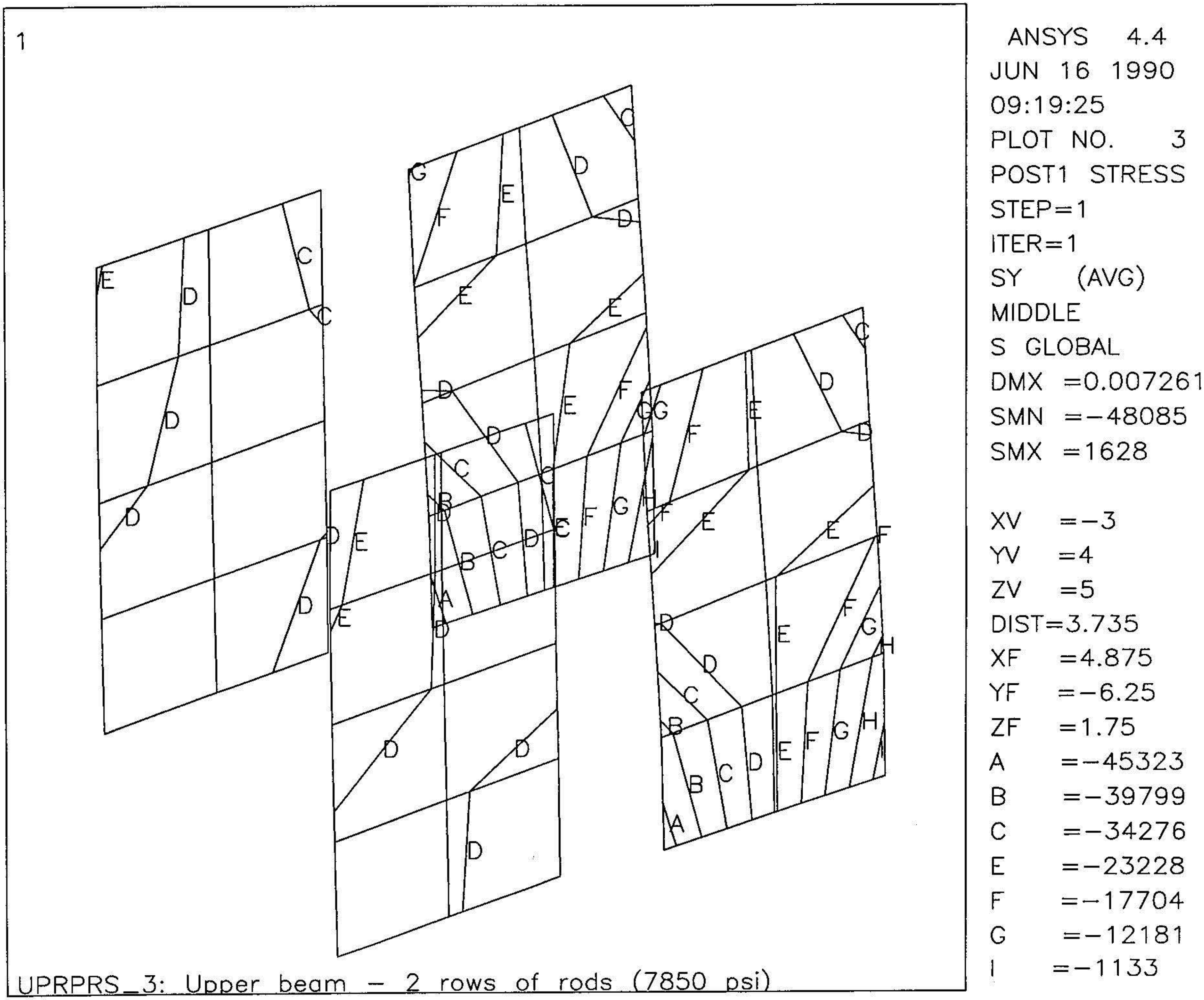
UPRPRS_3: Upper beam – 2 rows of rods (7850 psi)

Figure 9



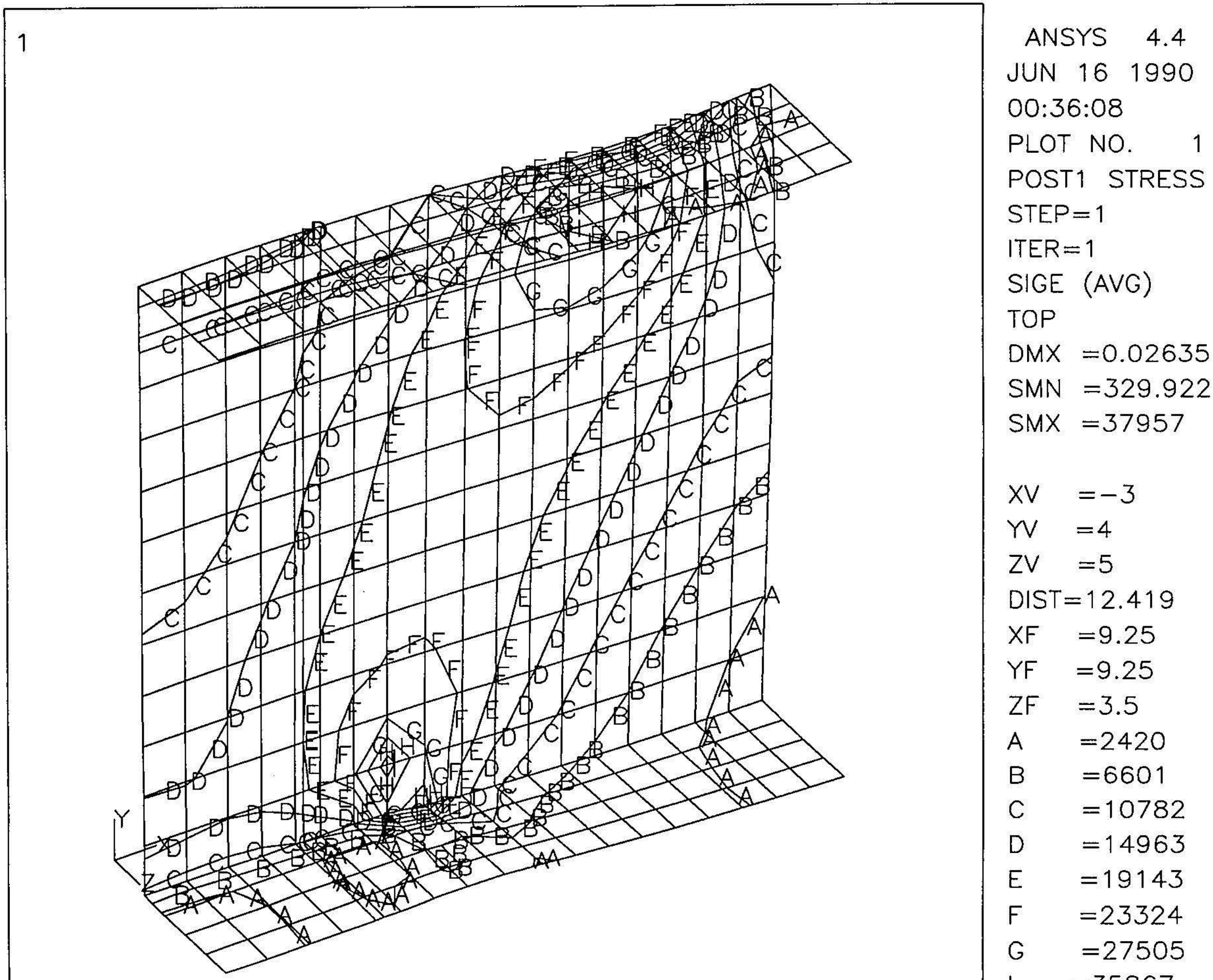
UPRPRS_3: Upper beam - 2 rows of rods (7850 psi)

FIGURE 10



UPRPRS_3: Upper beam - 2 rows of rods (7850 psi)

FIGURE 11



UPRPRS_4: Upper beam – permanent fix (10000 psi)

FIGURE 17

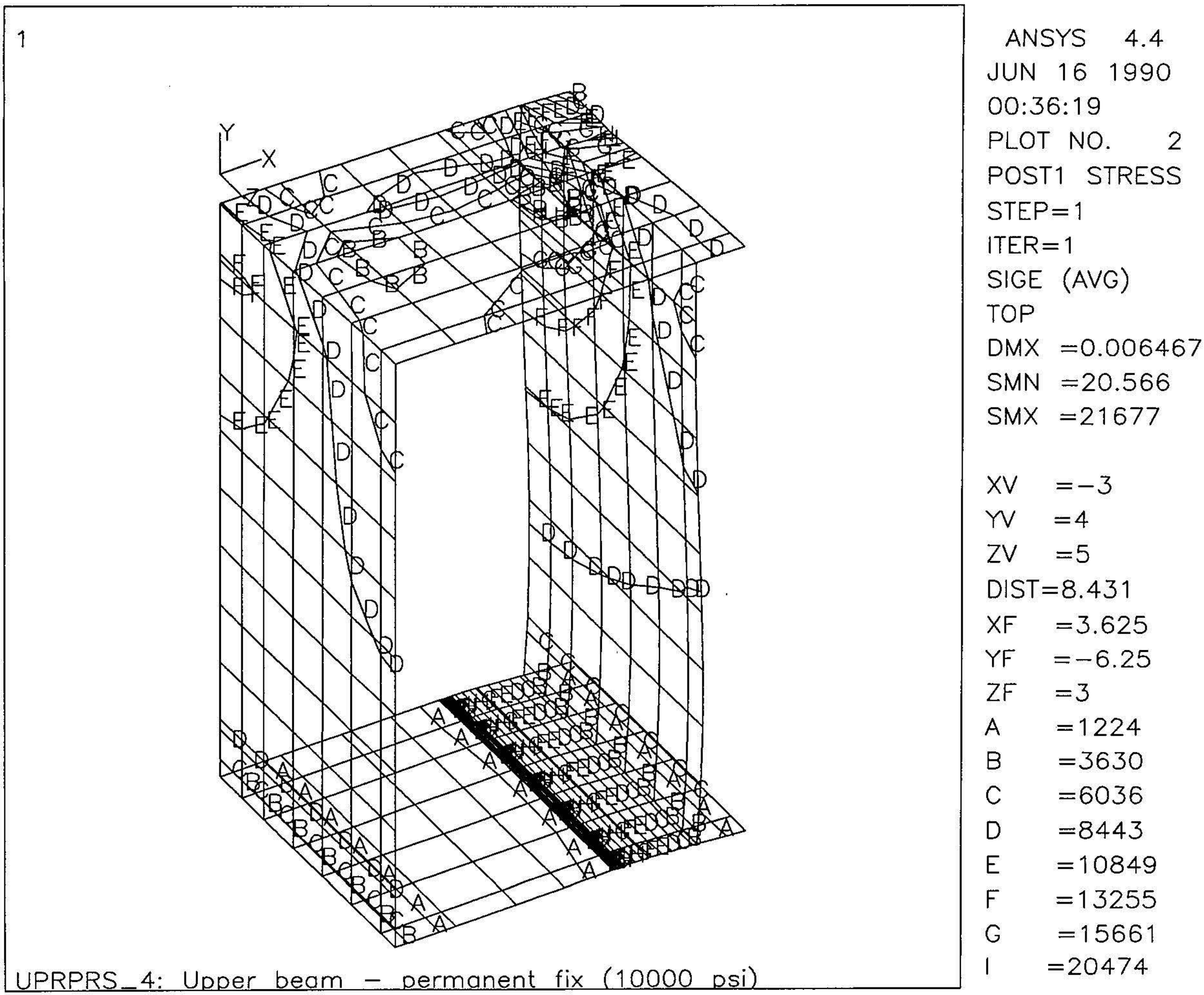
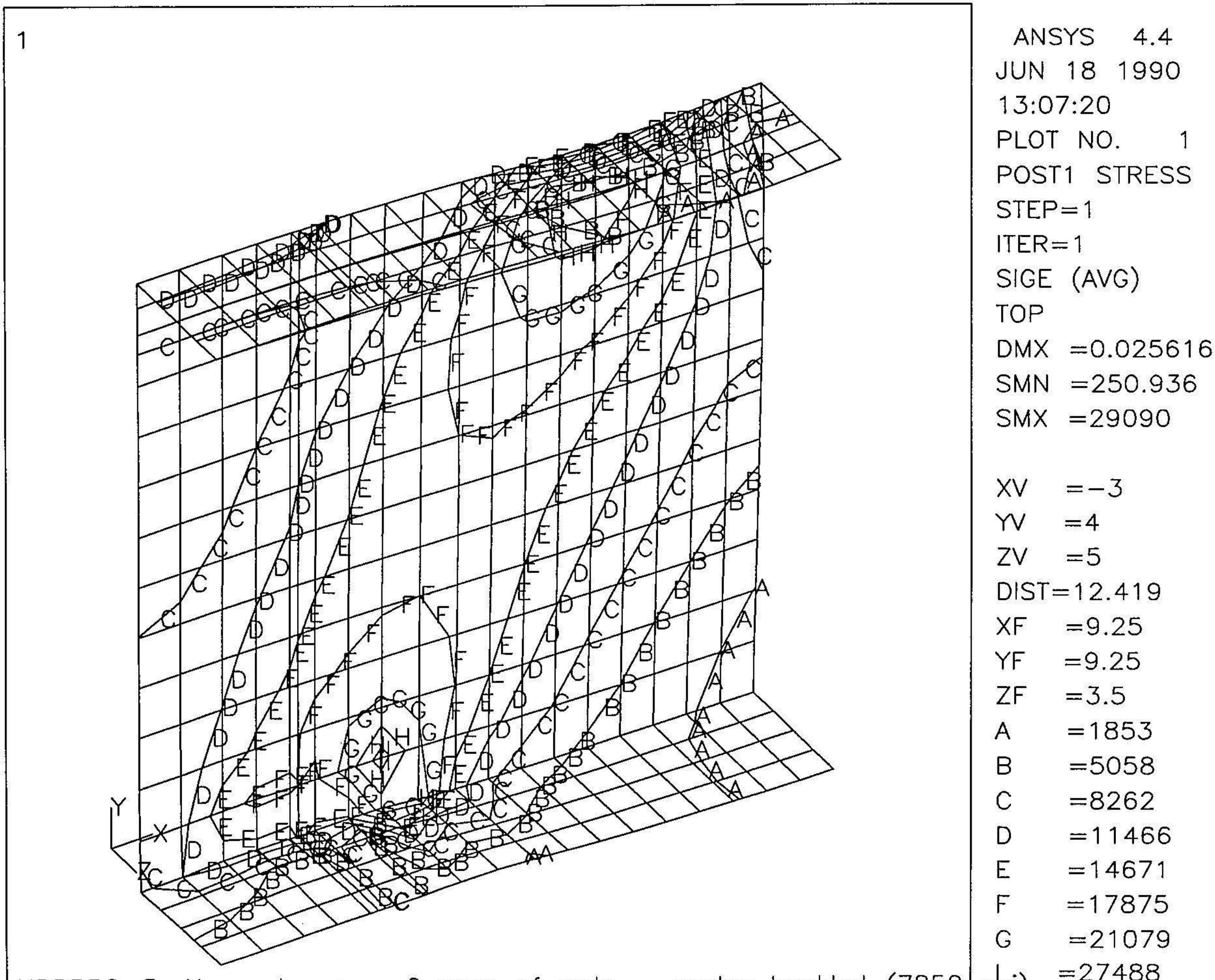
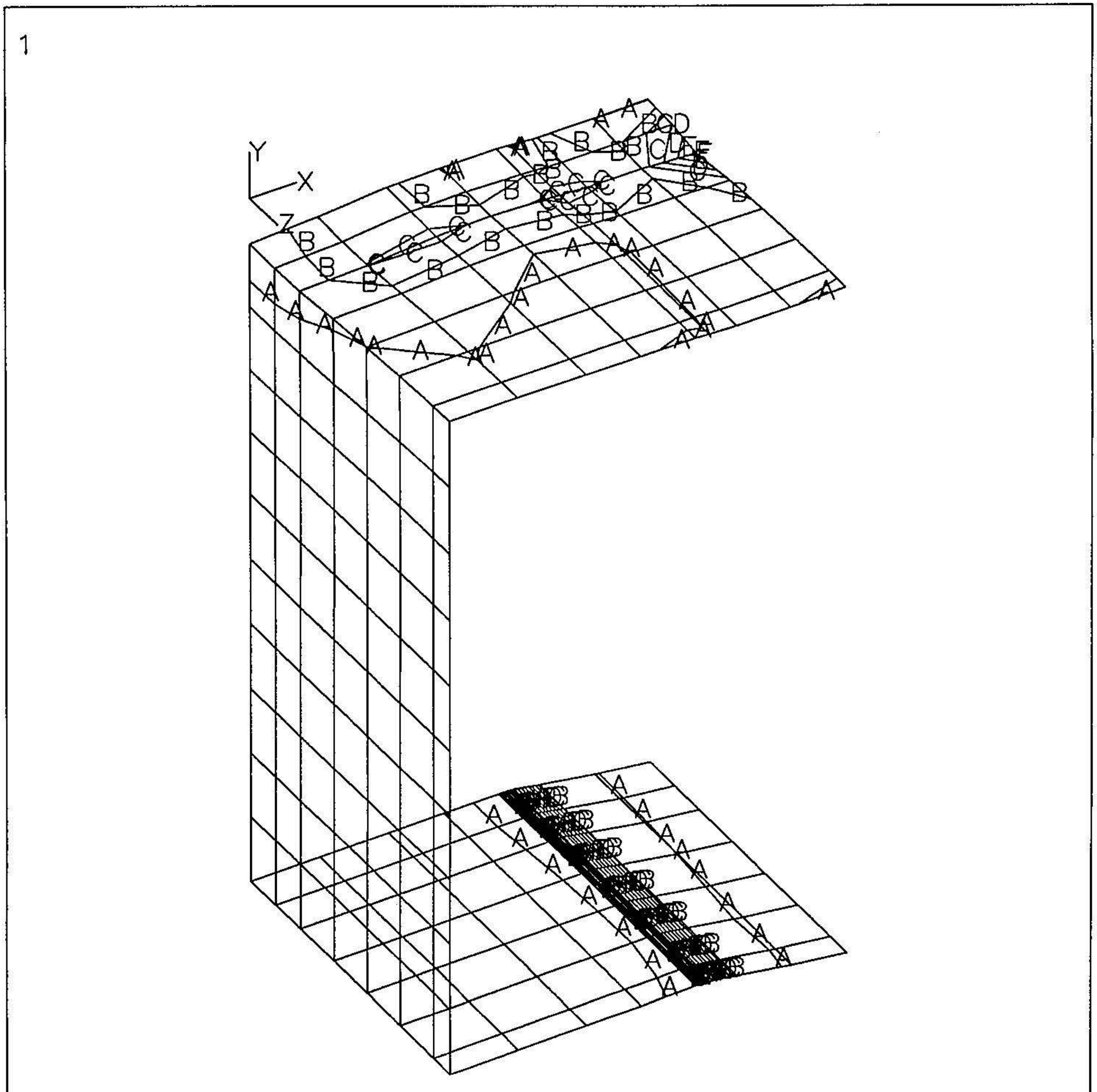

1
ANSYS 4.4
JUN 16 1990
00:36:19
PLOT NO. 2
POST1 STRESS
STEP=1
ITER=1
SIGE (AVG)
TOP
DMX =0.006467
SMN =20.566
SMX =21677
XV =-3
YV =4
ZV =5
DIST=8.431
XF =3.625
YF =-6.25
ZF =3
A =1224
B =3630
C =6036
D =8443
E =10849
F =13255
G =15661
I =20474
UPRPRS_4: Upper beam - permanent fix (10000 psi)

FIGURE 13



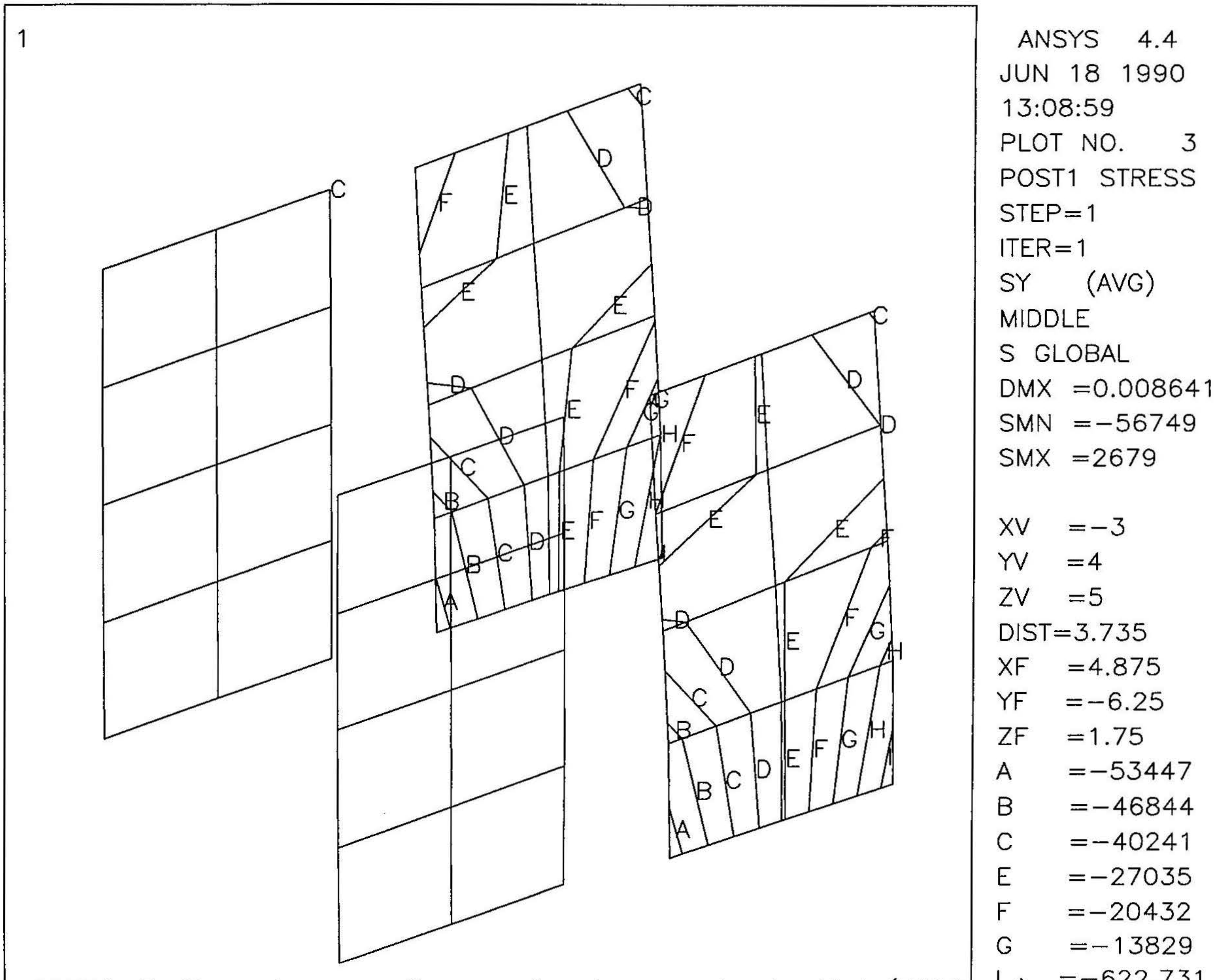
UPRPRS_5: Upper beam - 2 rows of rods - center buckled (7850 psi)

FIGURE 14



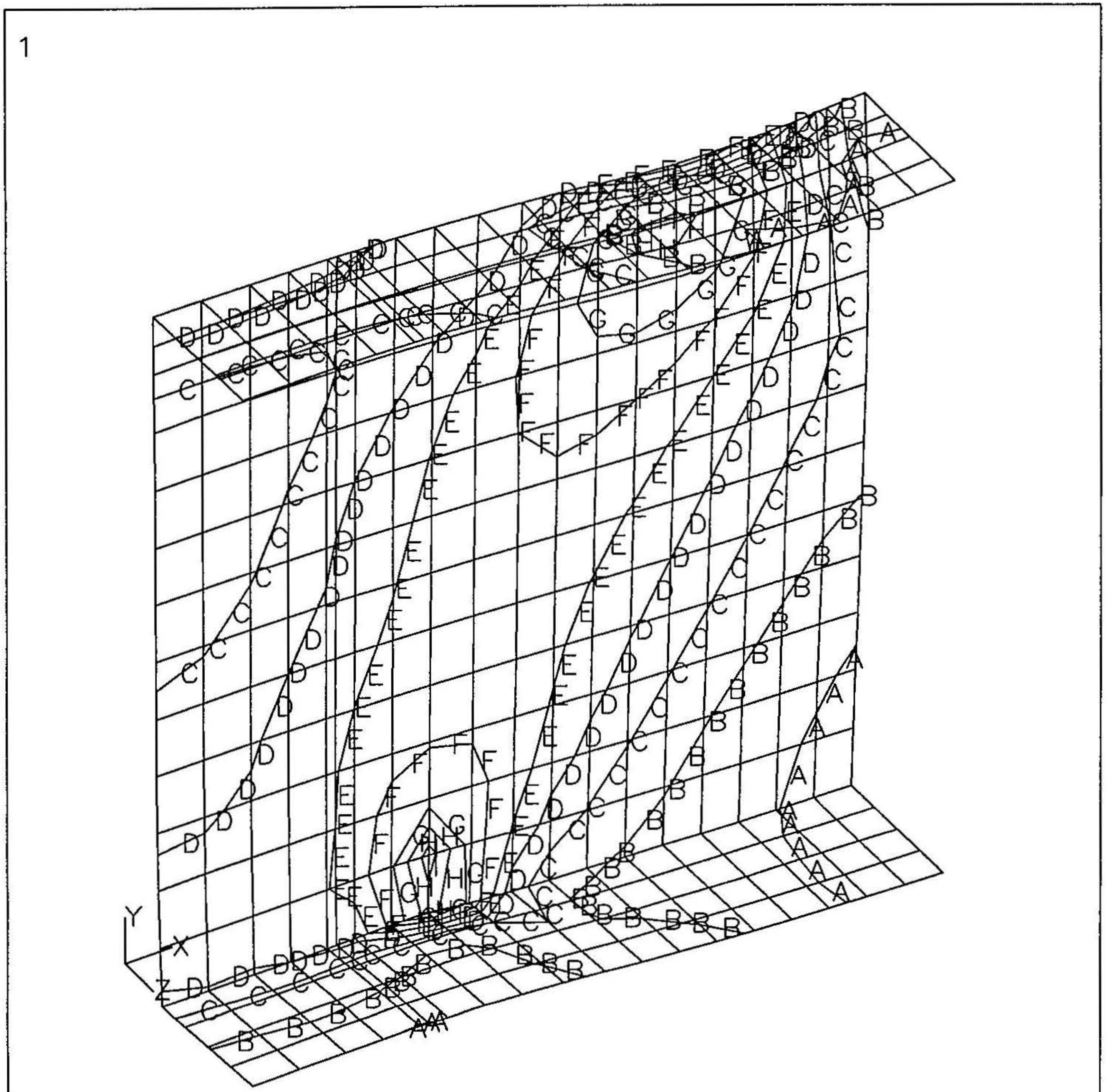
UPRPRS_5: Upper beam - 2 rows of rods - center buckled (7850 psi)

FIGURE 15



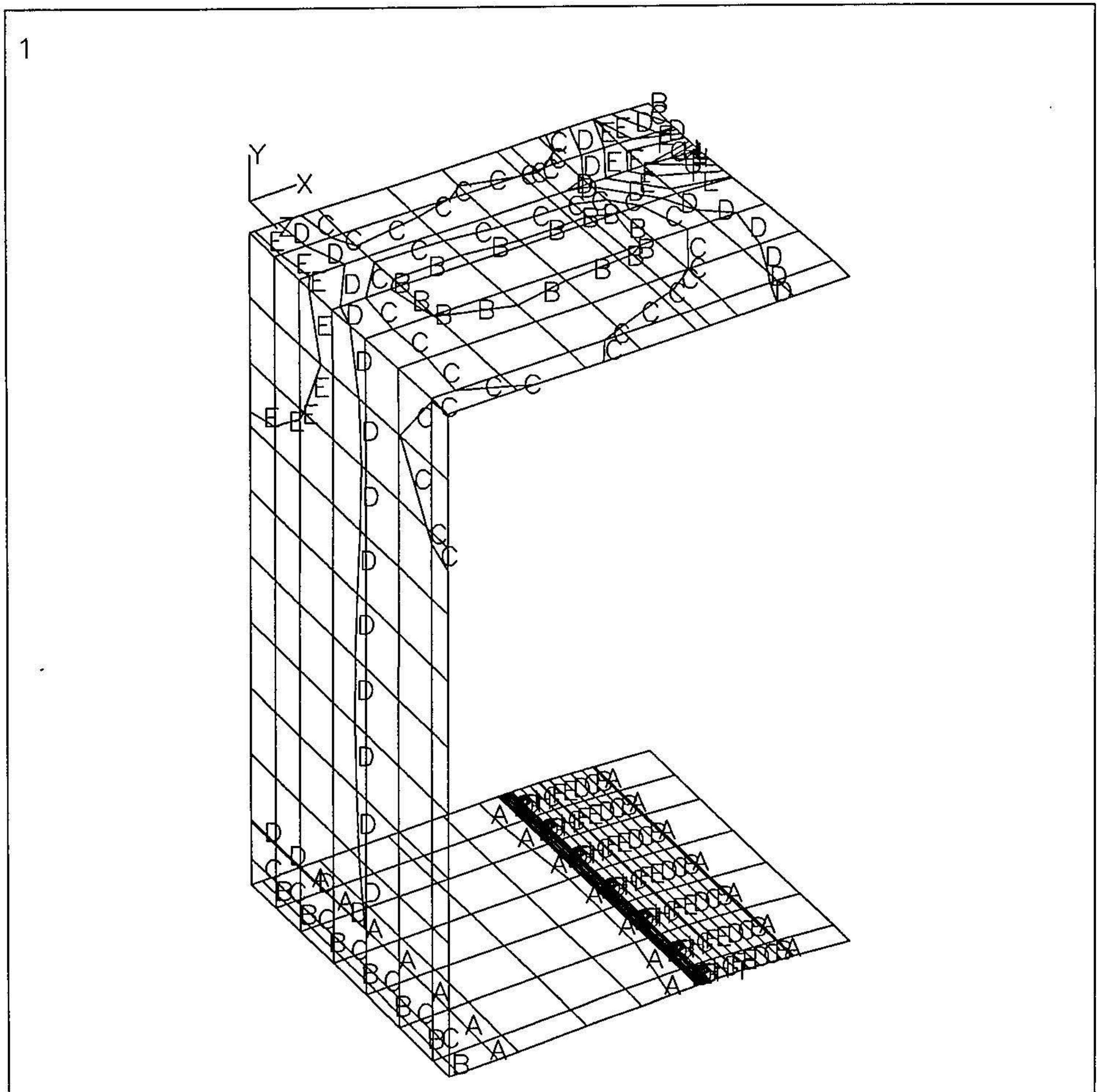
UPRPRS_5: Upper beam - 2 rows of rods - center buckled (7850 psi)

FIGURE 16



UPRPRS_6: Upper beam – permanent fix –bolted (10000 psi)

FIGURE 17

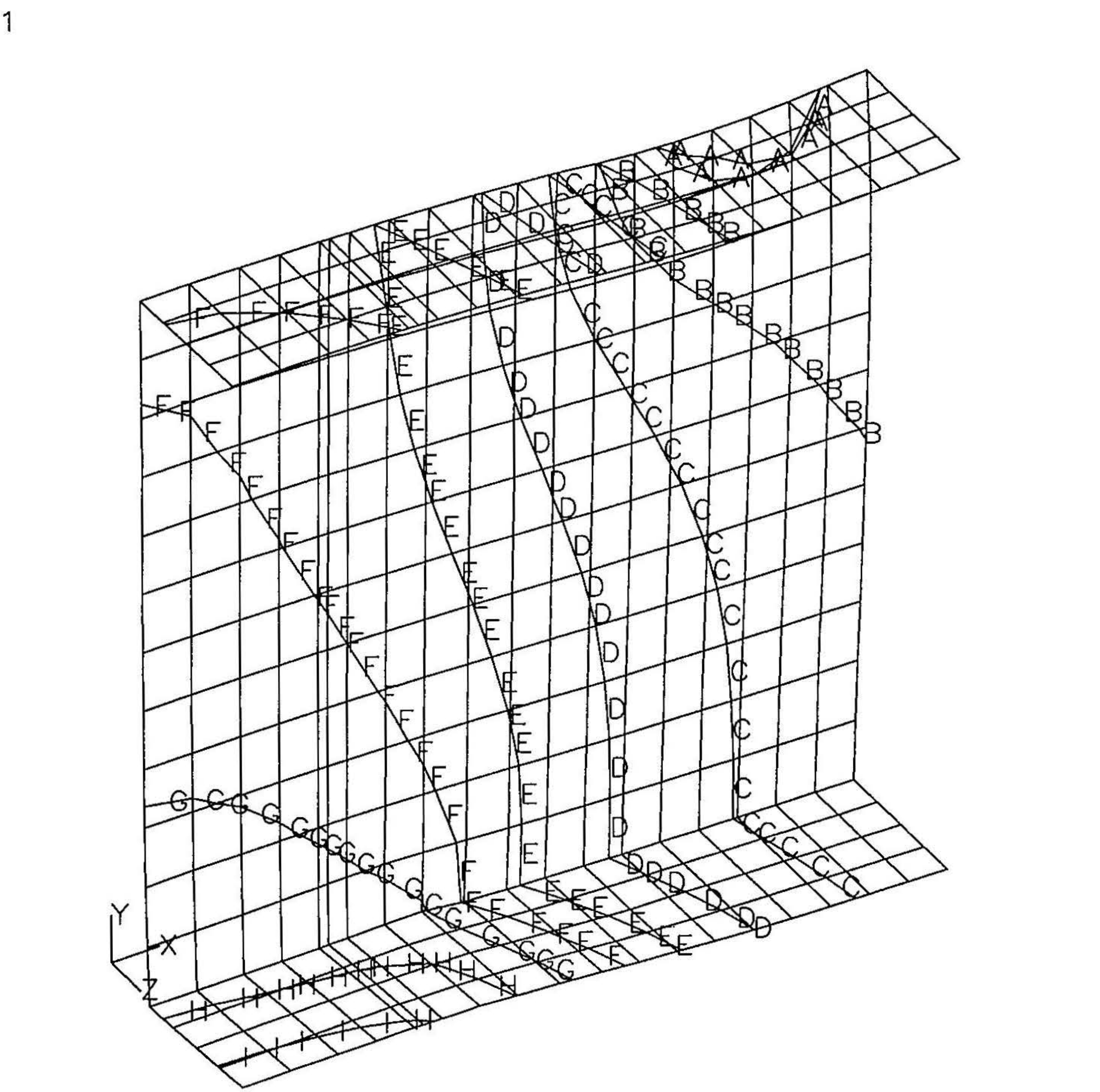


UPRPRS_6: Upper beam – permanent fix –bolted (10000 psi)

ANSYS 4.4
JUN 20 1990
11:39:01
PLOT NO. 2
POST1 STRESS
STEP=1
ITER=20
SIGE (AVG)
TOP
DMX =0.006553
SMN =18.001
SMX =23186

XV =-3
YV =4
ZV =5
DIST=8.431
XF =3.625
YF =-6.25
ZF =3
A =1305
B =3879
C =6454
D =9028
E =11602
F =14176
G =16751
I =21899

FIGURE 18

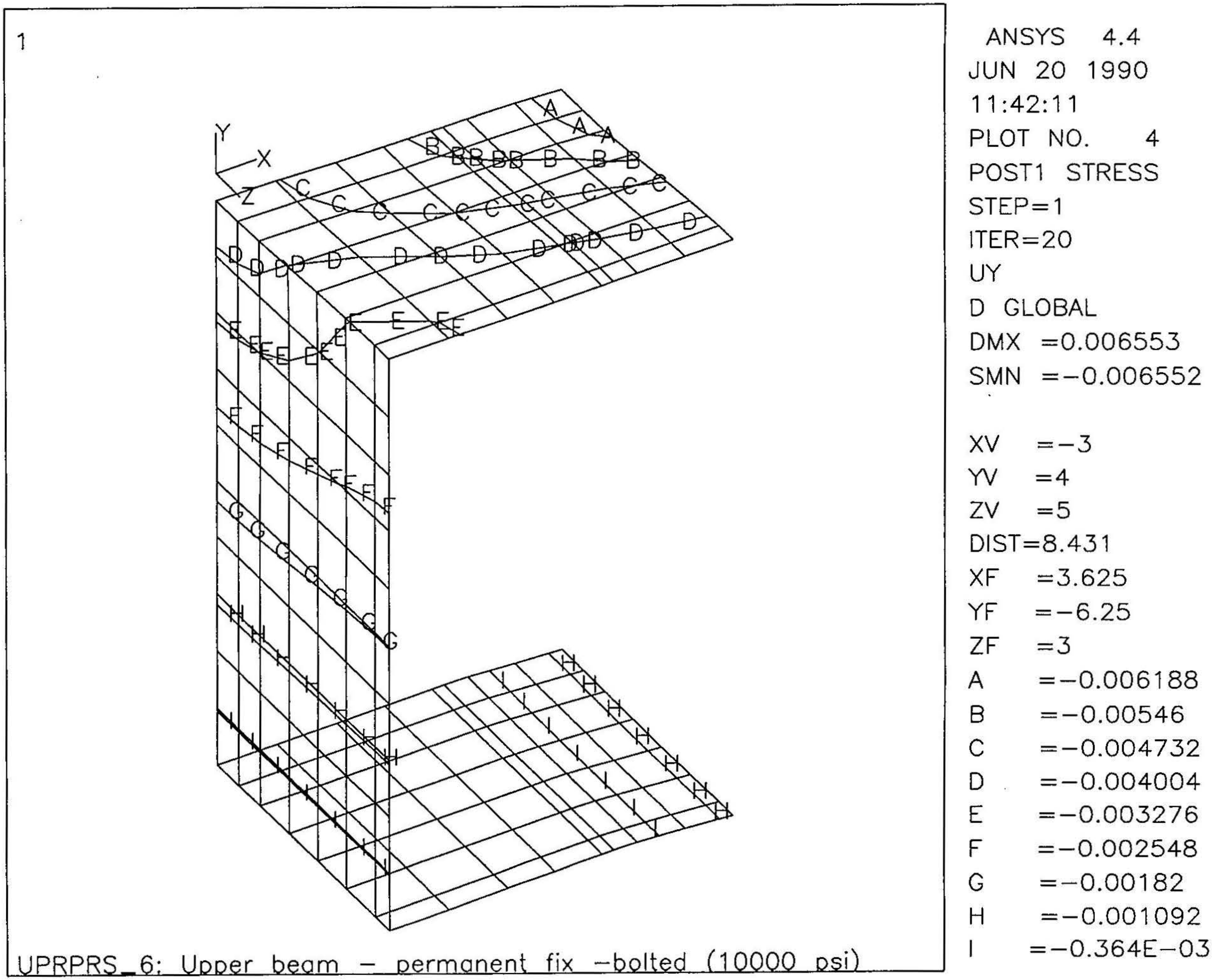


UPRPRS_6: Upper beam – permanent fix –bolted (10000 psi)

ANSYS 4.4
JUN 20 1990
11:41:54
PLOT NO. 3
POST1 STRESS
STEP=1
ITER=20
UY
D GLOBAL
DMX =0.027375
SMN =–0.02702
SMX =0.001054

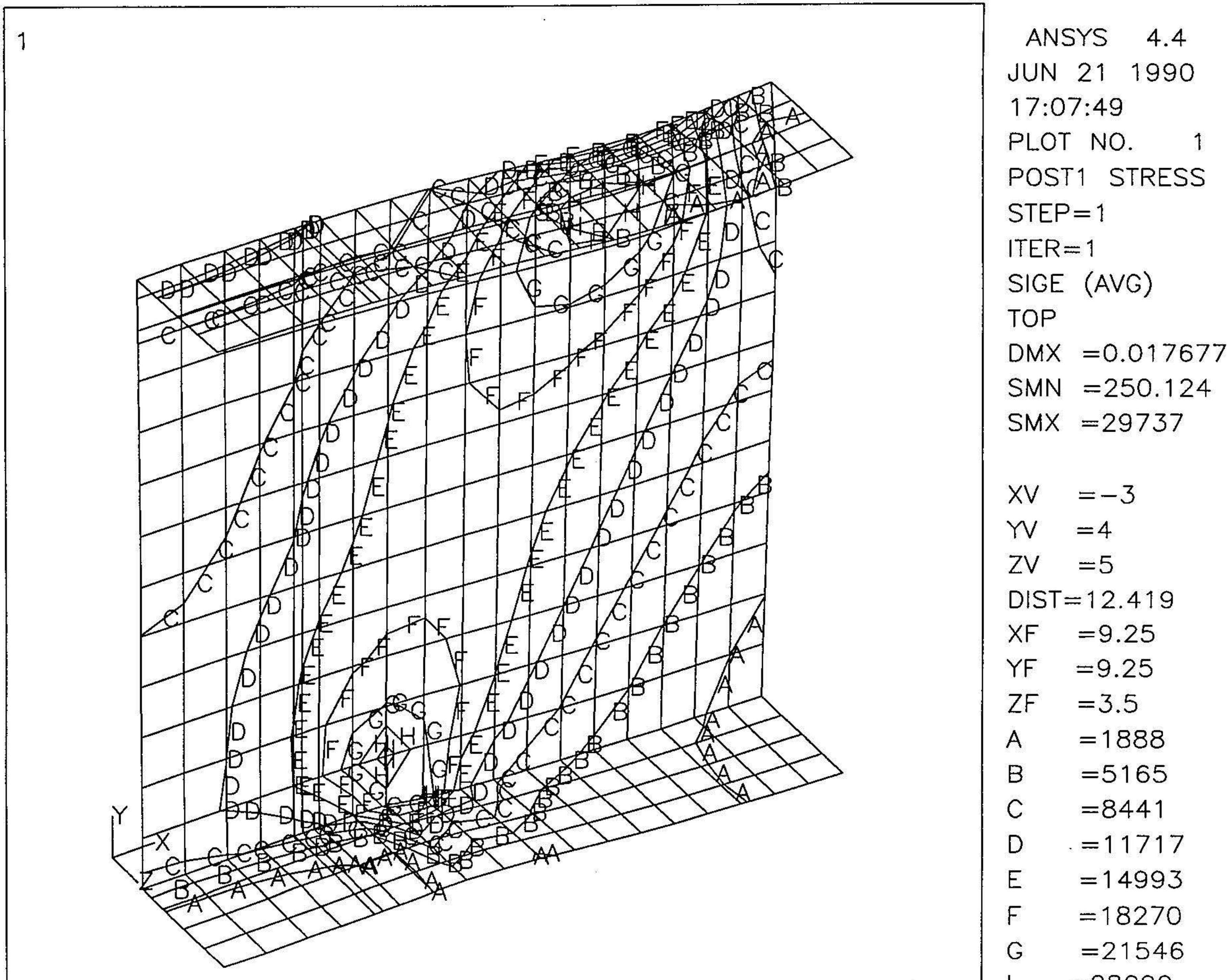
XV =–3
YV =4
ZV =5
DIST=12.419
XF =9.25
YF =9.25
ZF =3.5
A =–0.025461
B =–0.022341
C =–0.019222
D =–0.016103
E =–0.012983
F =–0.009864
G =–0.006745
I =–0.506E–03

FIGURE 19



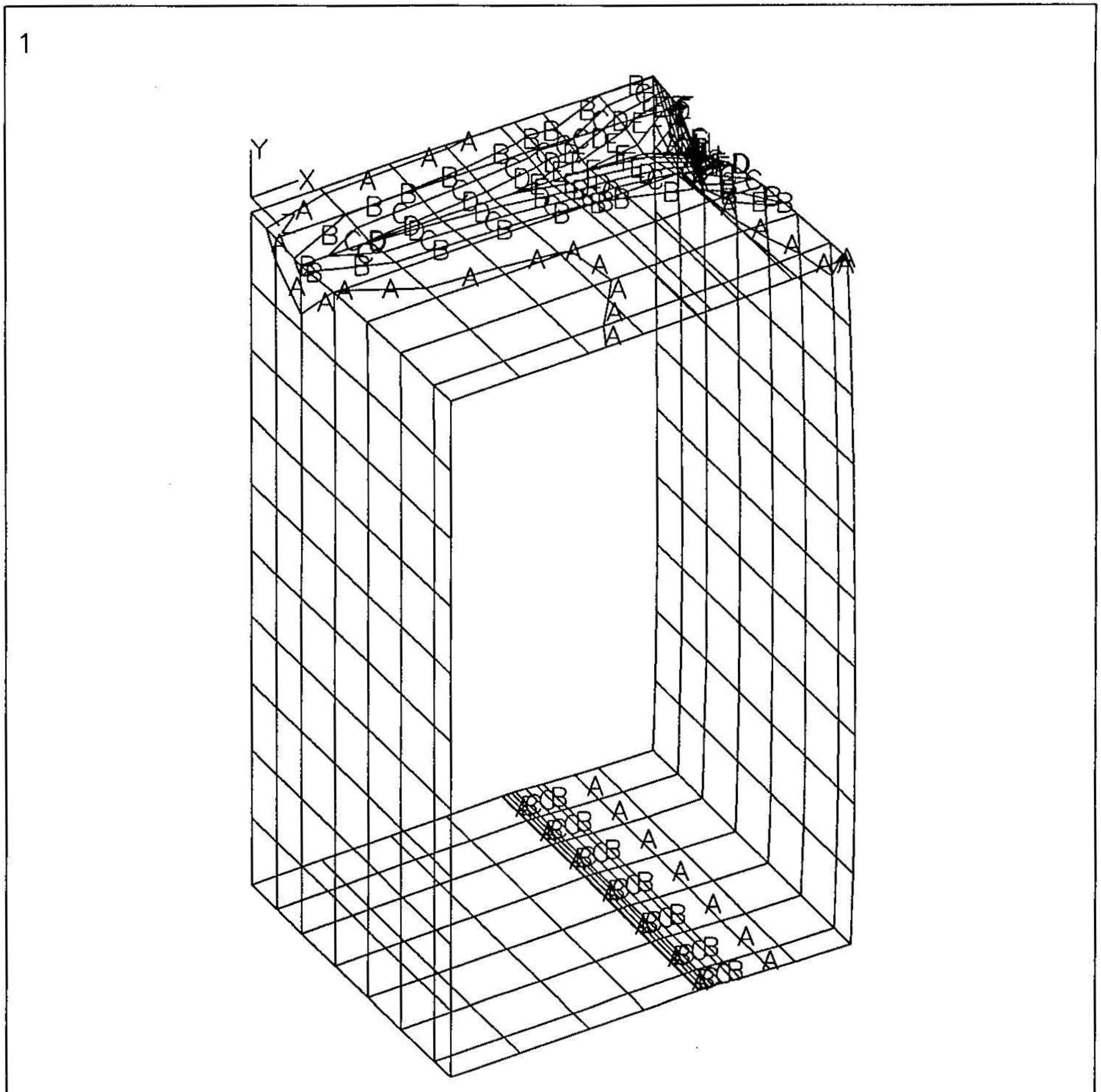
UPRPRS_6: Upper beam - permanent fix -bolted (10000 psi)

FIGURE 20



UPRPRS_7: Upper beam – buckled section w/ grout (7850 psi)

FIGURE 21

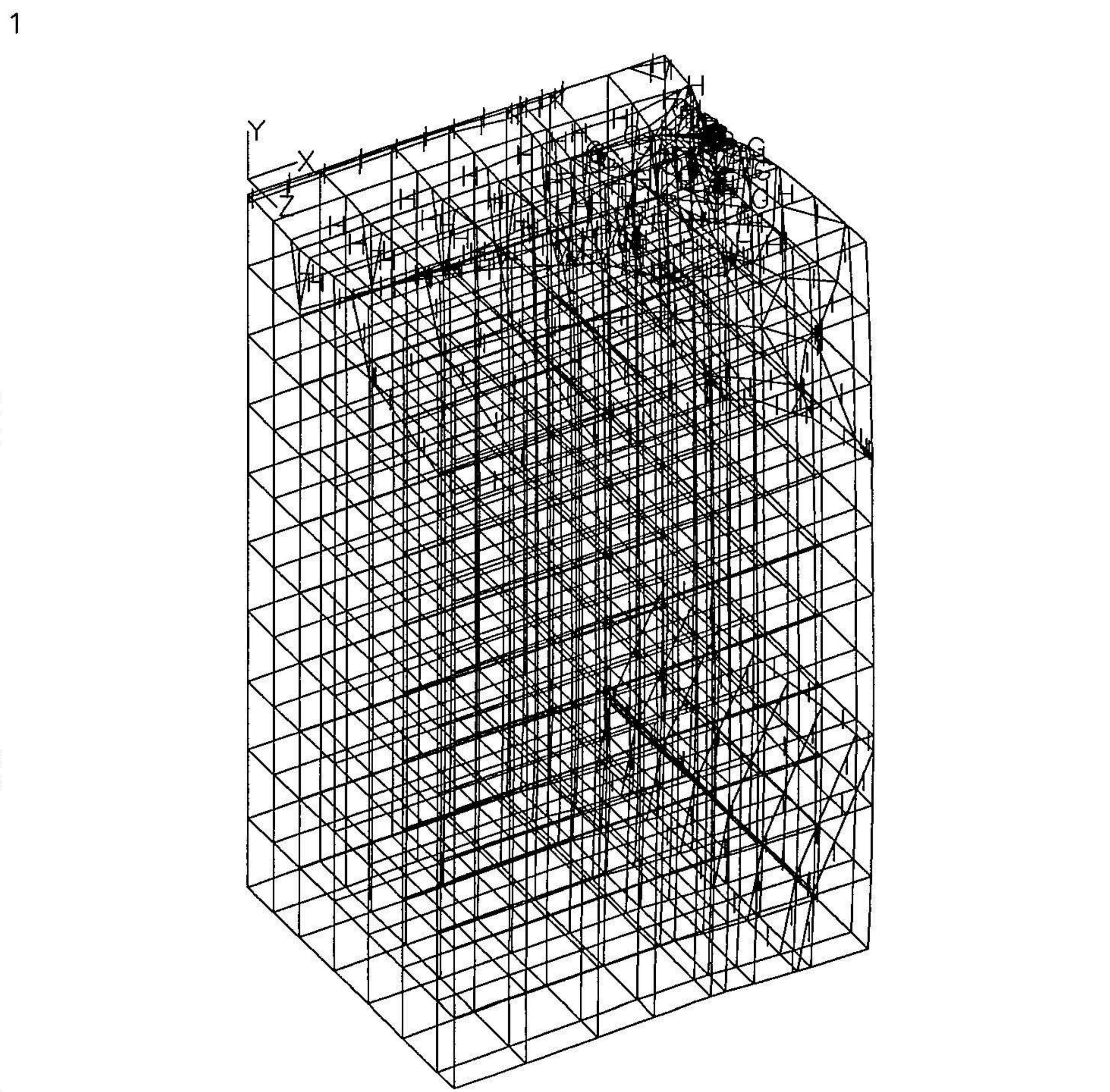


UPRPRS_7: Upper beam – buckled section w/ grout (7850 psi)

ANSYS 4.4
JUN 21 1990
17:09:02
PLOT NO. 2
POST1 STRESS
STEP=1
ITER=1
SIGE (AVG)
TOP
DMX =0.002037
SMN =5.943
SMX =16329

XV =-3
YV =4
ZV =5
DIST=8.431
XF =3.625
YF =-6.25
ZF =3
A =912.754
B =2726
C =4540
D =6354
E =8167
F =9981
G =11794
I =15422

FIGURE 22

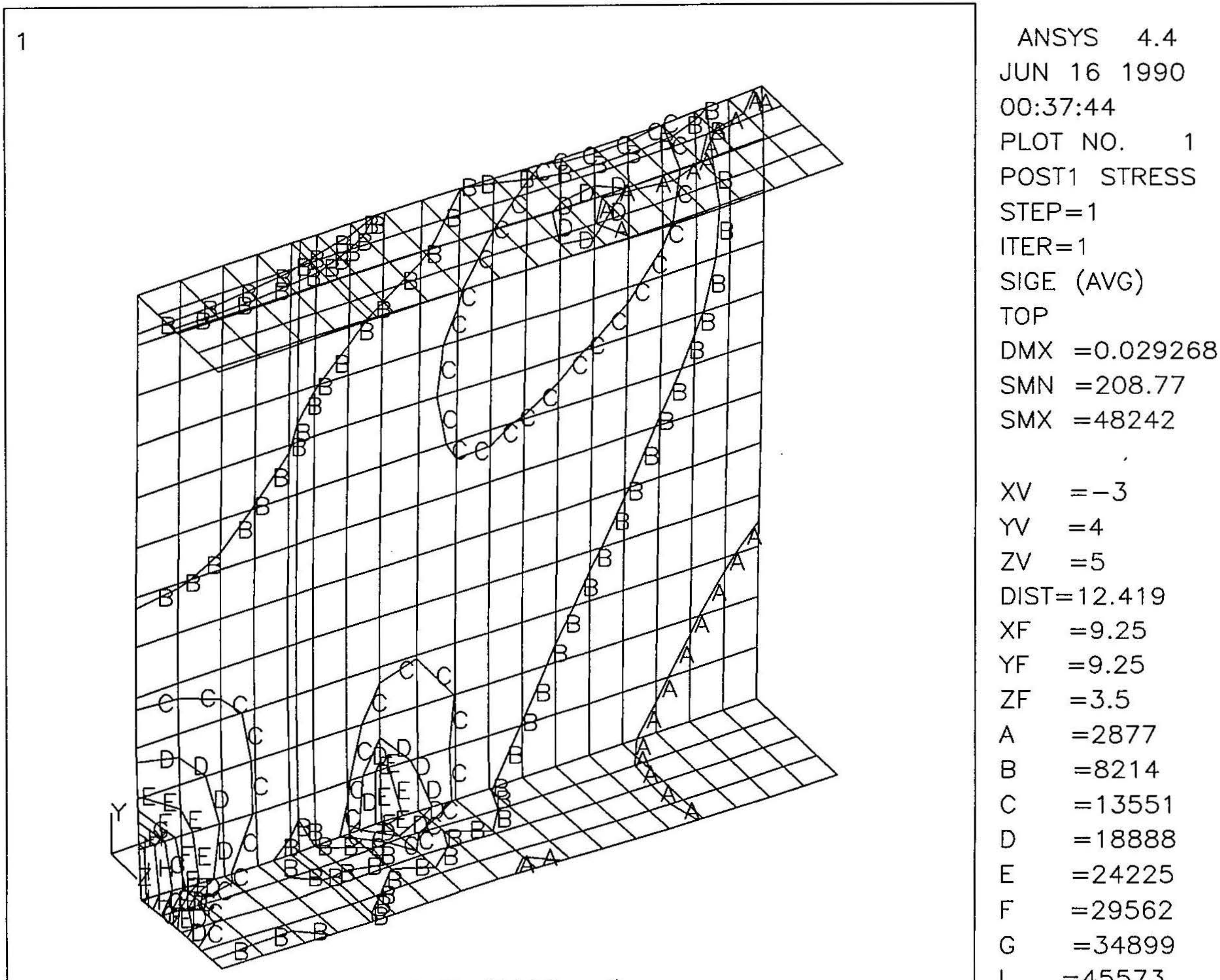


UPRPRS_7: Upper beam – buckled section w/ grout (7850 psi)

ANSYS 4.4
JUN 21 1990
17:10:47
PLOT NO. 3
POST1 STRESS
STEP=1
ITER=1
SY (AVG)
MIDDLE
S GLOBAL
DMX =0.002037
SMN =-32698
SMX =1544

XV =-3
YV =4
ZV =5
DIST=8.431
XF =3.625
YF =-6.25
ZF =3
A =-30795
B =-26991
C =-23186
E =-15577
F =-11772
G =-7968
I =-358.375

FIGURE 23



LRWPRS_1: Lower beam as built (6000 psi)

FIGURE 24

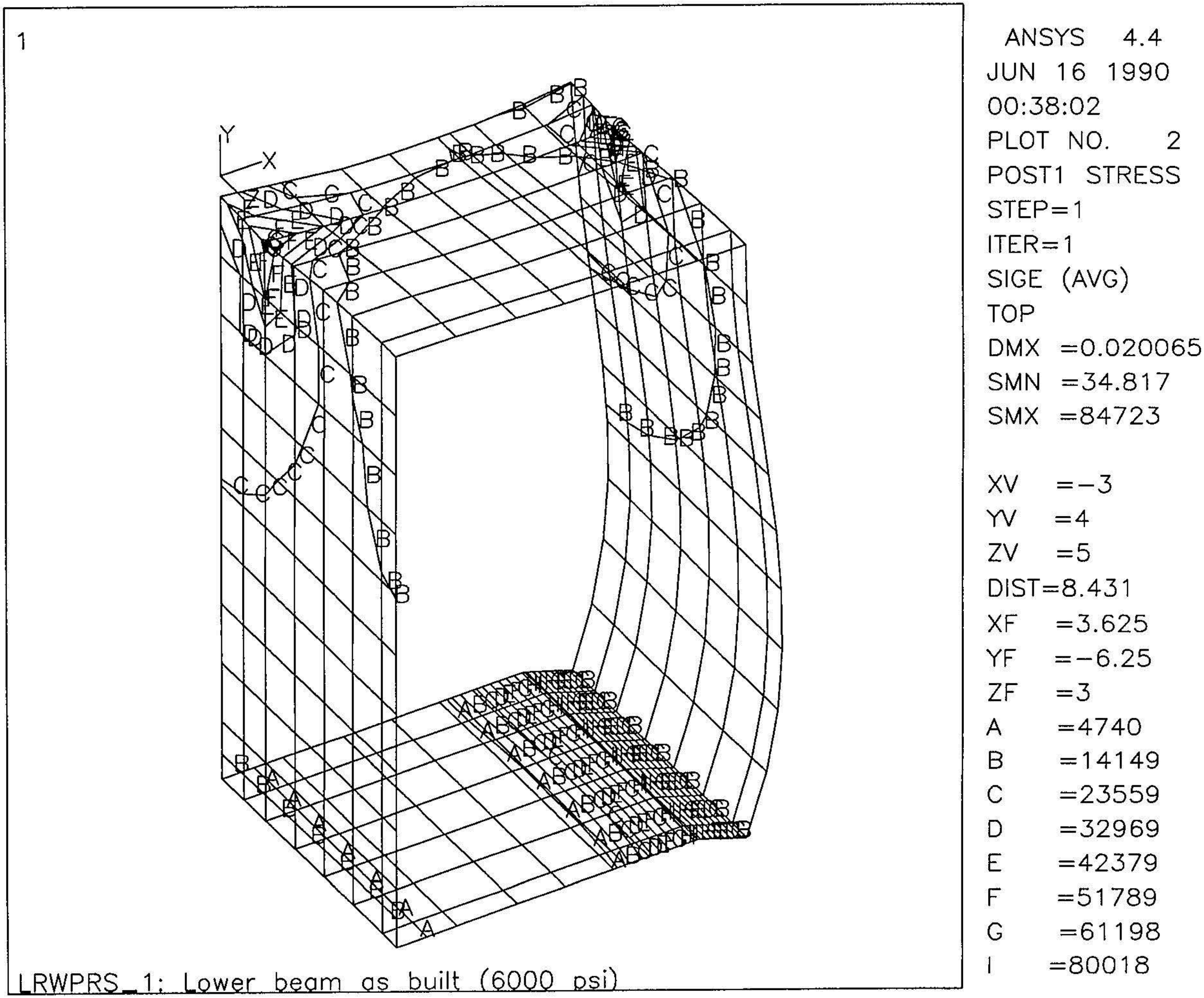
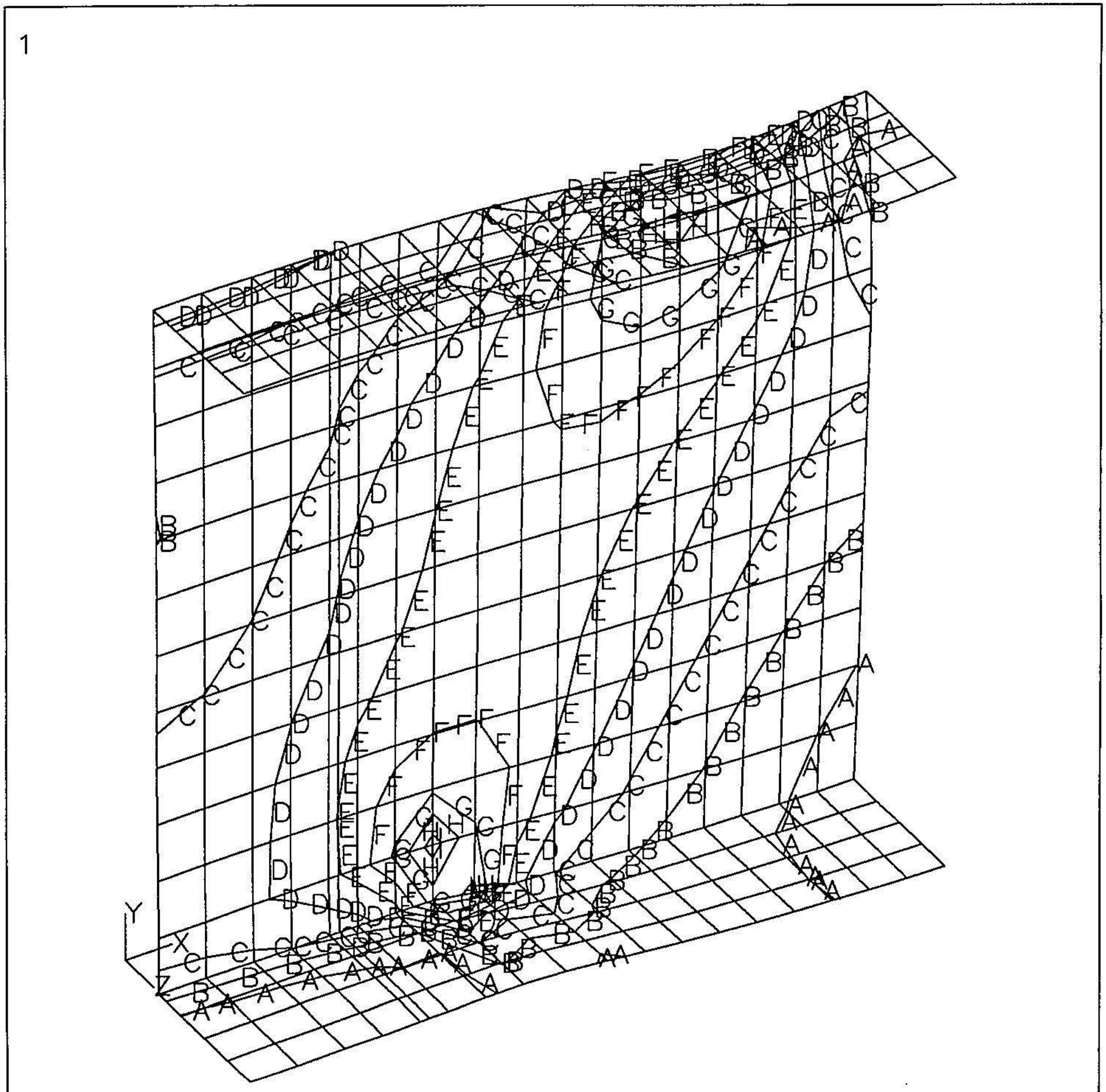

1
Y
X
ANSYS 4.4
JUN 16 1990
00:38:02
PLOT NO. 2
POST1 STRESS
STEP=1
ITER=1
SIGE (AVG)
TOP
DMX =0.020065
SMN =34.817
SMX =84723
XV =-3
YV =4
ZV =5
DIST=8.431
XF =3.625
YF =-6.25
ZF =3
A =4740
B =14149
C =23559
D =32969
E =42379
F =51789
G =61198
I =80018
LRWPRS_1: Lower beam as built (6000 psi)

FIGURE 25

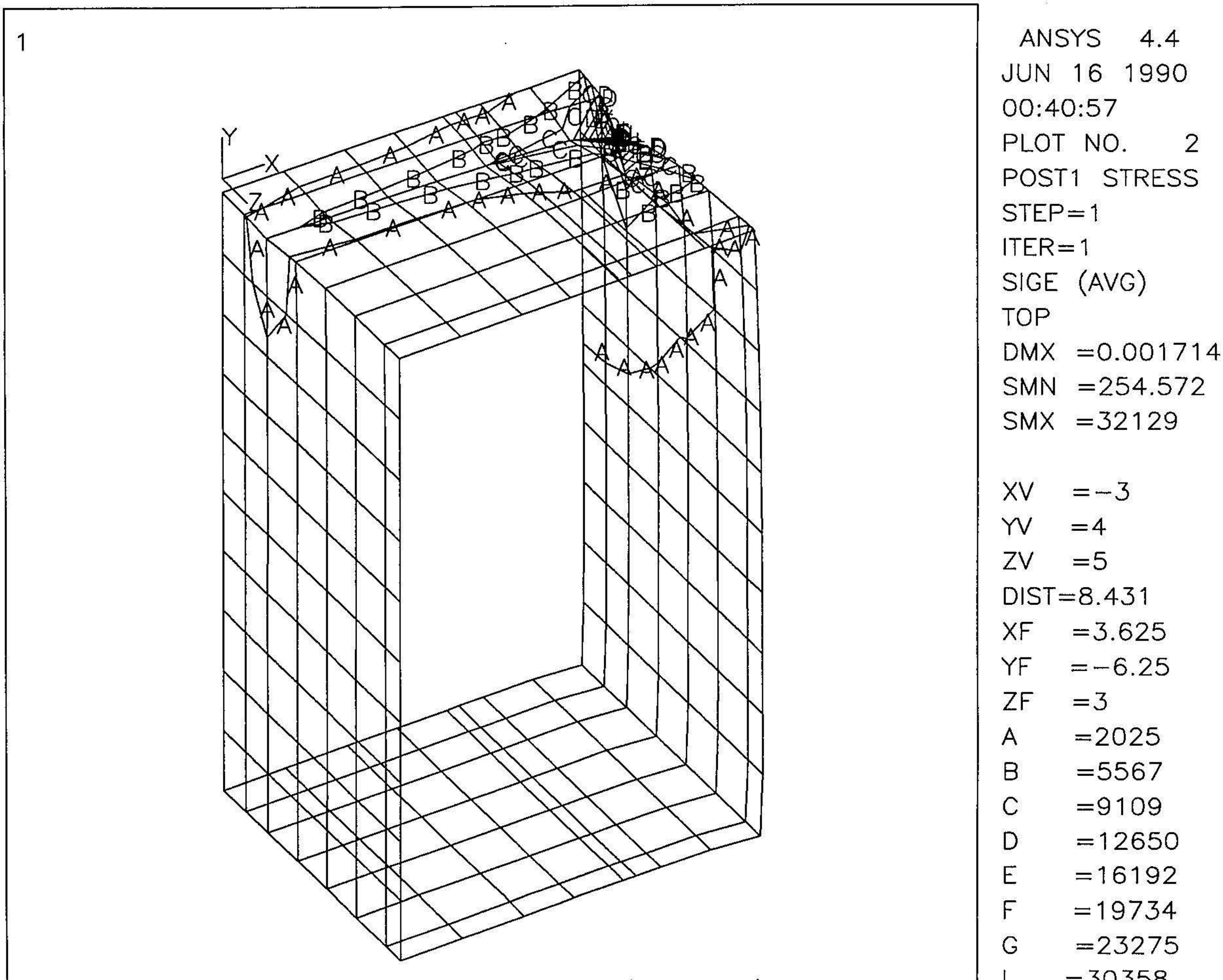


LRWPRS_2: Lower beam – 3.5M psi grout (7850 psi)

ANSYS 4.4
JUN 16 1990
11:46:31
PLOT NO. 1
POST1 STRESS
STEP=1
ITER=1
SIGE (AVG)
TOP
DMX =0.01749
SMN =246.93
SMX =30656

XV =-3
YV =4
ZV =5
DIST=12.419
XF =9.25
YF =9.25
ZF =3.5
A =1936
B =5315
C =8694
D =12073
E =15452
F =18830
G =22209
I =28967

FIGURE 2C



LRWPRS_2: Lower beam – 3.5M psi grout (7850 psi)

