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**241-SY-101 Strain Concentration
Factor Development Via
Nonlinear Analysis**

VOLUME 1 OF 1

PREPARED BY

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Calculation Sheet

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1.0 INTRODUCTION/SCOPE

The 241-SY-101 waste storage tank at the Hanford-Site has been known to accumulate and release significant quantities of hydrogen gas. An analysis was performed to assess the tank's structural integrity when subjected to postulated hydrogen deflagration loads (Juryk, et.al., 1991). The analysis addressed many nonlinearities and appealed to a strain-based failure criteria. The model used to predict the global response of the tank was not refined enough to confidently predict local peak strains. Strain concentration factors were applied at structural discontinuities that were based on steel-lined reinforced-concrete containment studies (EPRI, 1989). The discontinuities included large penetrations, small penetrations, springline geometries, stud/liner connections, and the 1/2" to 3/8" liner thickness transition. The only tank specific strain concentration factor applied in the evaluation was for the 1/2" to 3/8" liner thickness change in the dome.

Review of the tank drawings reveals the possibility that a 4" Sch. 40 pipe penetrates the dome thickness transition region. It is not obvious how to combine the strain concentration factors for a small penetration with that of a thickness transition to arrive at a composite strain concentration factor. It is the goal of this effort to make an approximate determination of the relative significance of the 4" penetration and the 1/2" to 3/8" thickness transition in the 241-SY-101 dome geometry. This is accomplished by performing a parametric study with three general finite-element models. The first represents the thickness transition only, the second represents a 4" penetration only, and the third combines the thickness transition with a penetration model.

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2.0 METHODOLOGY

The three general models are developed to assess the significance of three structural discontinuities, a thickness change, a penetration, and a composite thickness change/penetration. Strain concentration factors are developed for each geometry as a function of global strain resulting from internal pressure loading. While the appropriate meridional tractions are intuitive ($P_r/2t$), the hoop tractions are complex at the thickness transition and penetration. Therefore, the dome curvature is modeled and internal pressure is applied instead of specifying biaxial tractions. Ideally, the peak strain should be normalized to the free-field strain, i.e., the strain that would be produced in the absence of the discontinuity. This is impractical in many nonlinear problems because the discontinuity affects the global response of the structure. Instead, it is common to normalize the peak strain with respect to the far-field strain, i.e., where the effect of the discontinuity is sufficiently attenuated. