Discussion on the

Structural Analysis Issues Raised by the NRC Staff in the RAI Dated November 17, 2009

By

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October 13, 2009 Meeting with the NRC Technical Staff Major Discussion Topics

- ANSYS FEM – Modeling Issues

  (RAI No. 2.8 & 2.9)

- Result Reporting - Stress Categorization Issues

  (RAI No. 2.7)

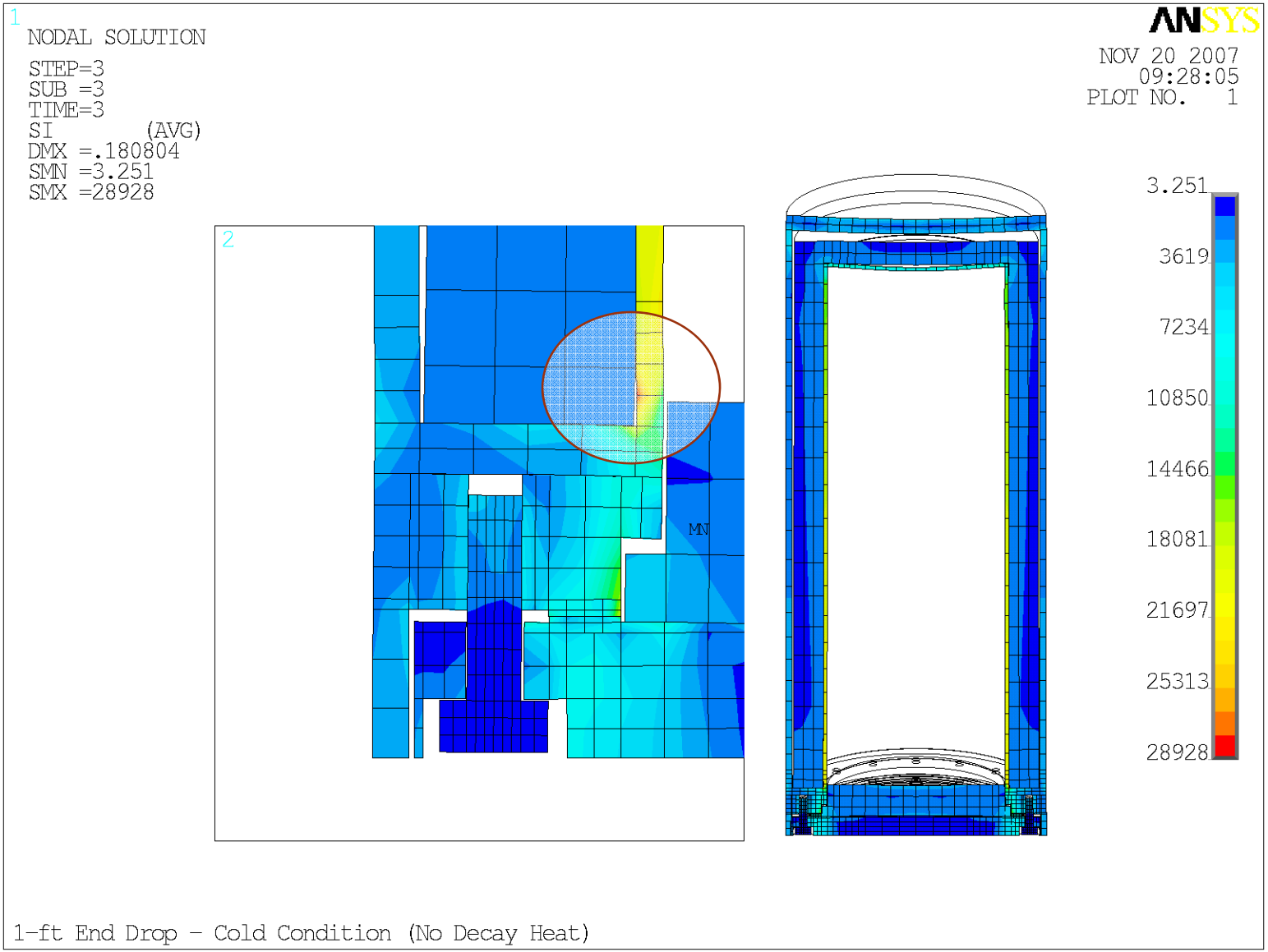
- Side Drop Results - Bolting Ring Skirt Deformation Issues

  (RAI No. 2.10)

ANSYS FEM – Modeling Issues

- Mesh Convergence Study

3-60B Cask SAR



ANSYS FEM – Modeling Issues

- Use of SOLID-185
- Adequacy of the Grid Density
  - Perform a mesh convergence study, using a fixed-edge shell under internal pressure loading, to show the adequacy of the 3-60B Cask mesh density.

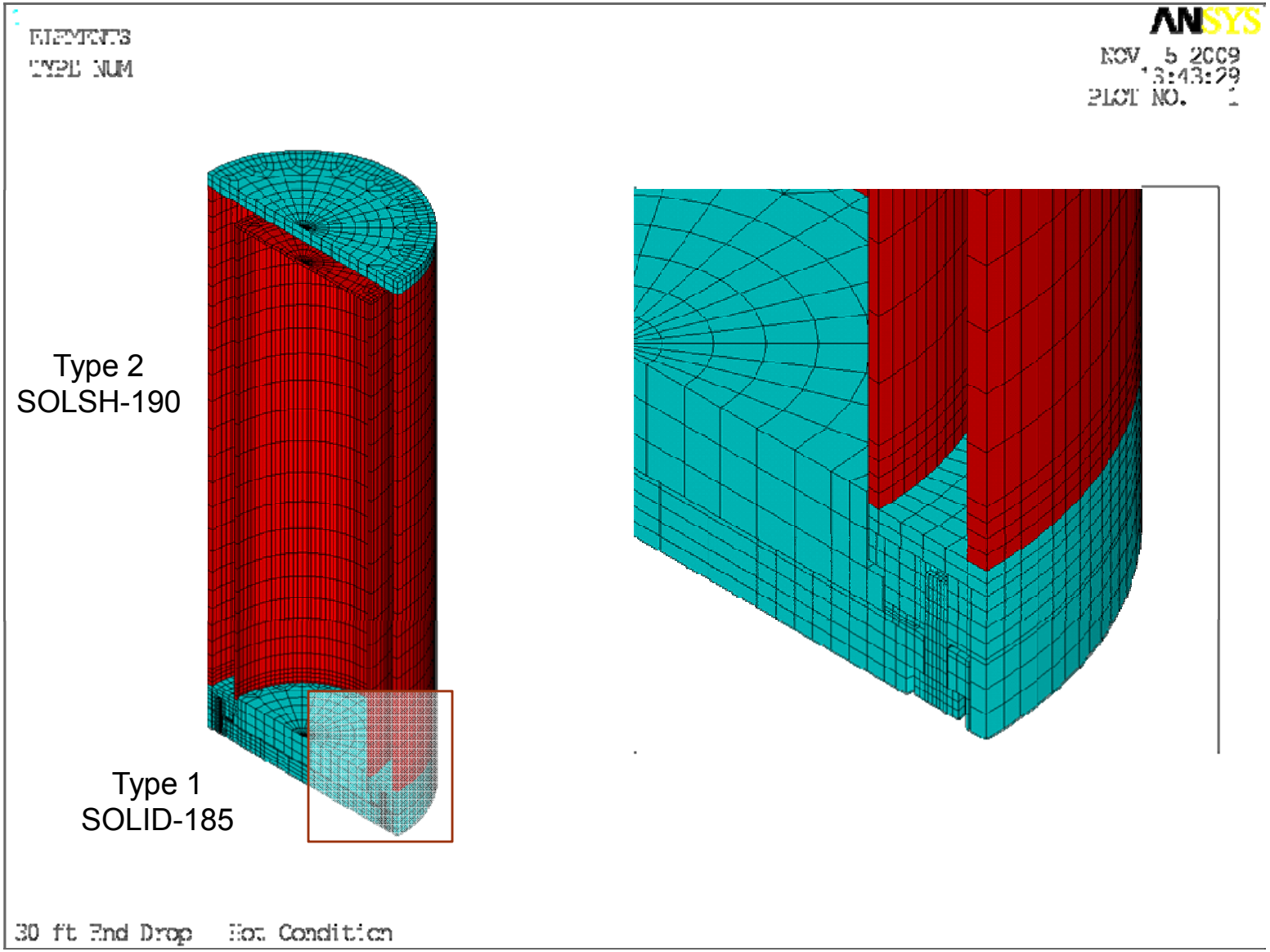
ANSYS SOLID-185 Finite Element

- Default element uses selective reduced integration technique.
- It is adequate for representing structural components which undergo mostly volumetric deformation.
- Very efficient for convergence in a geometric nonlinear model.
- In its default form it is woefully inadequate for representing bending dominated deformation.

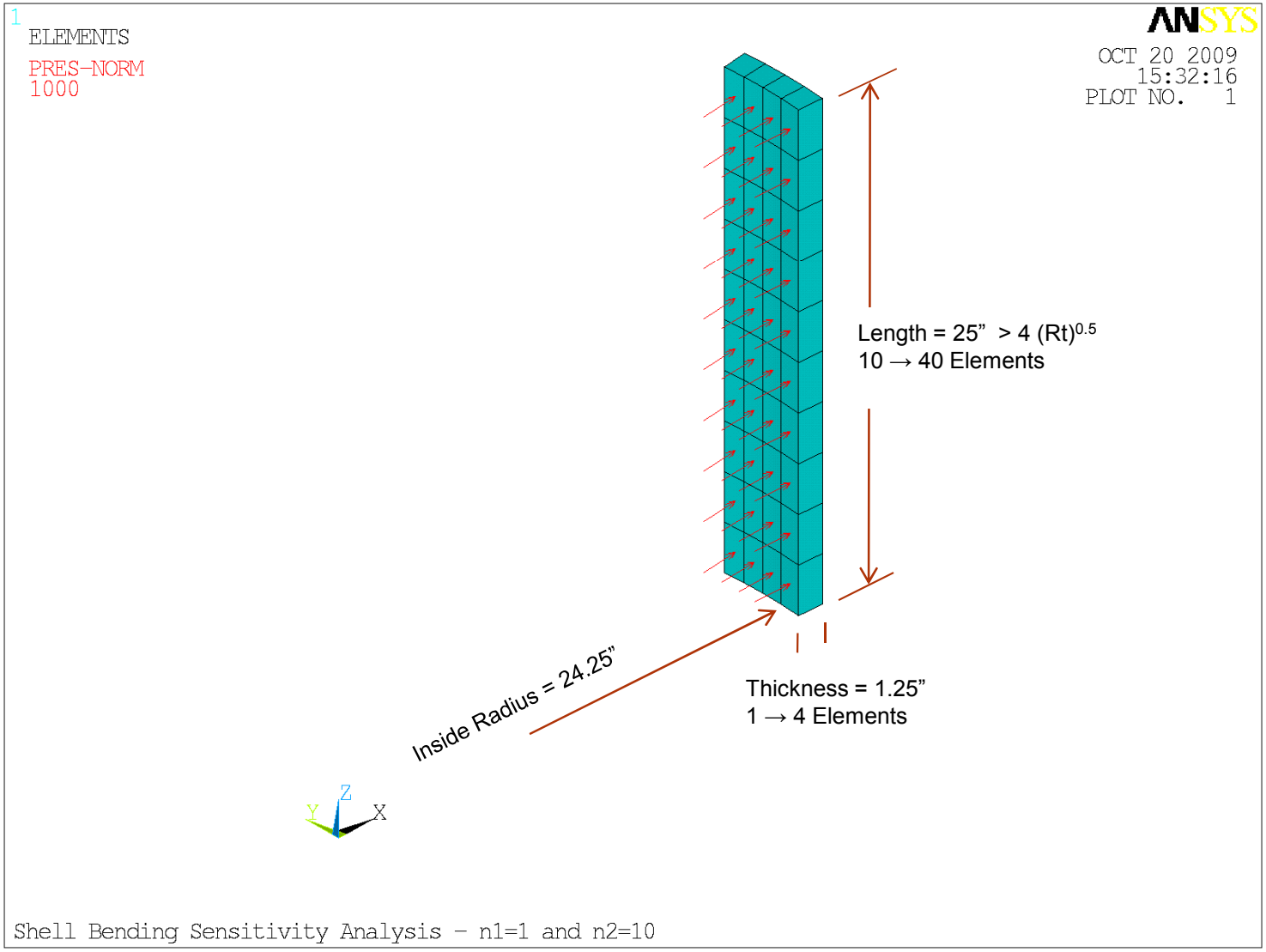
3-60B Cask Modeling Philosophy

- Use SOLID-185 to represent the structural components which undergo mostly volumetric deformation.
- Use Solid Shell SOLSH-190 elements to represent the structural components that are dominated by bending deformation.
- The SAR did not identify this distinction.
  - The information was available only in the detailed listing of the model. So it was logical for the staff to assume that SOLID-185 has been used everywhere in the model.

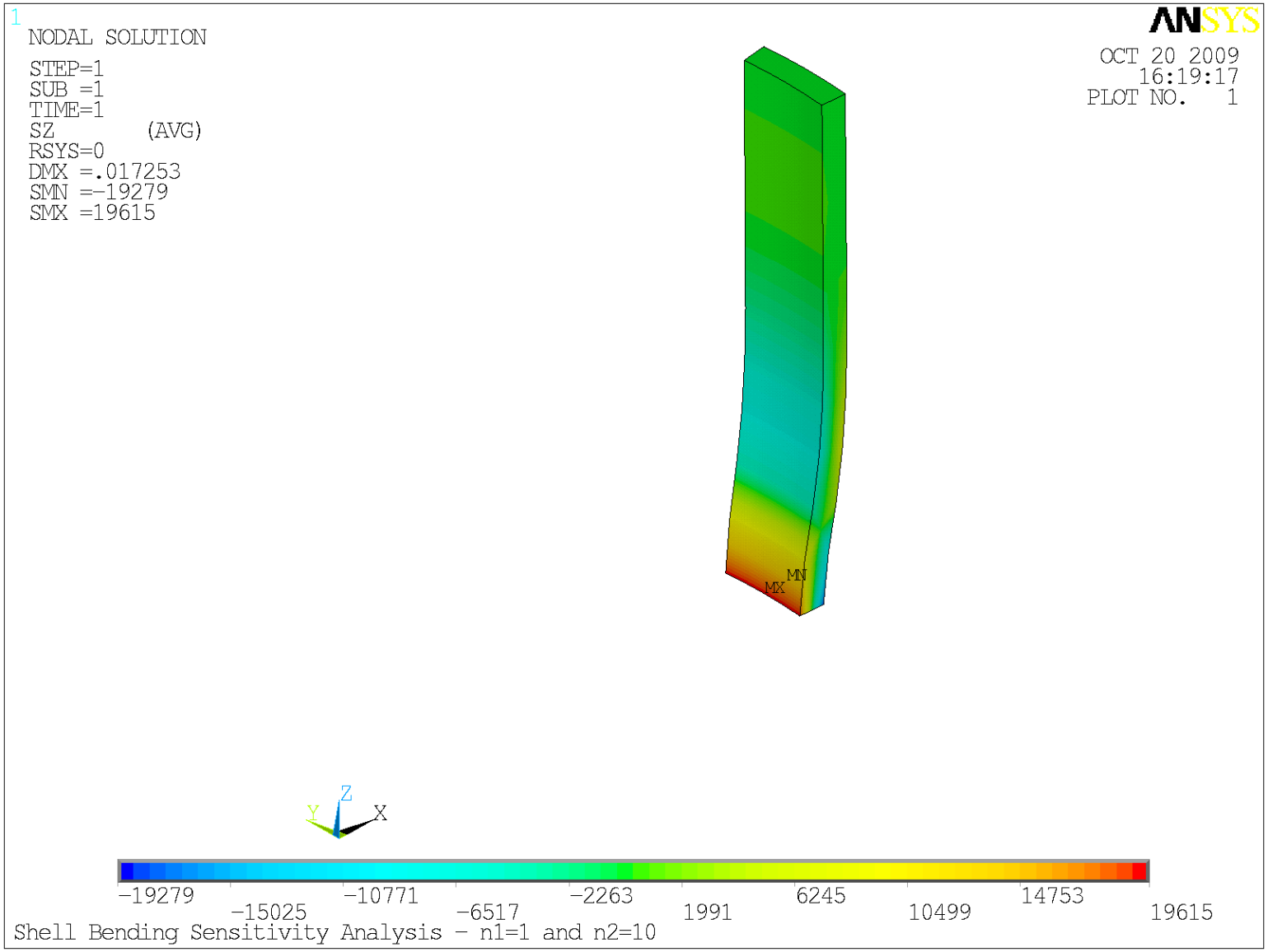
3-60B Cask SAR



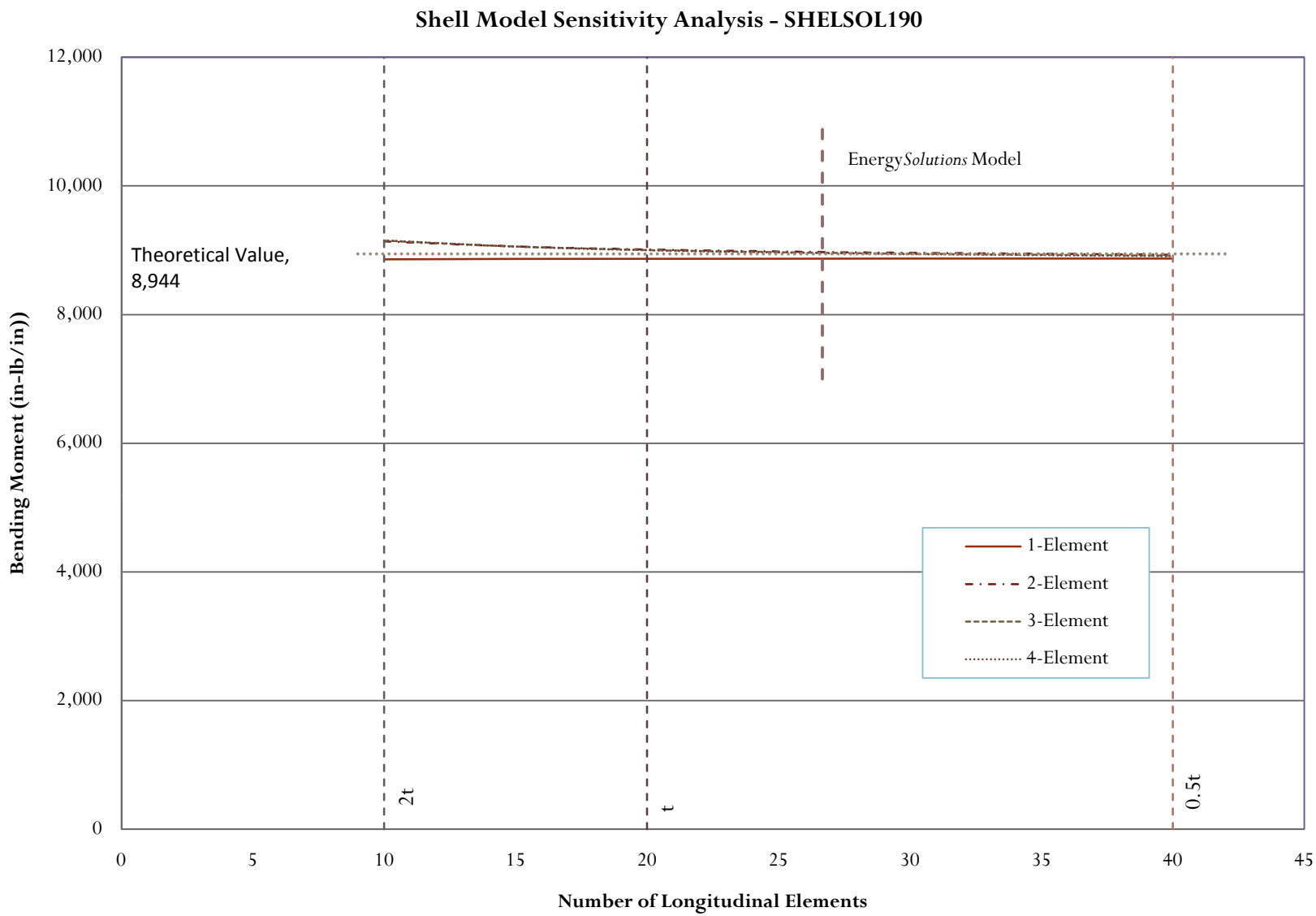
3-60B Cask SAR



3-60B Cask SAR



3-60B Cask SAR



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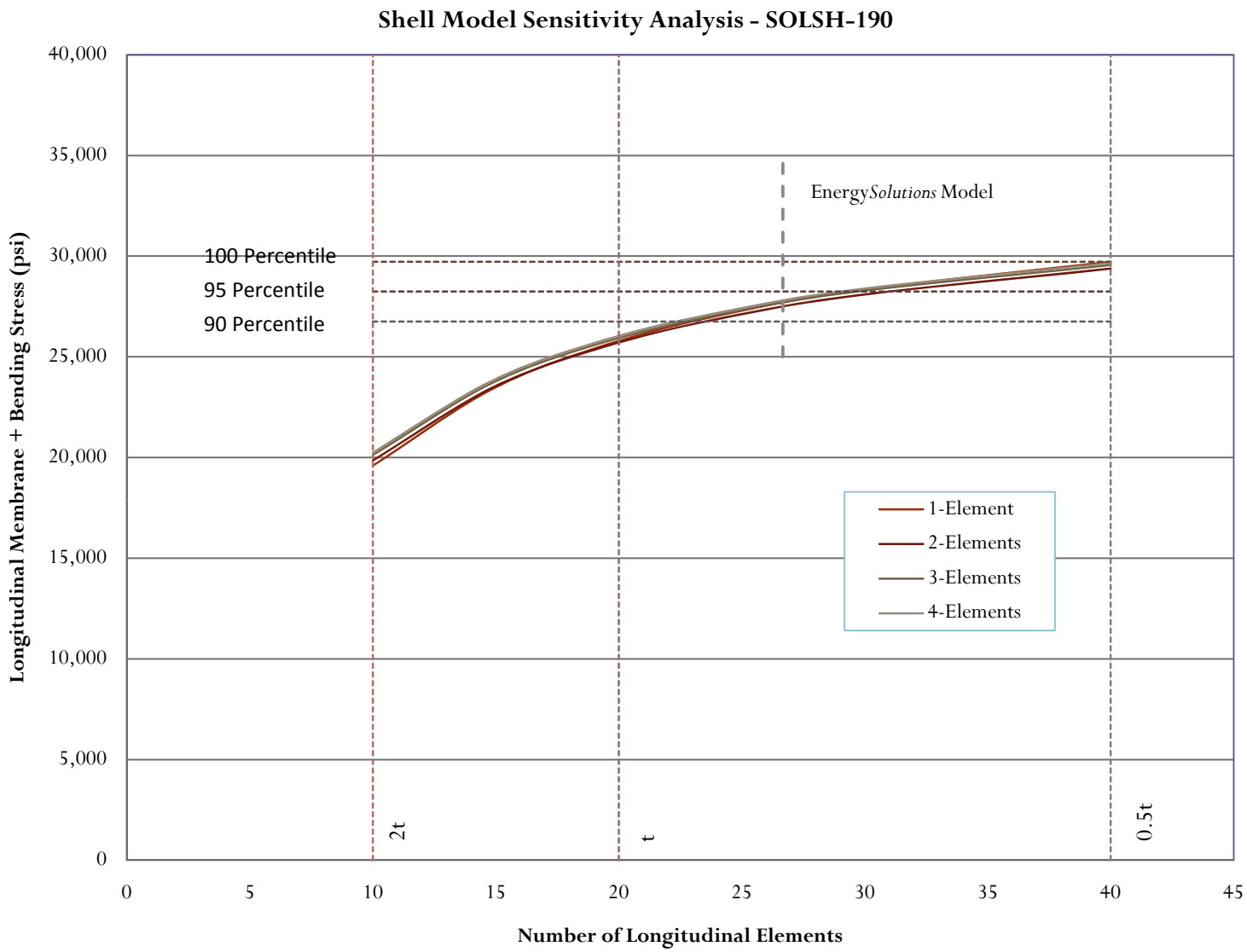
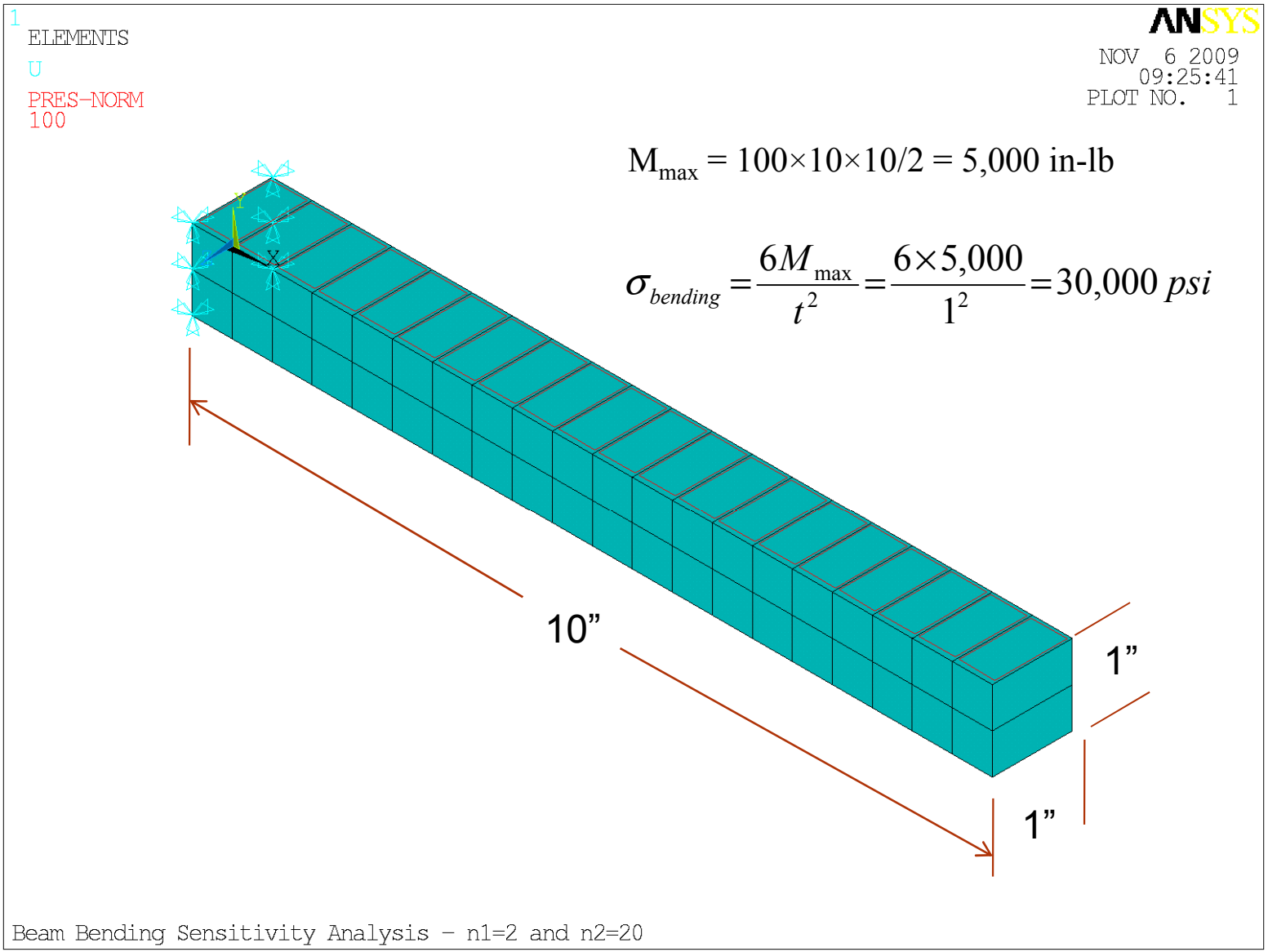
3-60B Cask SAR



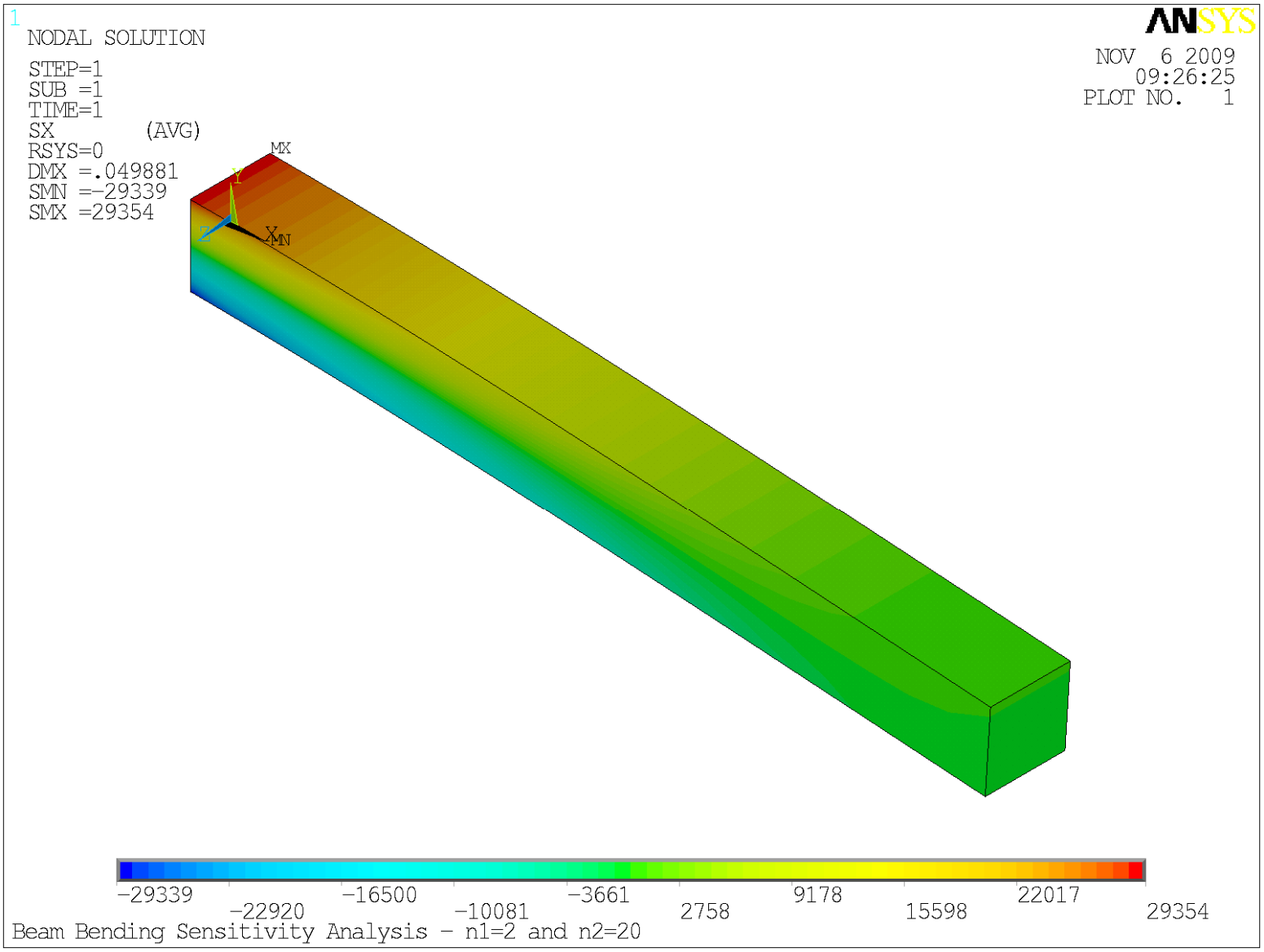
3-60B Cask SAR



$$M_{max} = 100 \times 10 \times 10/2 = 5{,}000 \text{ in-lb}$$

$$\sigma_{bending} = \frac{6M_{max}}{t^2} = \frac{6 \times 5{,}000}{1^2} = 30{,}000\ psi$$

3-60B Cask SAR



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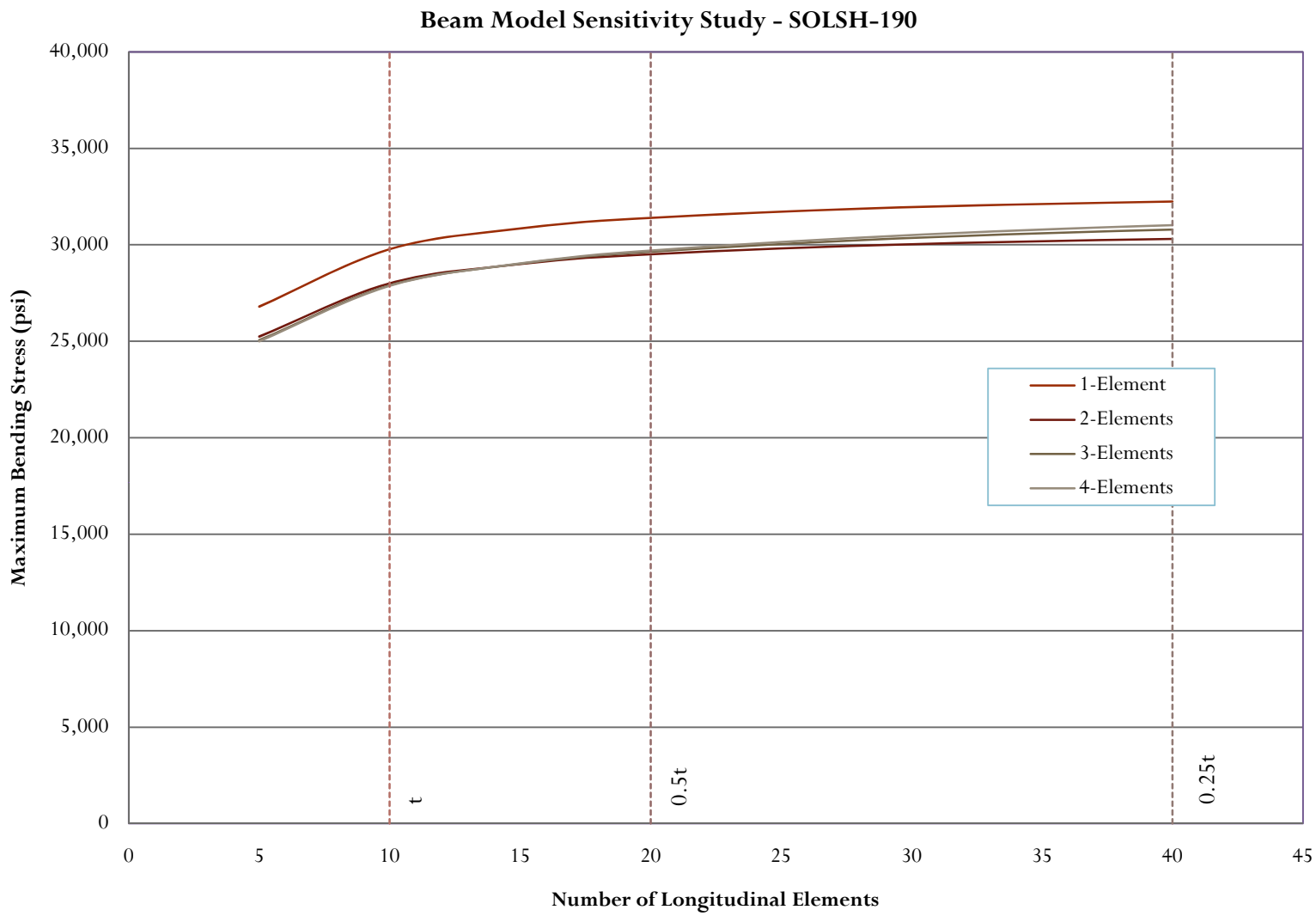
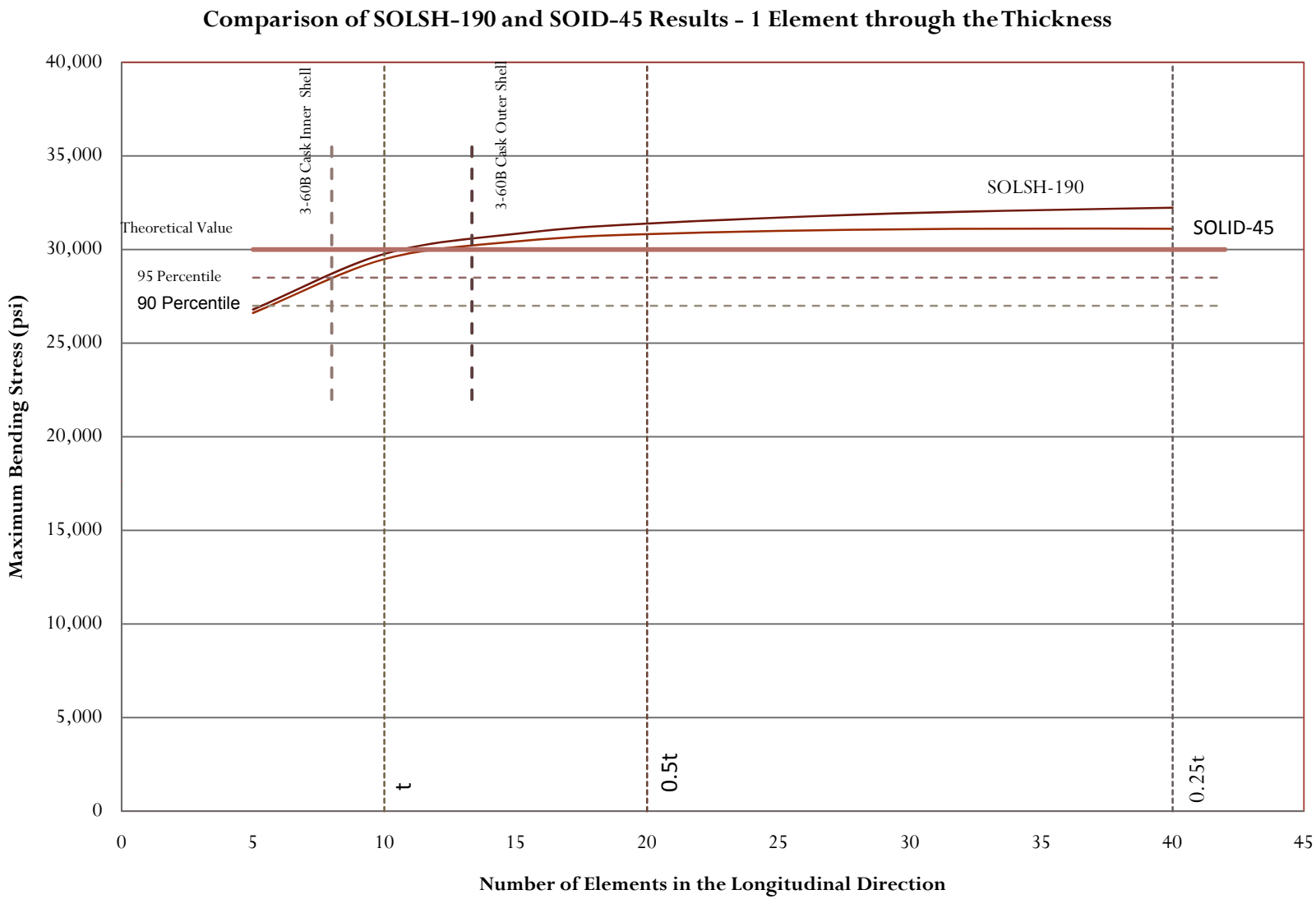
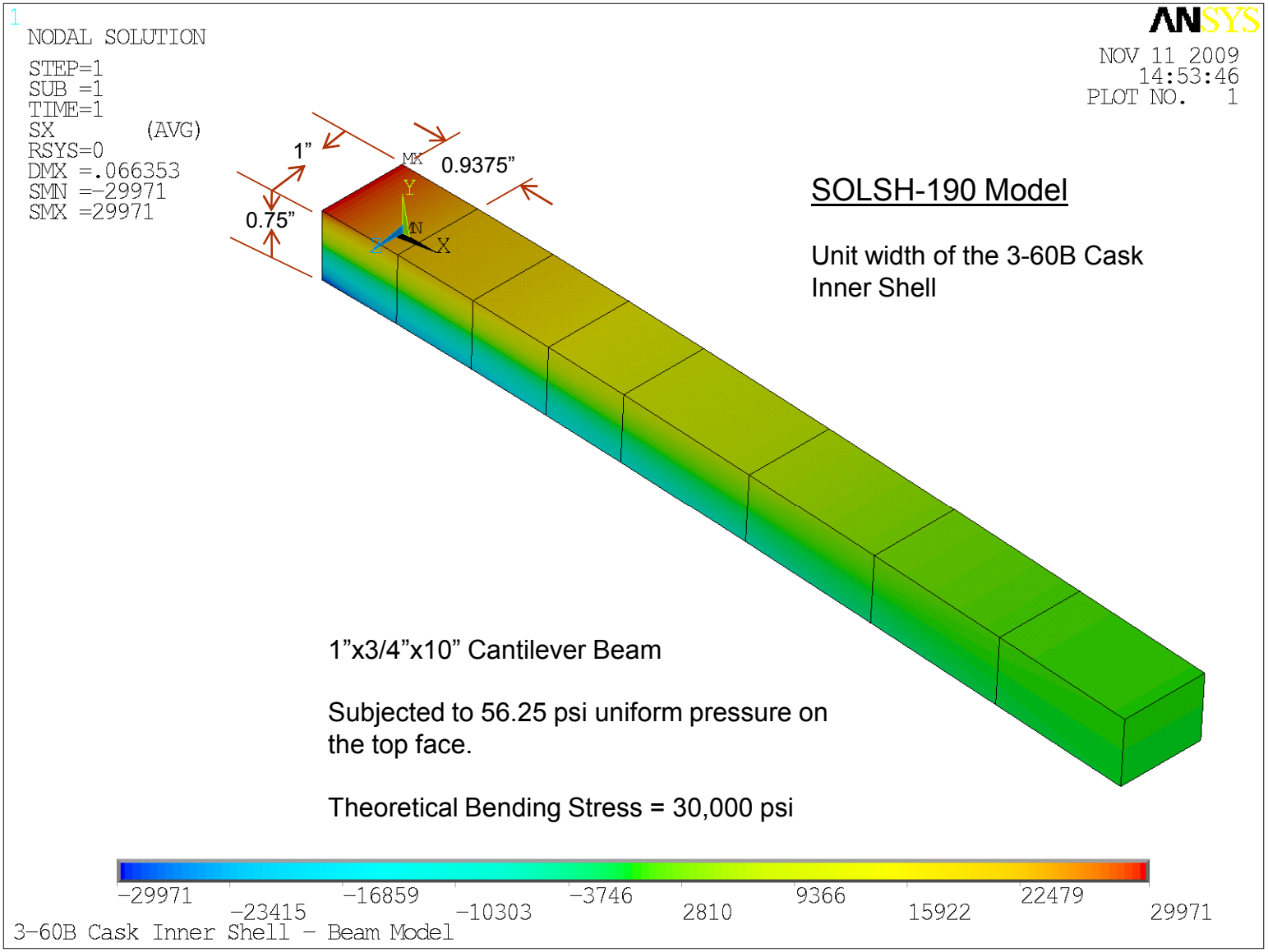


3-60B Cask SAR



ENERGYSOLUTIONS

3-60B Cask SAR



Sensitivity Analyses - Conclusions

- ANSYS SOLID-185 element with default options is not an appropriate finite element to represent structural components whose deformation is dominated by bending.
- ANSYS SOLSH-190 gives good moment and bending results for these components.

Sensitivity Analyses – Conclusions (contd.)

- The moment results are not sensitive to the mesh density in either thickness or length direction.
- The stresses are not sensitive to mesh density in the thickness direction.
- The stresses are highly sensitive to the mesh density in the length direction.
- For SOLSH-190 elements one element through the thickness gives good moment and stress results.
- The current element size in the ES finite element model near the bolting-ring juncture corresponds to element length that gives stress results that are within 95% of the theoretical value.

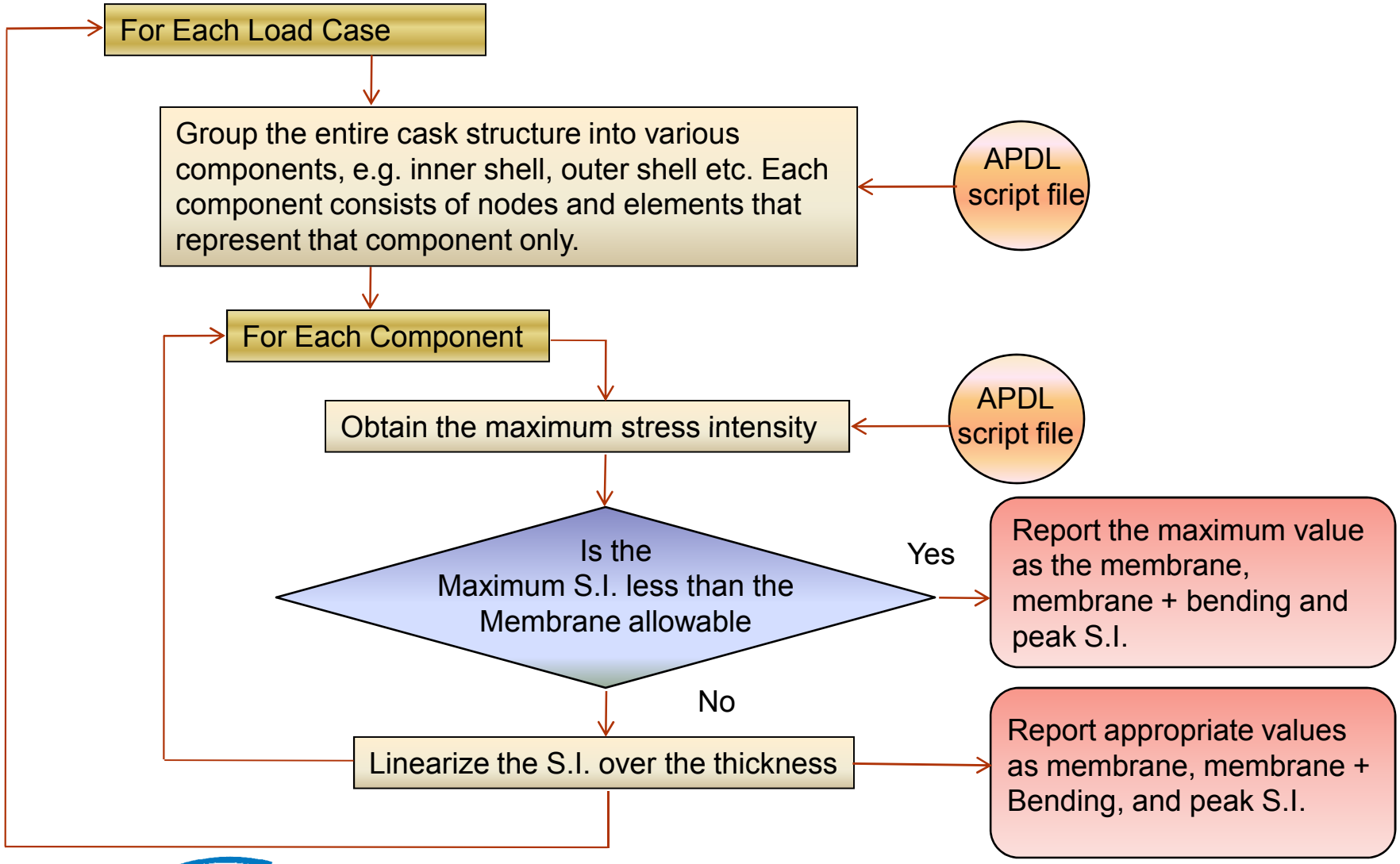
ANSYS FEM Modeling Issues - Implementation

- The entire analyses presented here will be documented in an Energy*Solutions* document ST-xxx, which will be included as a reference in the SAR.
- The reference will be provided to the staff for review.
- The SAR and the reference material will mention the use of SOLID-190 in the model.

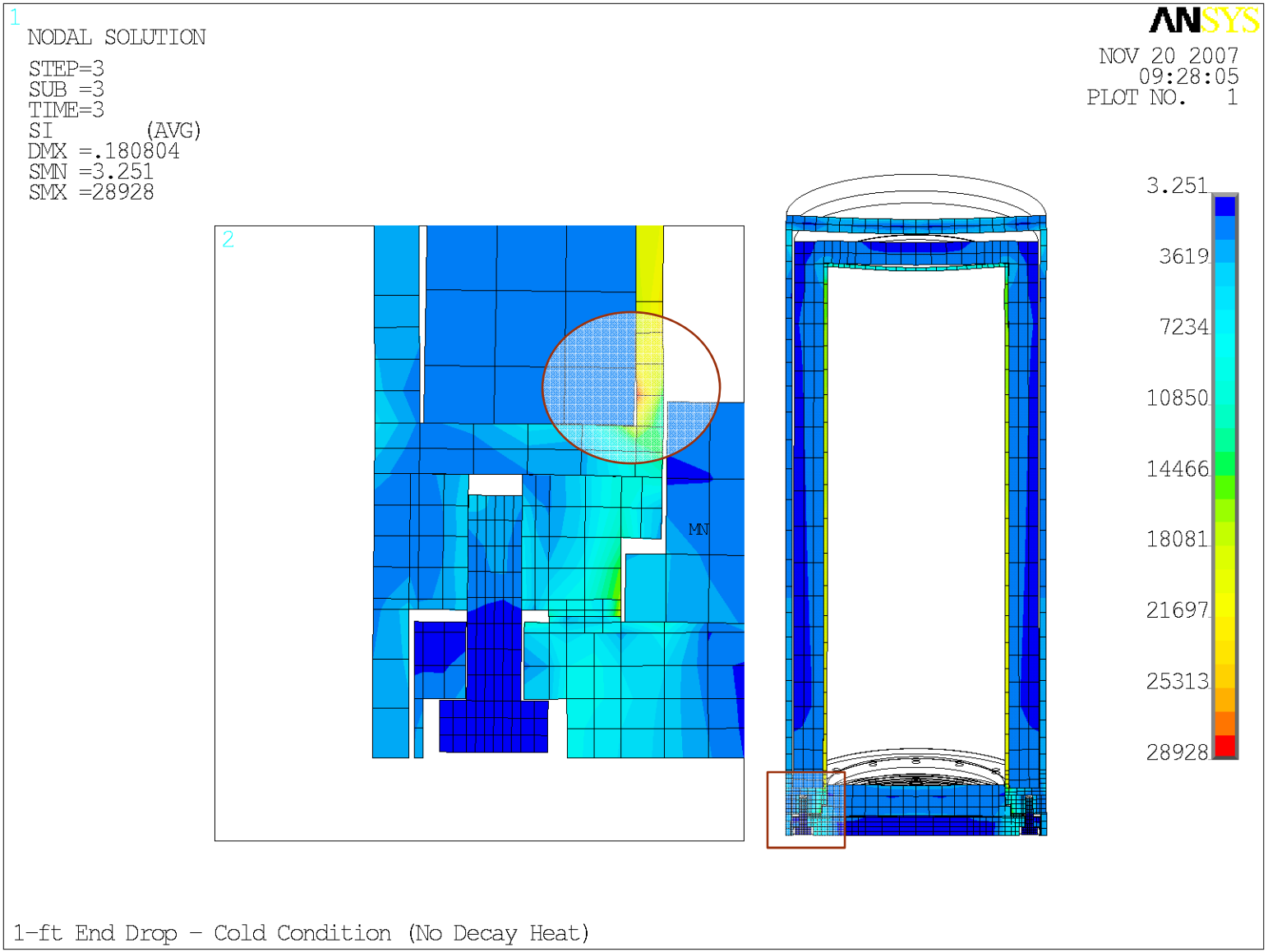
Result Reporting - Stress Categorization Issues

- Nodal Averaging of Stress Components
- Section Location of Max. S.I.
- ES's use of "peak stress" terminology in the SAR that is incompatible with the ASME B&PV Code definition.

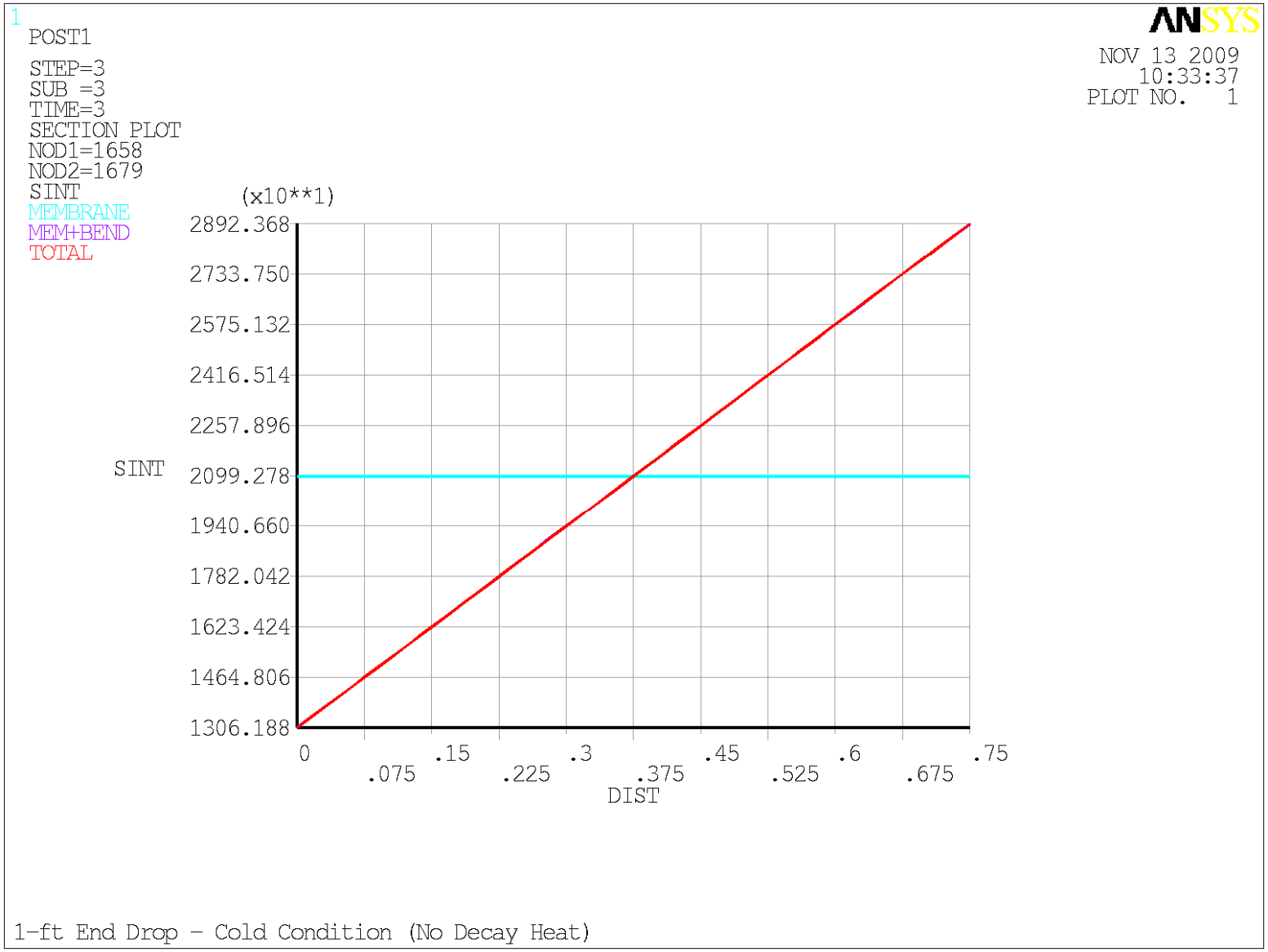
Stress Intensity Categorization Algorithm



3-60B Cask SAR



3-60B Cask SAR



3-60B Cask SAR

```
        ***** POST1 LINEARIZED STRESS LISTING *****
       INSIDE NODE =   1658     OUTSIDE NODE =   1679

 LOAD STEP     3  SUBSTEP=     3
 TIME=    3.0000         LOAD CASE=  0

THE FOLLOWING X,Y,Z STRESSES ARE IN THE GLOBAL COORDINATE SYSTEM.

            ** MEMBRANE **
     SX          SY          SZ          SXY         SYZ         SXZ
  563.2      -7978.     -0.2029E+05   210.0       28.35       1079.
     S1          S2          S3          SINT        SEQV
  624.1      -7984.     -0.2035E+05  0.2097E+05  0.1826E+05

            ** MEMBRANE PLUS BENDING **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   549.4      -5824.     -0.1232E+05   156.7       29.08       1116.
C   563.2      -7978.     -0.2029E+05   210.0       28.35       1079.
O   577.0     -0.1013E+05 -0.2826E+05   263.2       27.61       1042.
     S1          S2          S3          SINT        SEQV
I   649.4      -5827.     -0.1242E+05  0.1307E+05  0.1132E+05
C   624.1      -7984.     -0.2035E+05  0.2097E+05  0.1826E+05
O   621.1     -0.1014E+05 -0.2830E+05  0.2892E+05  0.2532E+05

            ** PEAK **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I -0.5990E-02  0.9357       3.461     -0.2313E-01  0.3189E-03  0.1601E-01
C   0.000      0.4547E-11  0.7276E-11 -0.5684E-13  0.2842E-13   0.000
O  0.5990E-02 -0.9357      -3.461      0.2313E-01 -0.3189E-03 -0.1601E-01
     S1          S2          S3          SINT        SEQV
I   3.461      0.9363     -0.6632E-02   3.468       3.106
C  0.7276E-11  0.4548E-11 -0.7104E-15  0.7277E-11  0.6367E-11
O  0.6632E-02 -0.9363      -3.461       3.468       3.106

            ** TOTAL **  I=INSIDE C=CENTER O=OUTSIDE
     SX          SY          SZ          SXY         SYZ         SXZ
I   549.4      -5823.     -0.1232E+05   156.7       29.08       1116.
C   563.2      -7978.     -0.2029E+05   210.0       28.35       1079.
O   577.0     -0.1013E+05 -0.2826E+05   263.3       27.61       1042.
     S1          S2          S3          SINT        SEQV        TEMP
I   649.4      -5826.     -0.1241E+05  0.1306E+05  0.1131E+05  -20.00
C   624.1      -7984.     -0.2035E+05  0.2097E+05  0.1826E+05
O   621.1     -0.1014E+05 -0.2830E+05  0.2892E+05  0.2532E+05  -20.00
```

Note: This file is included in the data on the harddrive.

Table 2-11

Stress Intensities in 3-60B Cask under 1-ft End Drop – Cold Condition

Component	Stress Category	Allowable S.I. (psi)	Calculated S.I.(1) (psi)	F.S.(2)
Bolting Ring	P_m	24,900	20,970	1.19
	$P_m + P_b$	37,350	28,920	1.29
	F	74,700	28,928	2.58
Inner Shell	P_m	24,900	20,190	1.23
	$P_m + P_b$	37,350	21,180	1.76
	F	74,700	21,183	3.53
Outer Shell	P_m	16,700	7,467	2.24
	$P_m + P_b$	25,050	7,467	3.35
	F	50,100	7,467	6.71

Table continues

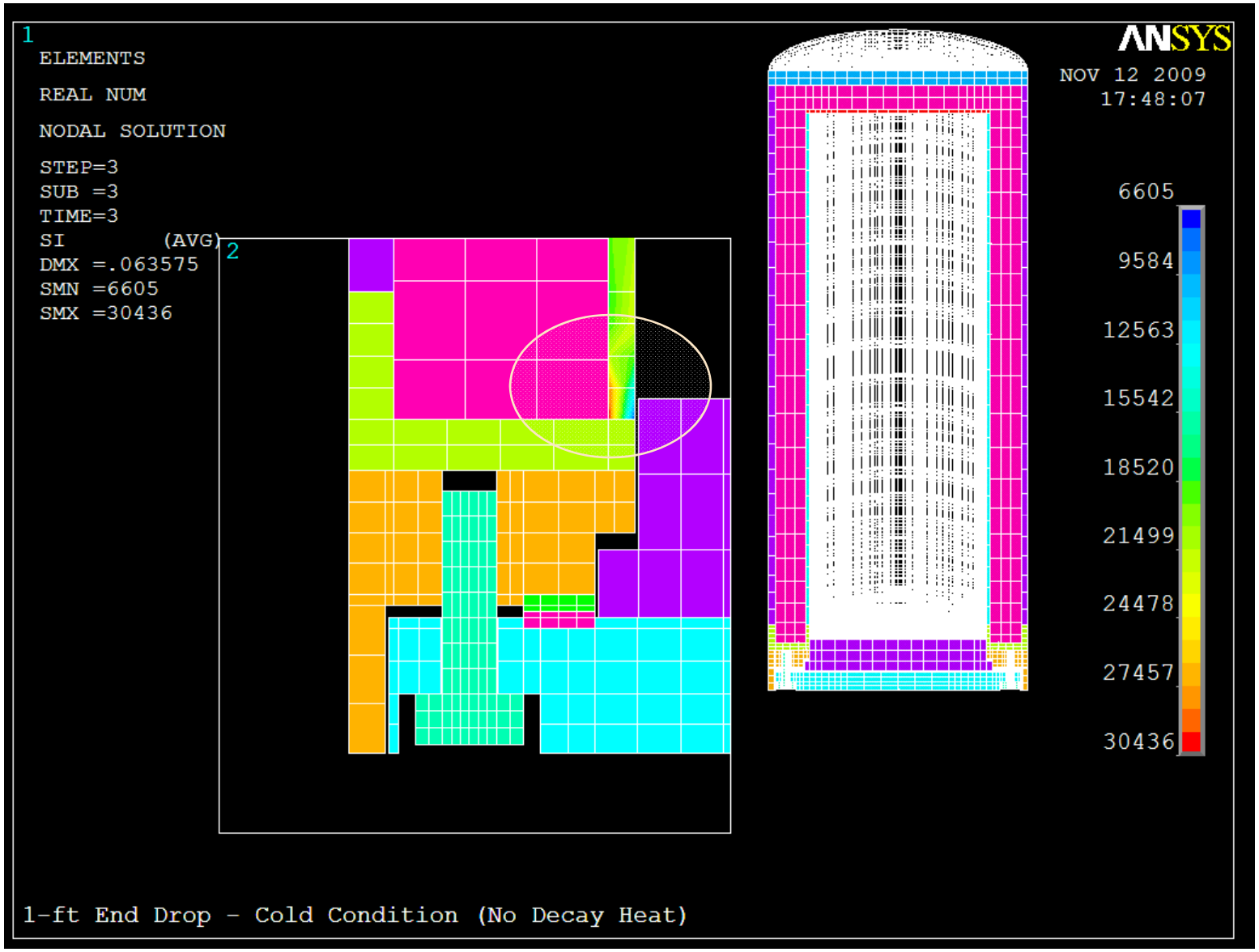
Selection of the Section Location

- The location of the section where the S.I. was linearized corresponded to the location of the maximum S.I.
- For the bolting ring this location was the first node away from the shell-ring juncture.
- The staff correctly pointed out that the S.I. was being averaged over a larger number of nodes at the juncture than the first node away from it.

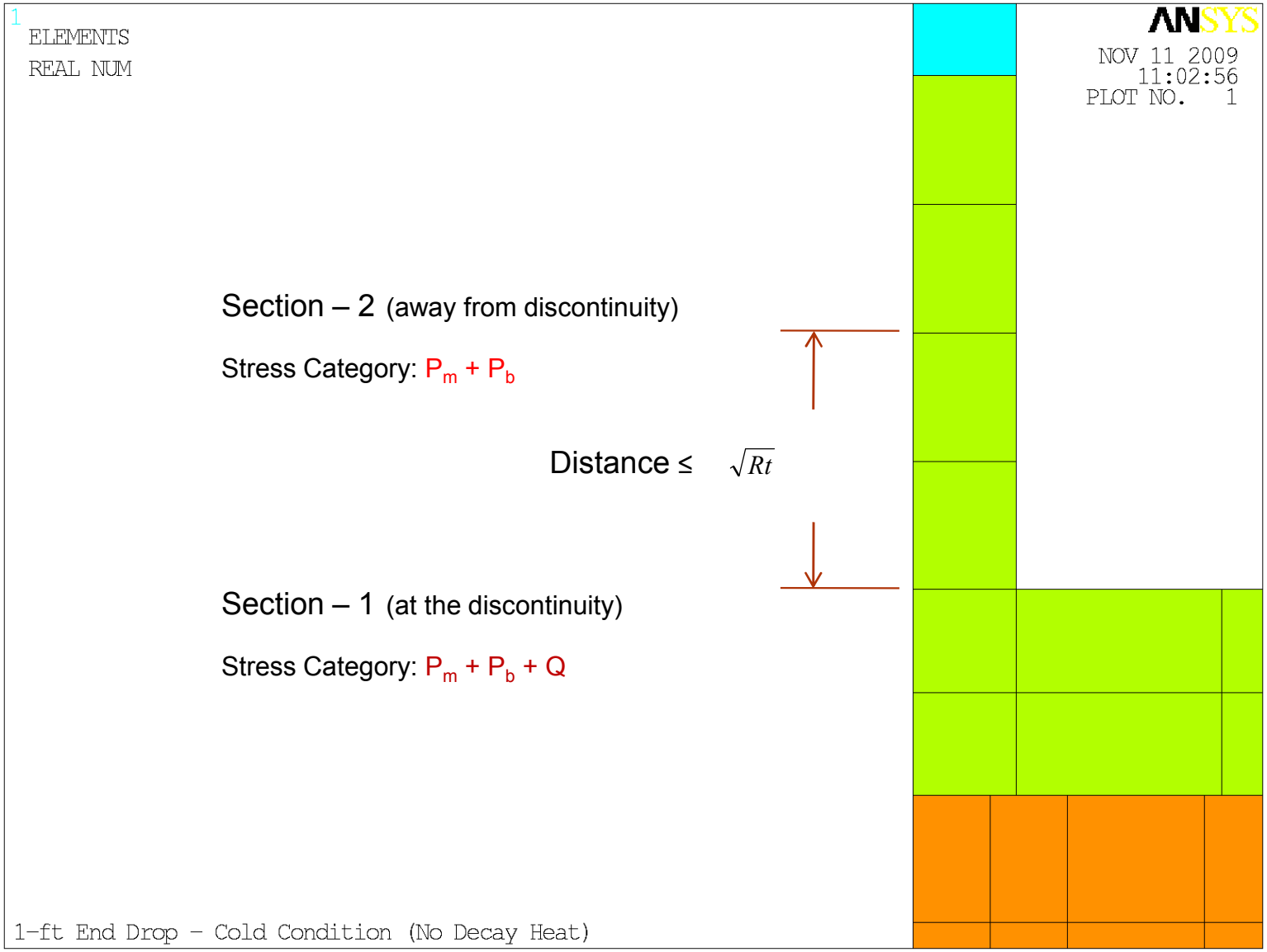
Rationale for the Selection

- The juncture constitutes a physical discontinuity in the continuum of the material. At infinitesimal distance away from the juncture the continuum has two different thicknesses.
- Theoretically the largest S.I. must occur in the thinner medium at an infinitesimal distance away from it.
- A fillet of ½" radius is provided at the transition.
- The location at the nearest node from the intersection was chosen for linearization.

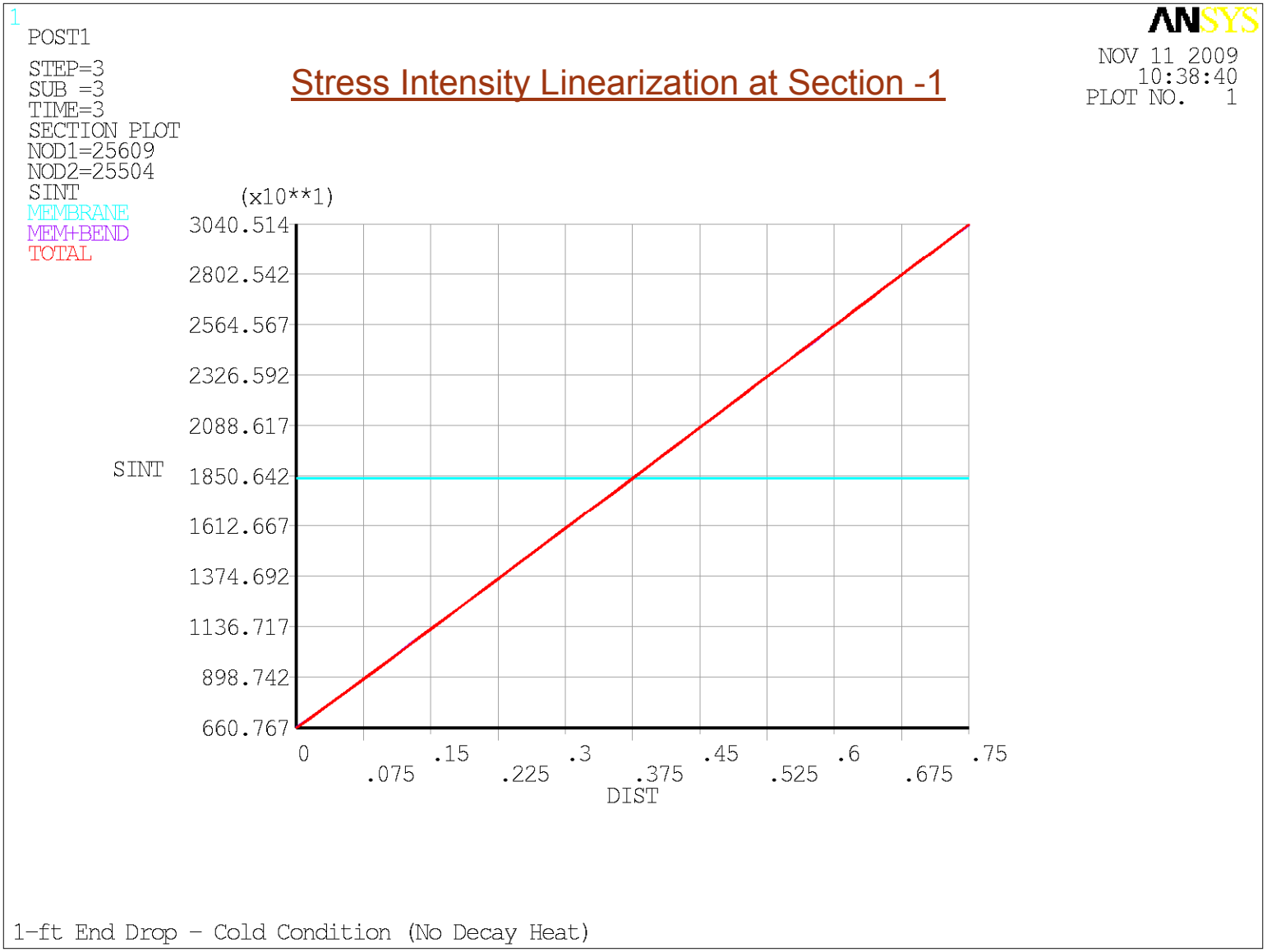
3-60B Cask SAR

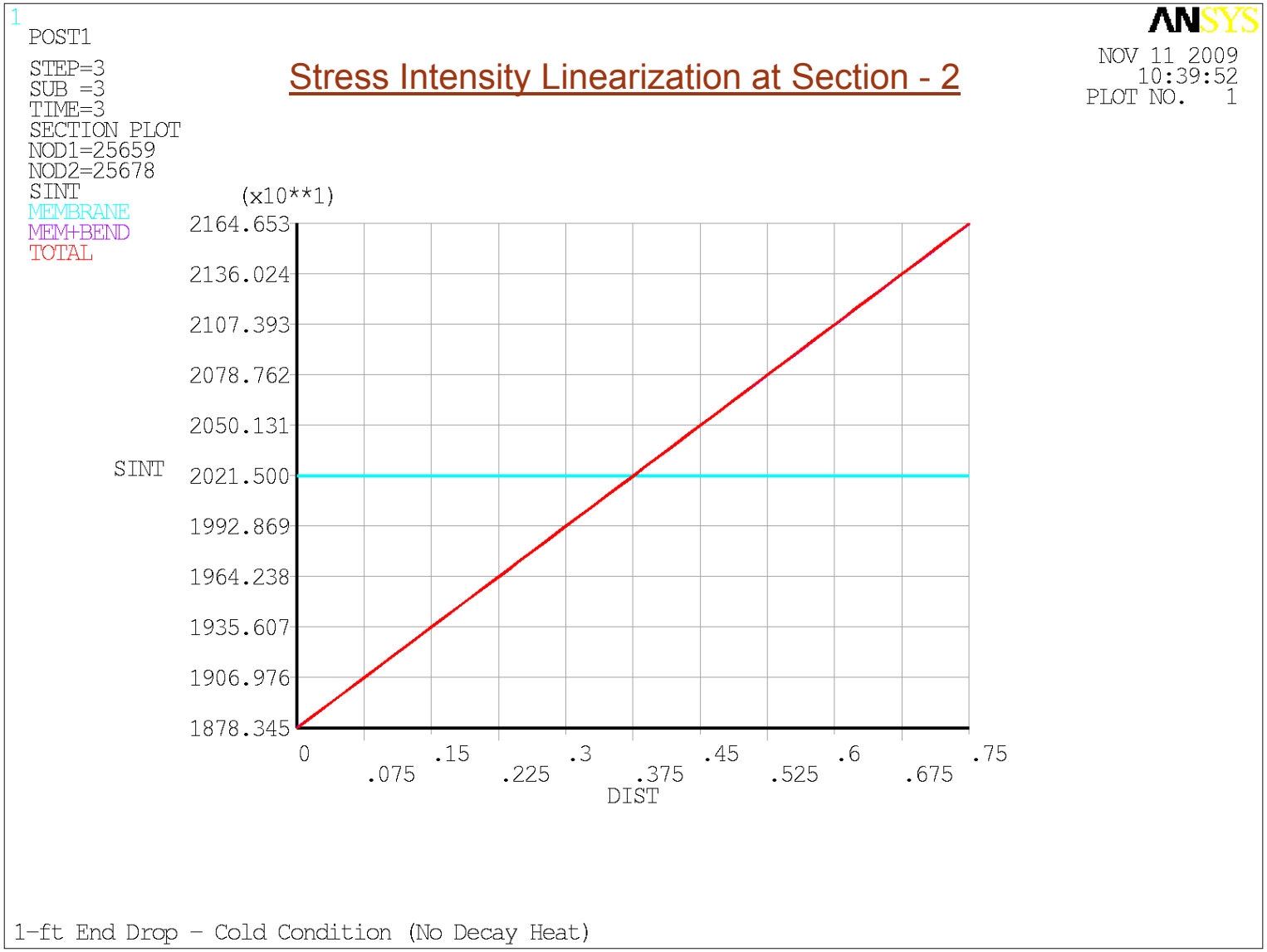


3-60B Cask SAR



3-60B Cask SAR




1
POST1
STEP=3
SUB =3
TIME=3
SECTION PLOT
NOD1=25659
NOD2=25678
SINT
MEMBRANE
MEM+BEND
TOTAL
Stress Intensity Linearization at Section - 2
ANSYS
NOV 11 2009
10:39:52
PLOT NO. 1
(x10**1)
2164.653
2136.024
2107.393
2078.762
2050.131
SINT
2021.500
1992.869
1964.238
1935.607
1906.976
1878.345
0
.075
.15
.225
.3
.375
.45
.525
.6
.675
.75
DIST
1-ft End Drop - Cold Condition (No Decay Heat)

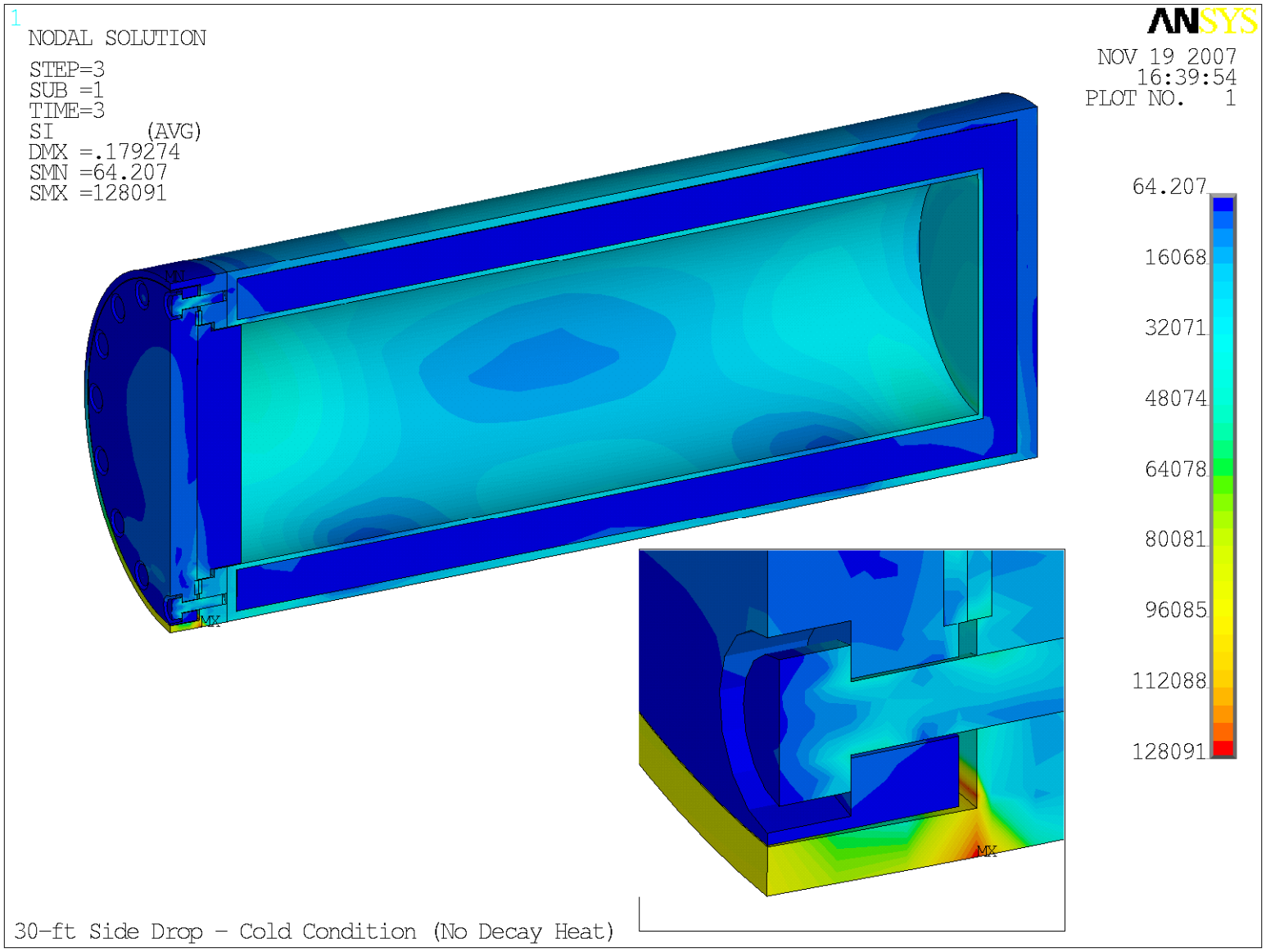
Result Reporting - Stress Categorization Issues - Implementation

- All references to the peak stress will be eliminated from the SAR.
- For the stress intensity evaluation, the shell and the ring portion of the bolting ring will be decomposed into different components. The S.I. will be computed in each component based on its own nodes only.
- Linearized S.I. at the shell-ring juncture will be categorized as P_m+P_b and compared with the appropriate allowable values.
- If necessary, the linearized S.I. at the gross-discontinuity may be categorized as P_m+P_b+Q. In this case, it must be shown that within the attenuation length the linearized S.I. also satisfies the P_m+P_b allowable value.
- Appropriate stress intensity tables in the SAR will be updated.

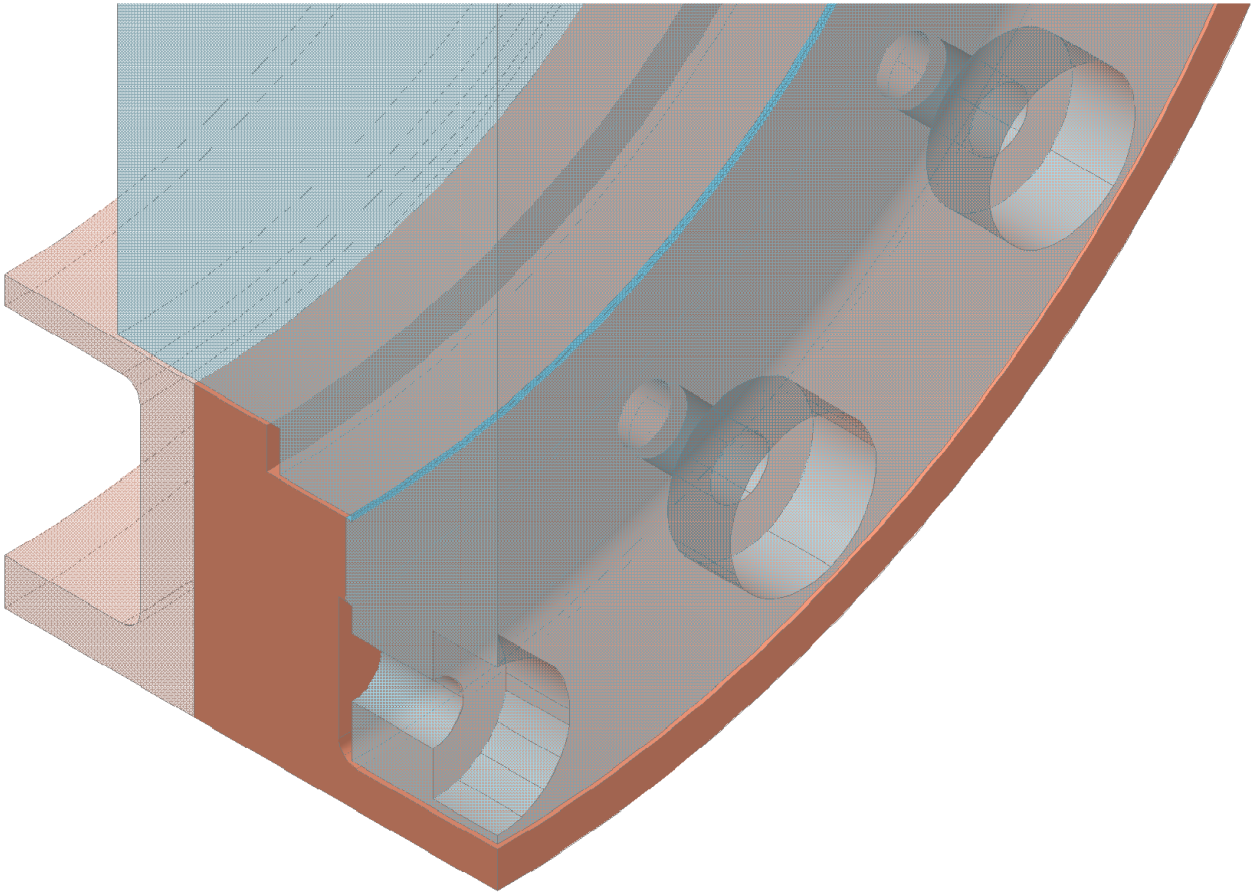
Bolting Ring Skirt Deformation Issues

- Excessive stress in the bolt-ring skirt
- Inelastic deformation of the skirt is expected
- Perform an inelastic analysis to establish realistic load-path for impact limiter reaction.
- Evaluate the bolts to react to these loads.

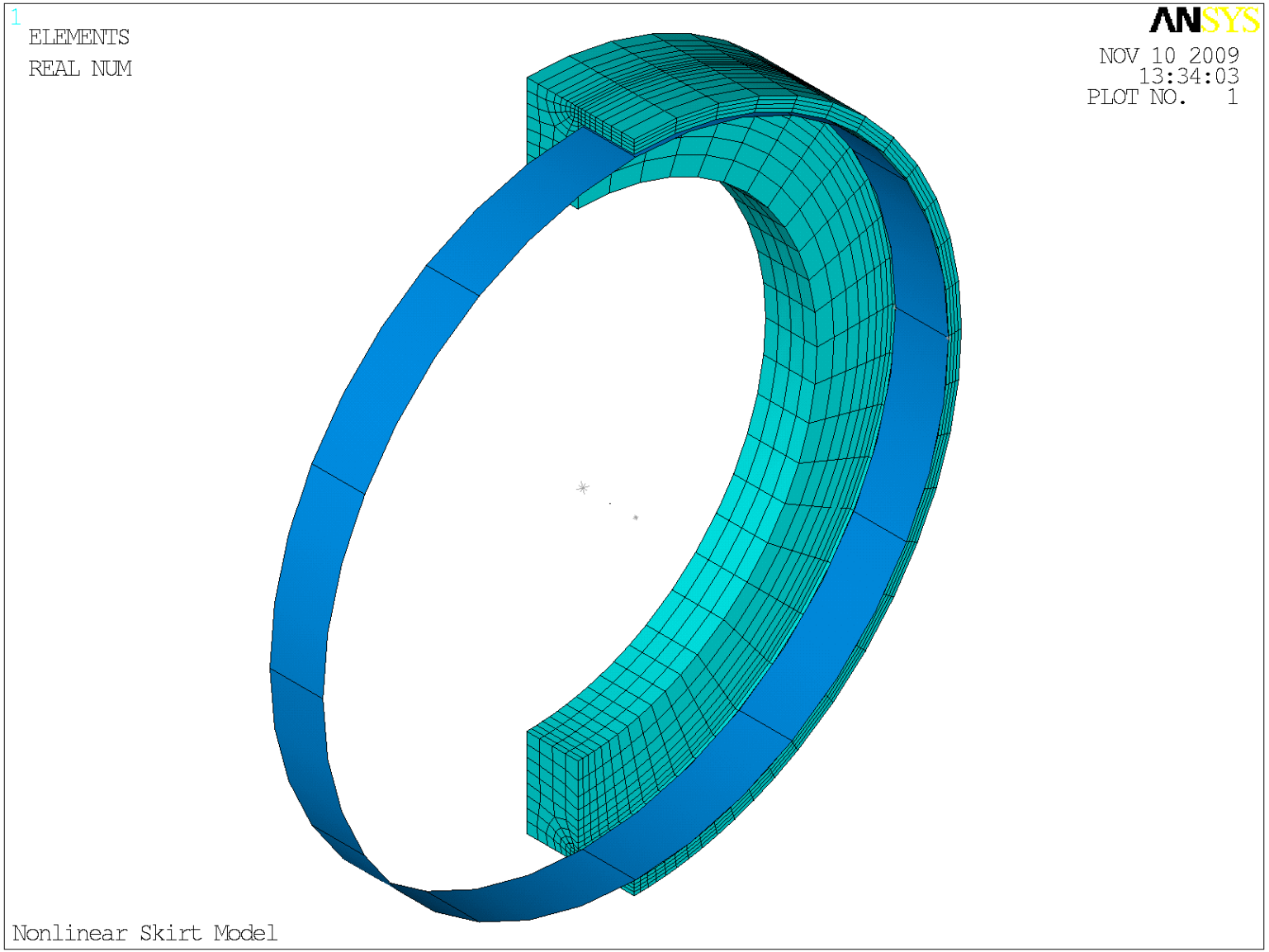
3-60B Cask SAR



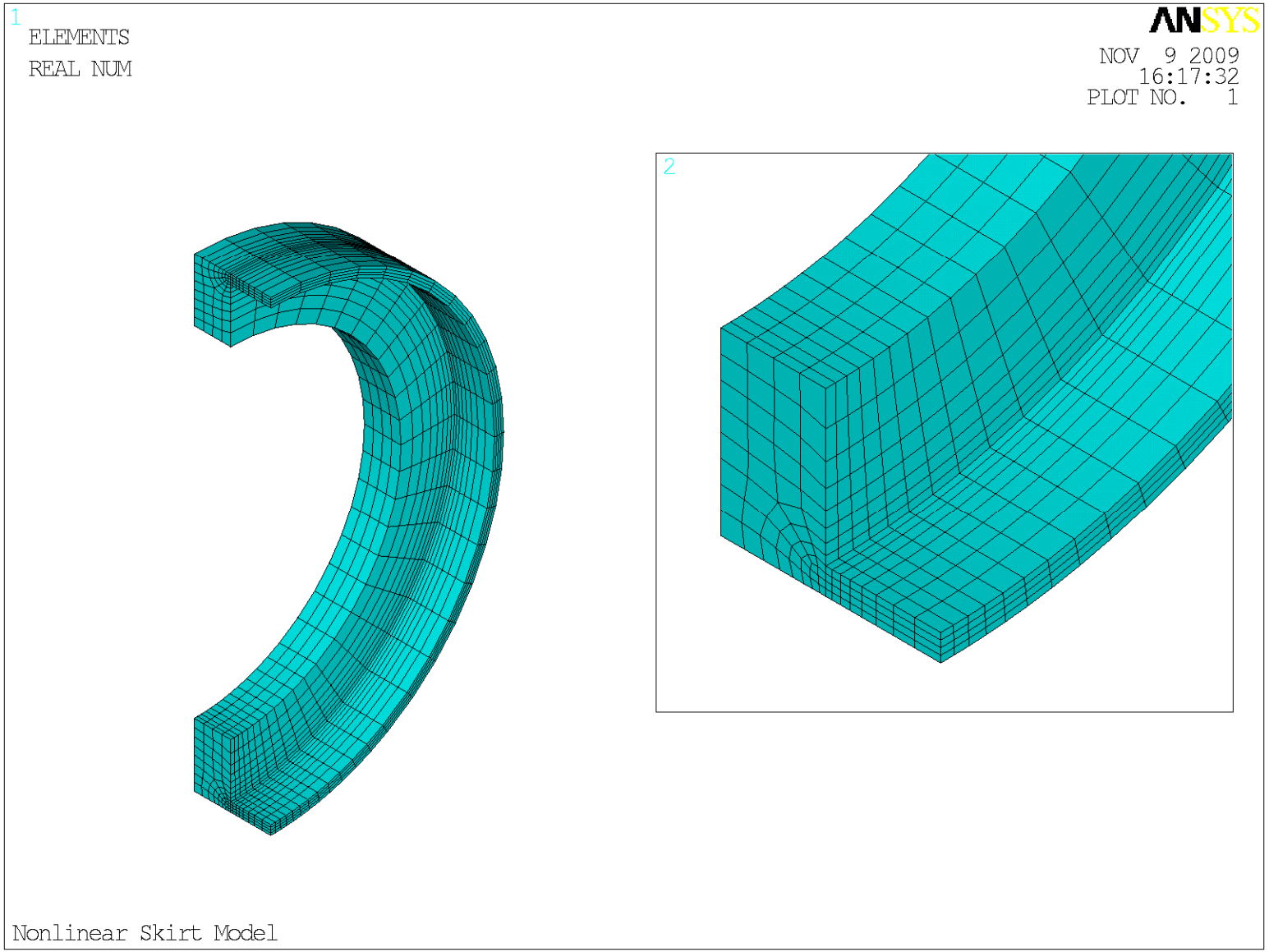
3-60B Cask SAR



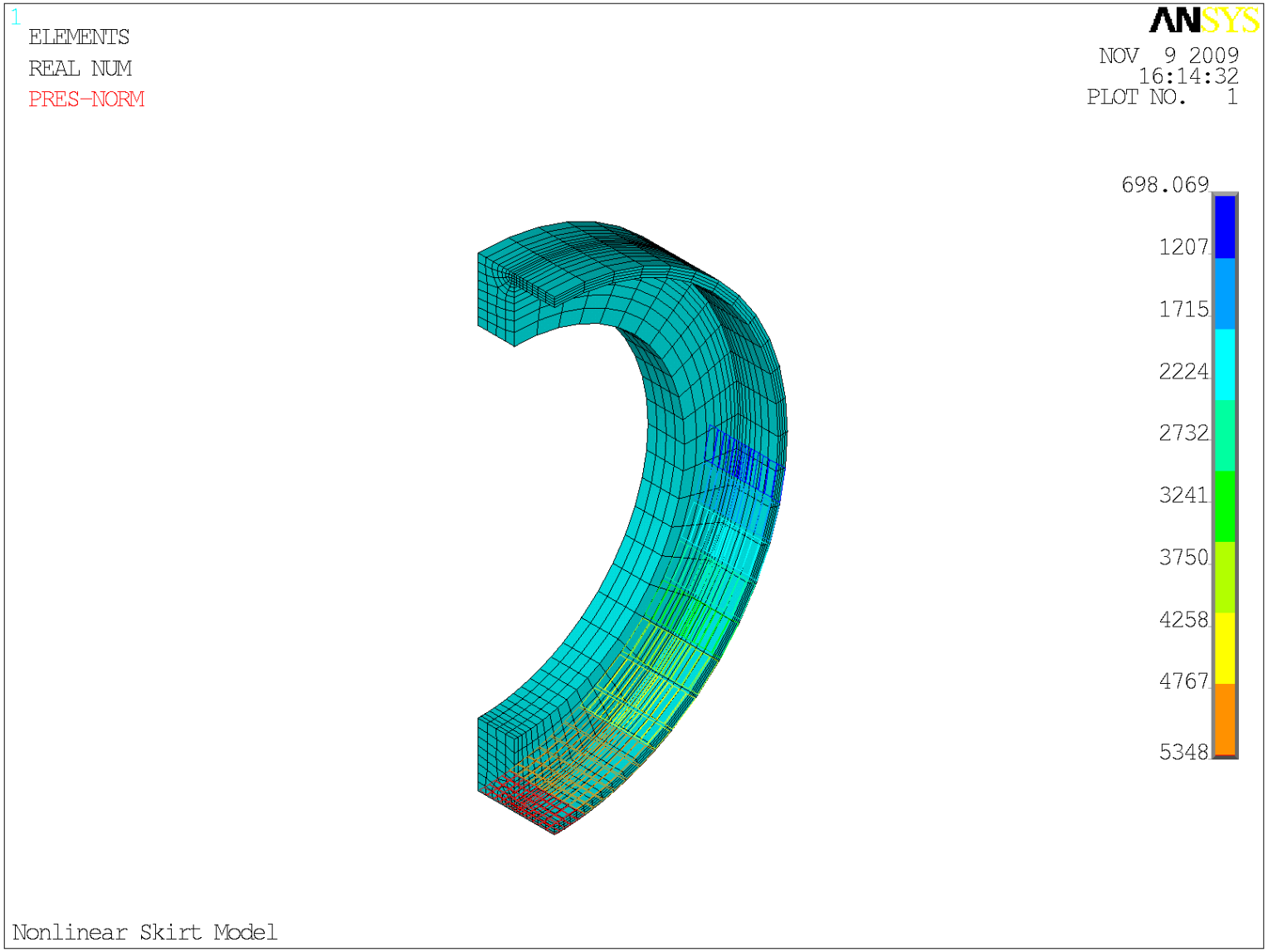
3-60B Cask SAR



3-60B Cask SAR



3-60B Cask SAR



3-60B Cask SAR

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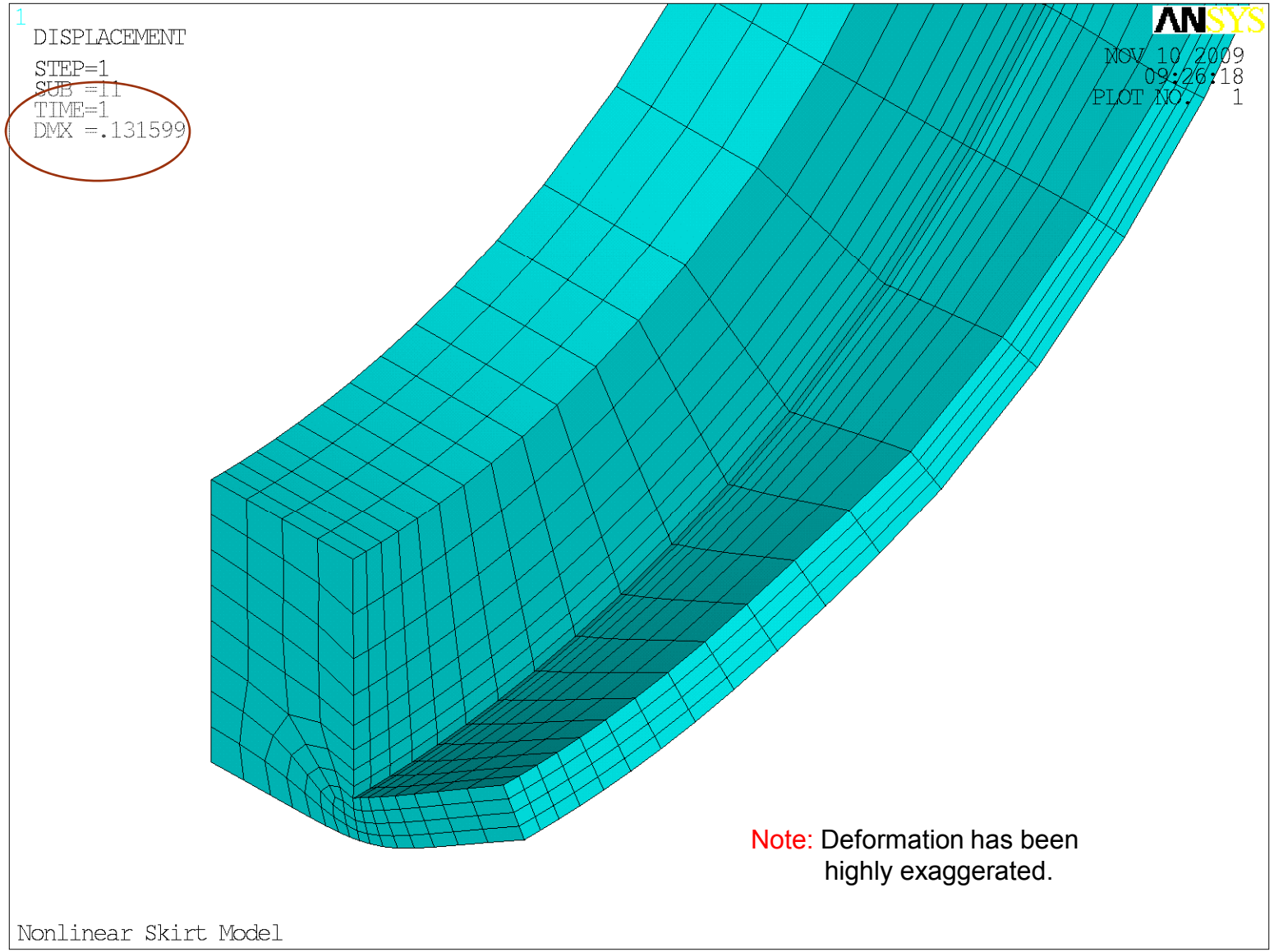
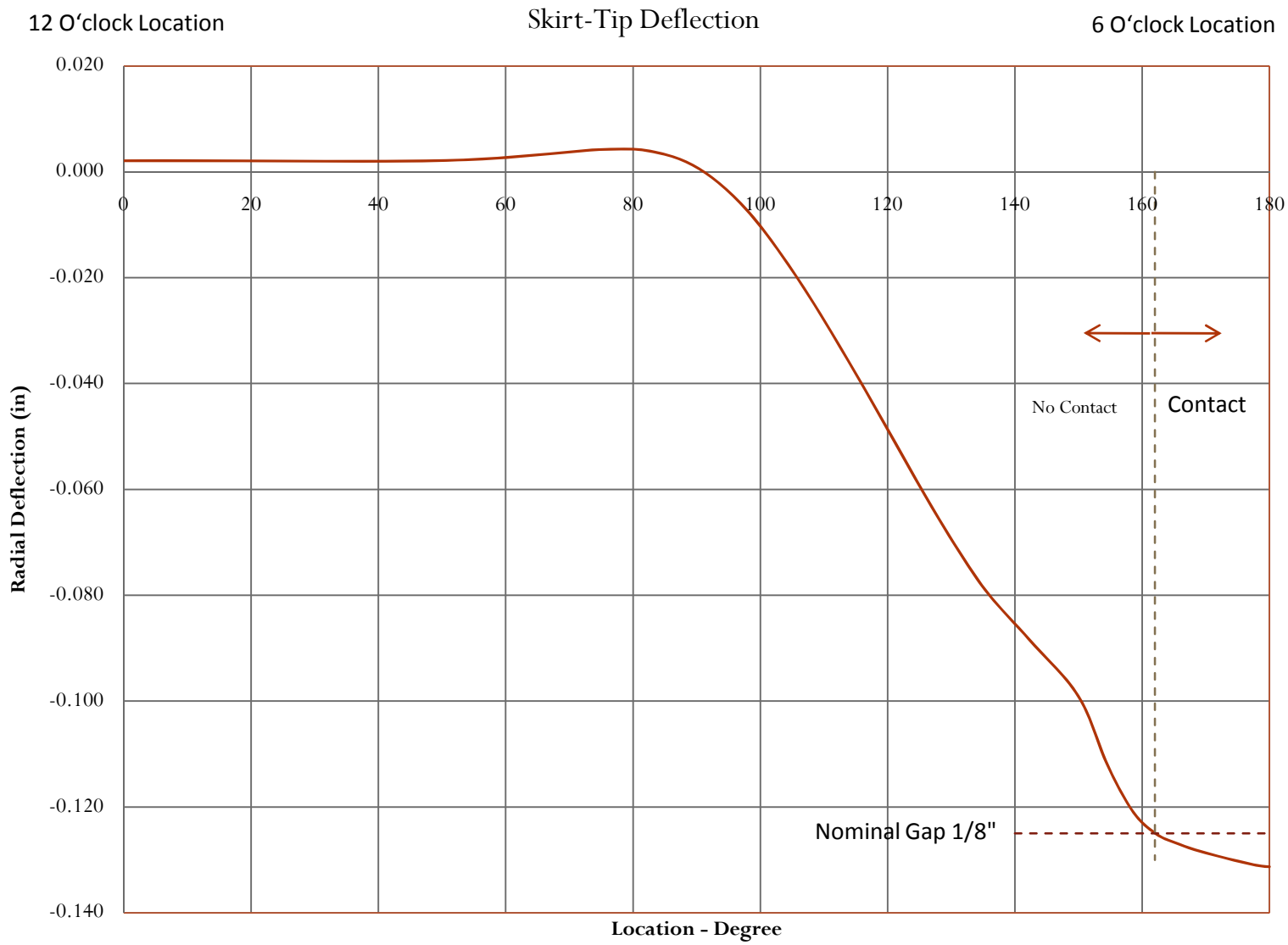


Note: Deformation has been highly exaggerated.

3-60B Cask SAR



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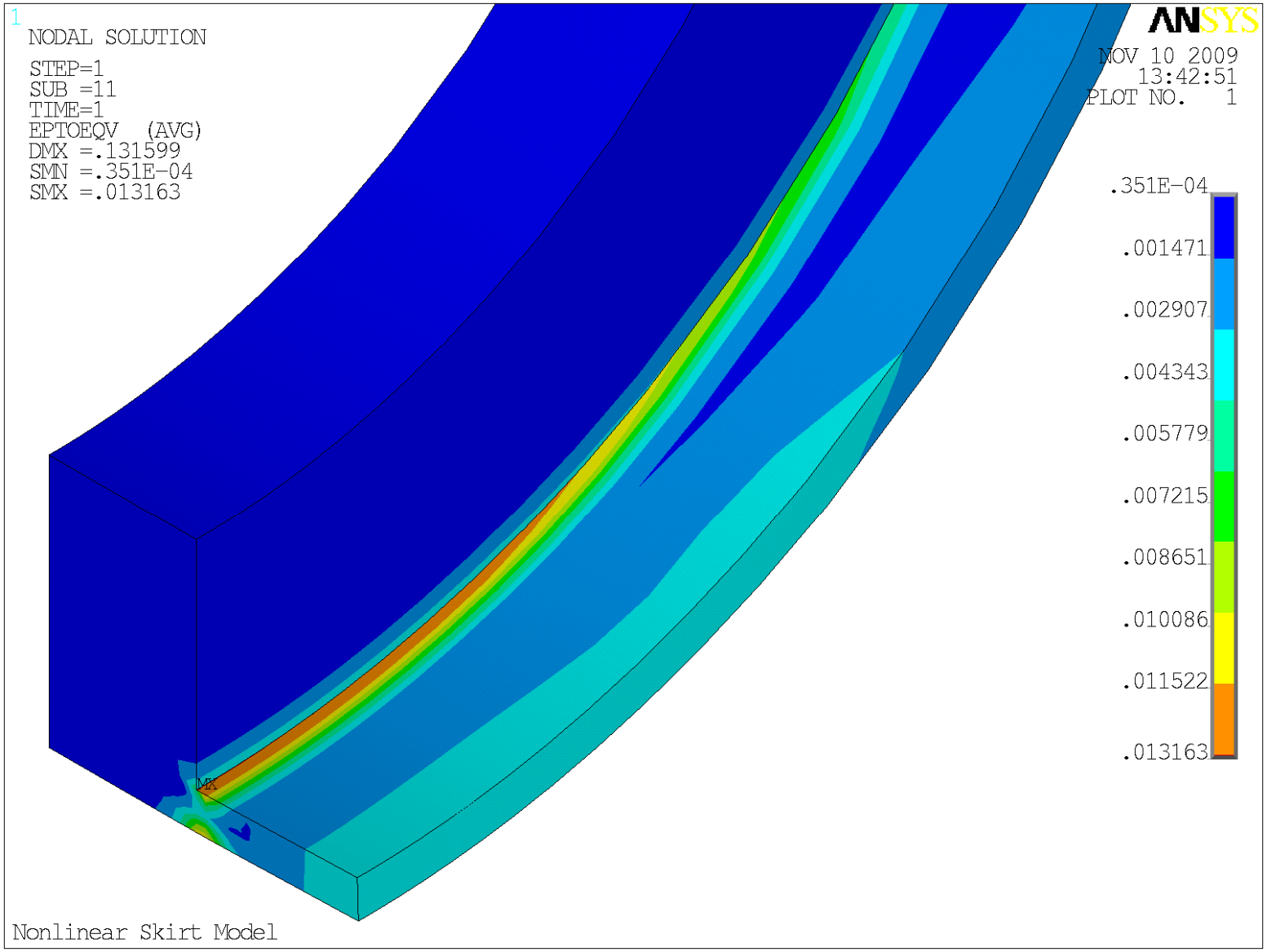

Nonlinear Skirt Analyses - Results

- Obtain reaction load on the lid – 2×45,000 = 90,000 lb
- Assume that the entire load is reacted by two bolts (located around 6 O'clock location) in shear.
- Under the above loading each bolt is subjected to the following stress:

  Shear stress = 32,051 psi < 63,000 psi (allowable shear stress)

Nonlinear Skirt Analyses - Conclusions

- Under the side drop conditions, the bolt stresses will remain within the allowable limit of the bolt material.
- The skirt will inelastically deform and will make contact with the lid over a segment of about 40º around 6 O'clock location.
- The skirt will be a subjected to < 2% equivalent plastic strain.

Bolting Ring Skirt Deformation Issues - Implementation

- The entire analyses presented here will be documented in an Energy*Solutions* document ST-xxx, which will be included as a reference in the SAR.
- The reference will be provided to the staff for review.
- The summary of the analysis will be included in the SAR.