FIGURE 27

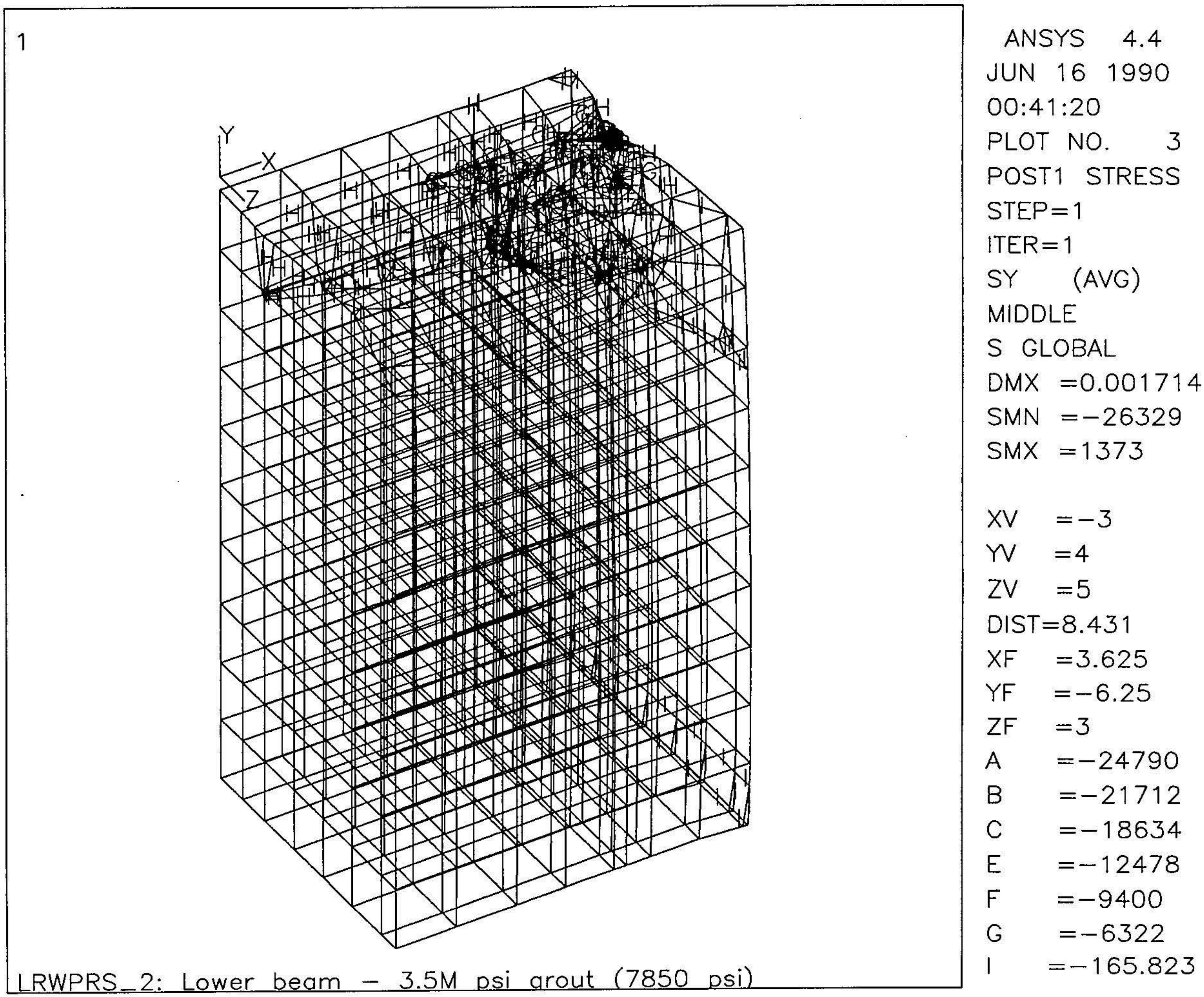
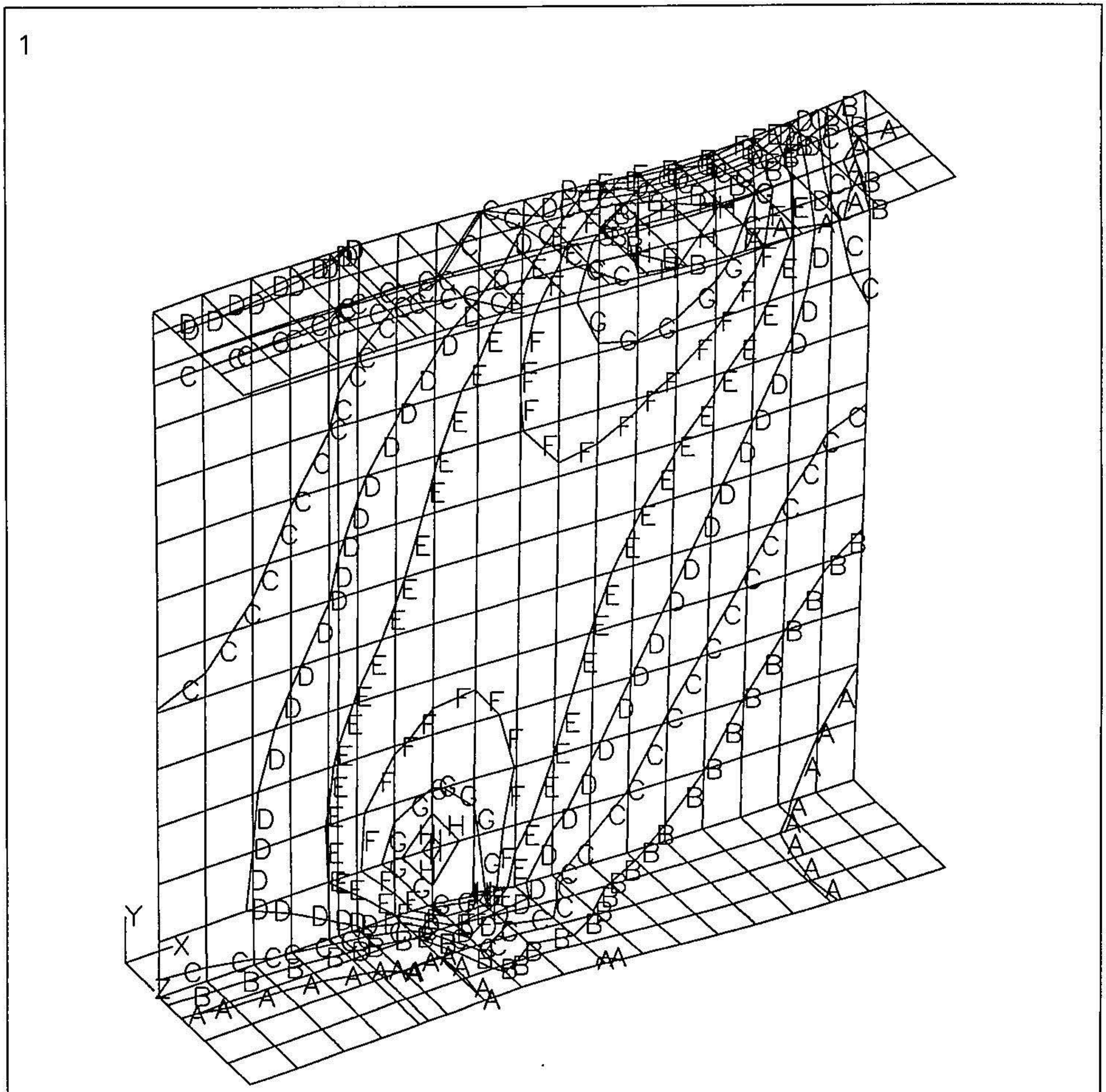

1
Y
X
Z
LRWPRS_2: Lower beam - 3.5M psi grout (7850 psi)
ANSYS 4.4
JUN 16 1990
00:41:20
PLOT NO. 3
POST1 STRESS
STEP=1
ITER=1
SY (AVG)
MIDDLE
S GLOBAL
DMX =0.001714
SMN =-26329
SMX =1373
XV =-3
YV =4
ZV =5
DIST=8.431
XF =3.625
YF =-6.25
ZF =3
A =-24790
B =-21712
C =-18634
E =-12478
F =-9400
G =-6322
I =-165.823

FIGURE 28



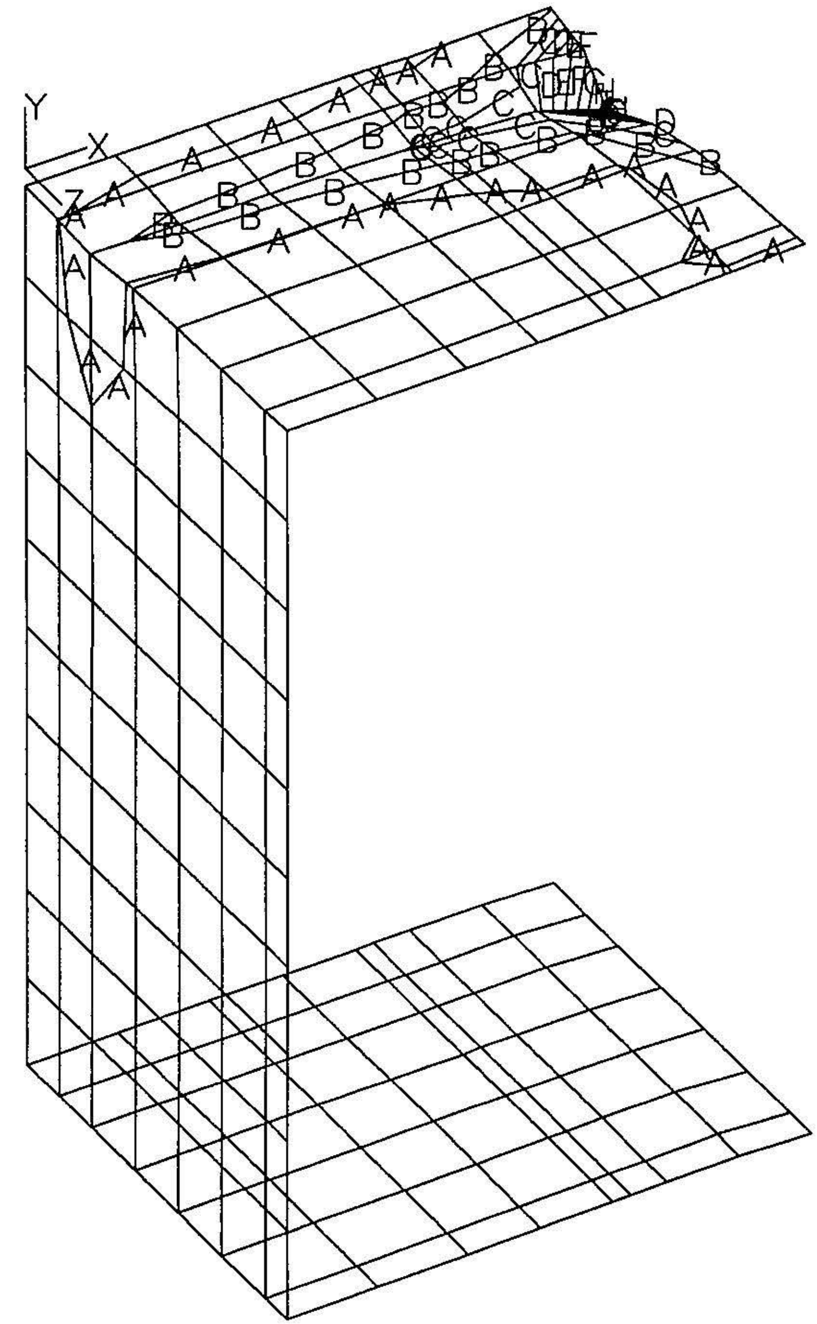
ANSYS 4.4
JUN 16 1990
11:47:51
PLOT NO. 1
POST1 STRESS
STEP=1
ITER=1
SIGE (AVG)
TOP
DMX =0.017602
SMN =249.869
SMX =29686

XV =-3
YV =4
ZV =5
DIST=12.419
XF =9.25
YF =9.25
ZF =3.5
A =1885
B =5156
C =8426
D =11697
E =14968
F =18238
G =21509
I =28050

LRWPRS_3: Lower beam - 3.5M psi grout - no faceplate (7850 psi)

FIGURE 29

1

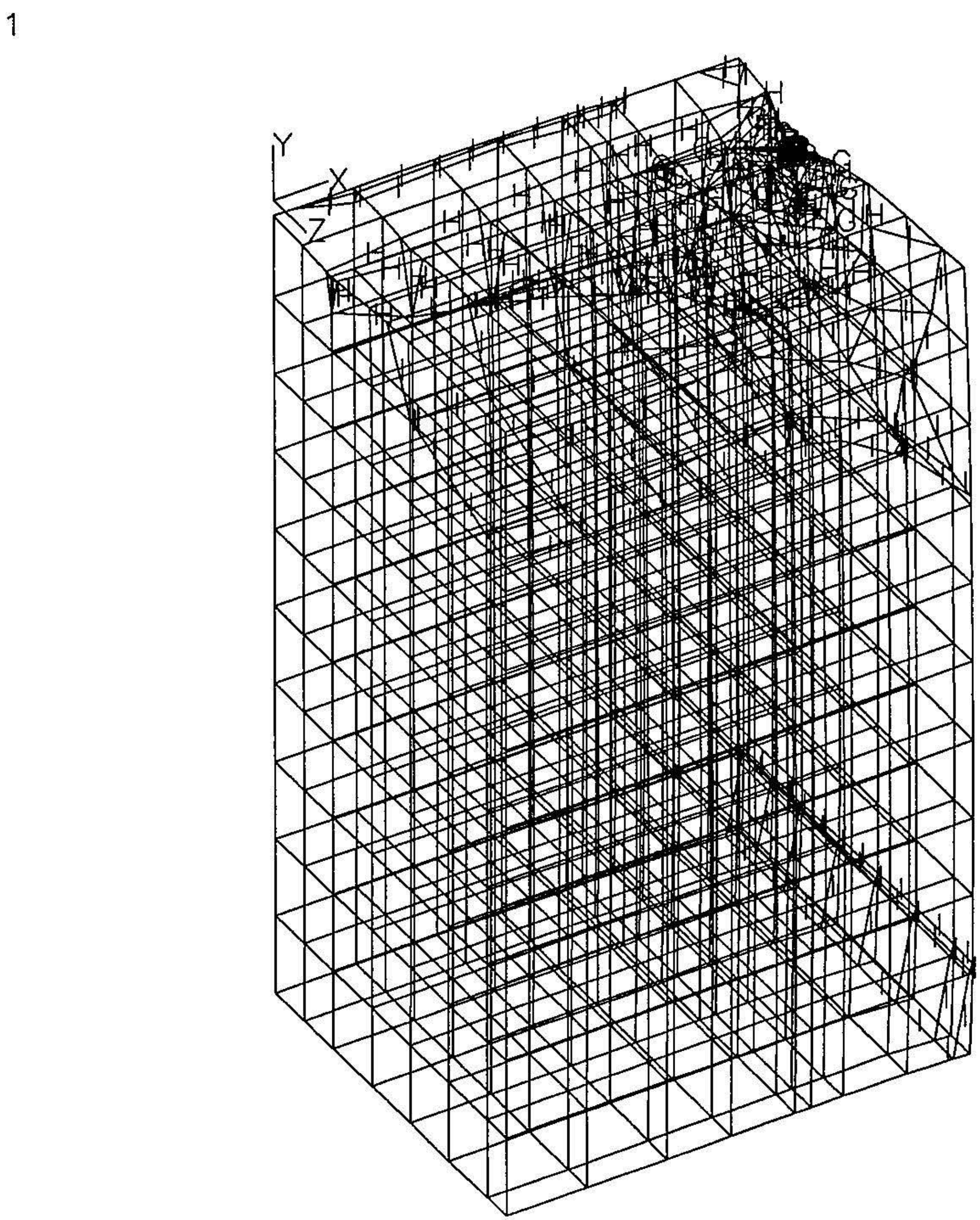


ANSYS 4.4
JUN 16 1990
00:44:41
PLOT NO. 2
POST1 STRESS
STEP=1
ITER=1
SIGE (AVG)
TOP
DMX =0.001966
SMN =181.721
SMX =31646

XV =-3
YV =4
ZV =5
DIST=8.431
XF =3.625
YF =-6.25
ZF =3
A =1930
B =5426
C =8922
D =12418
E =15914
F =19410
G =22906
I =29898

LRWPRS_3: Lower beam - 3.5M psi grout - no faceplate (7850 psi)

FIGURE 30

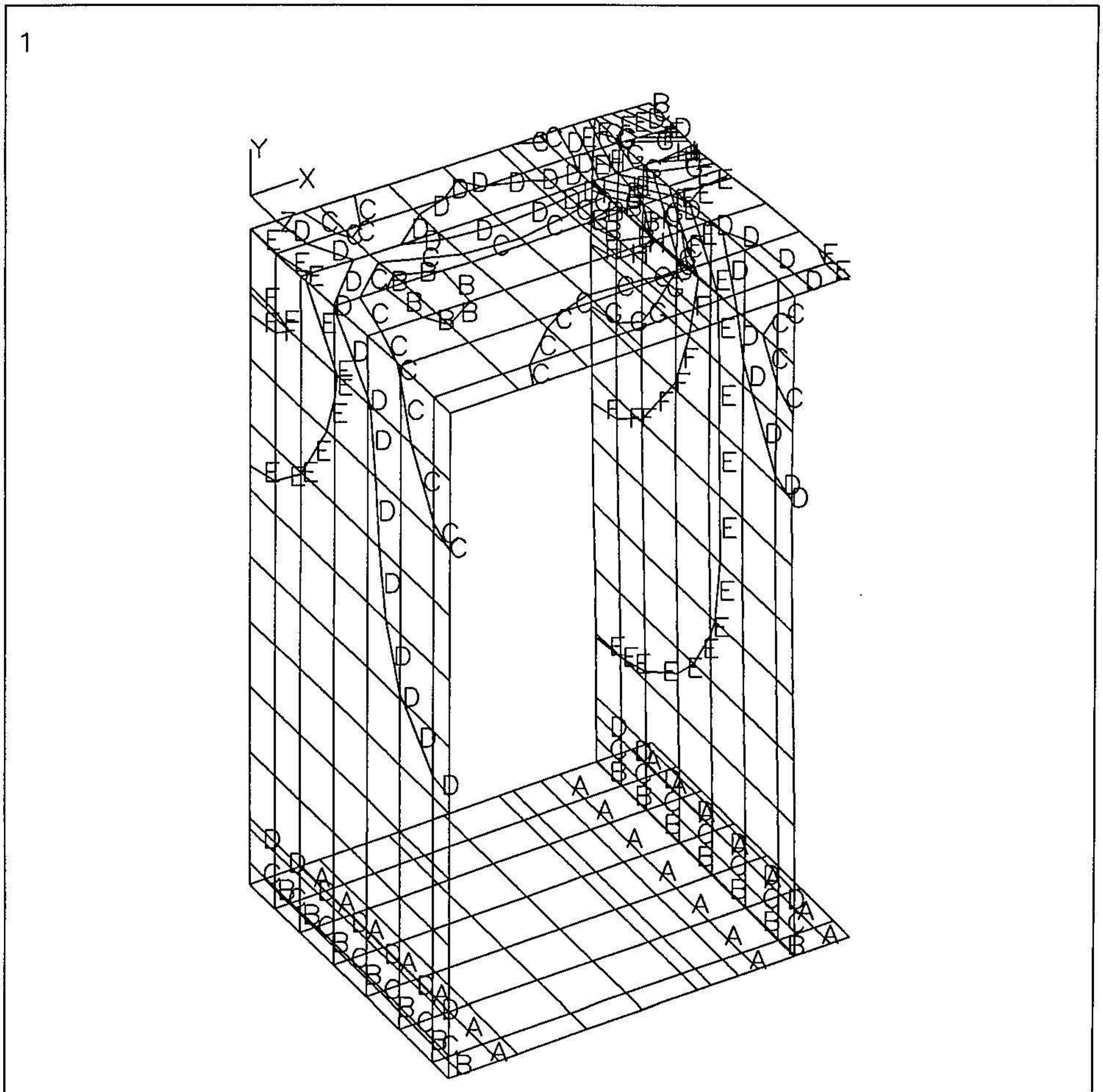


ANSYS 4.4
JUN 16 1990
00:44:59
PLOT NO. 3
POST1 STRESS
STEP=1
ITER=1
SY (AVG)
MIDDLE
S GLOBAL
DMX =0.001966
SMN =-32726
SMX =1534

XV =-3
YV =4
ZV =5
DIST=8.431
XF =3.625
YF =-6.25
ZF =3
A =-30823
B =-27016
C =-23210
E =-15596
F =-11790
G =-7983
I =-369.754

LRWPRS_3: Lower beam - 3.5M psi grout - no faceplate (7850 psi)

FIGURE 31



LWRPRS_4: Lower beam – permanent fix (10000 psi)

ANSYS 4.4
JUN 16 1990
00:46:42
PLOT NO. 2
POST1 STRESS
STEP=1
ITER=1
SIGE (AVG)
TOP
DMX =0.005935
SMN =9.782
SMX =20559

XV =–3
YV =4
ZV =5
DIST=8.431
XF =3.625
YF =–6.25
ZF =3
A =1151
B =3435
C =5718
D =8001
E =10284
F =12567
G =14851
I =19417

FIGURE 37

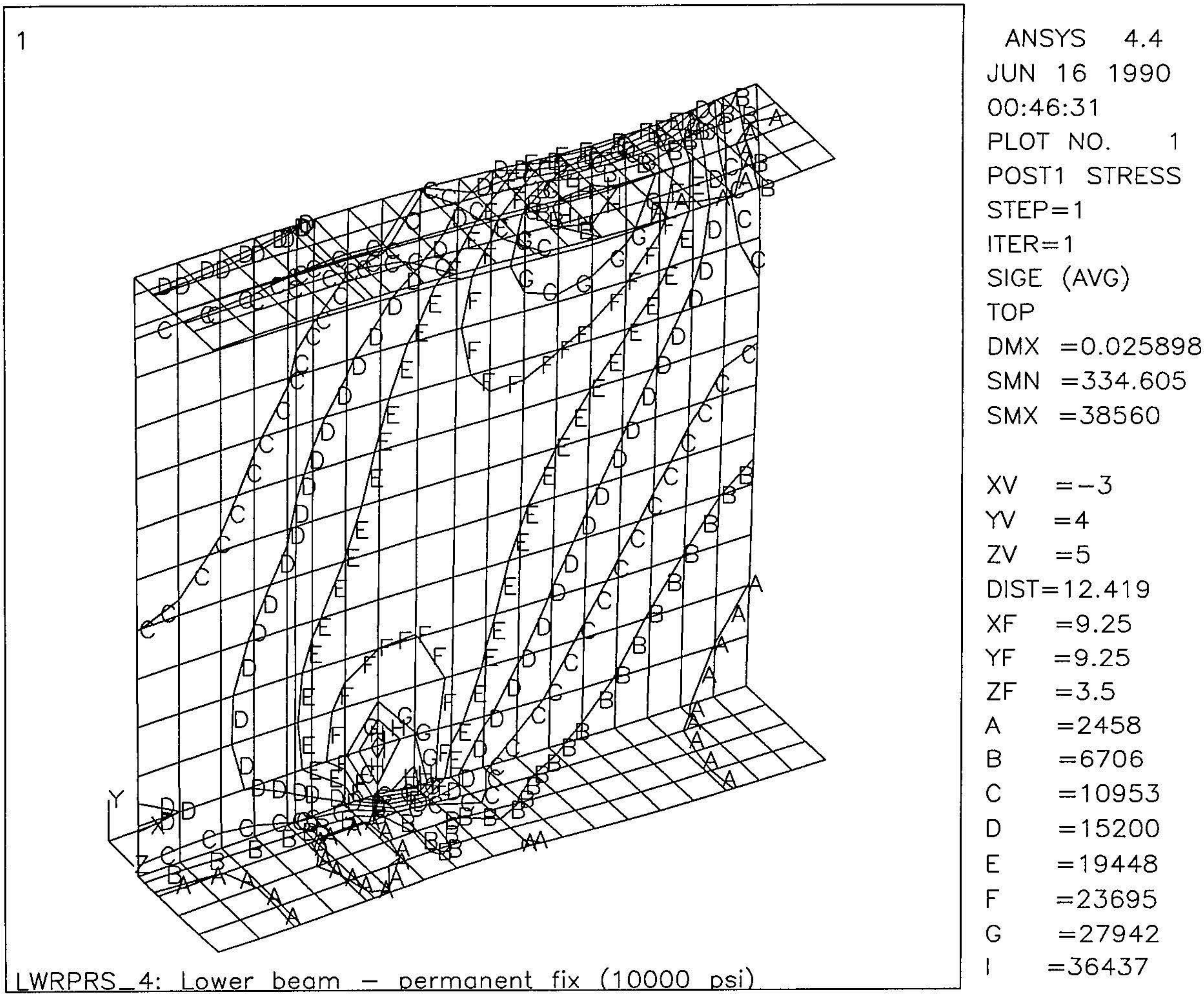

1
ANSYS 4.4
JUN 16 1990
00:46:31
PLOT NO. 1
POST1 STRESS
STEP=1
ITER=1
SIGE (AVG)
TOP
DMX =0.025898
SMN =334.605
SMX =38560
XV =-3
YV =4
ZV =5
DIST=12.419
XF =9.25
YF =9.25
ZF =3.5
A =2458
B =6706
C =10953
D =15200
E =19448
F =23695
G =27942
I =36437
LWRPRS_4: Lower beam - permanent fix (10000 psi)

FIGURE 33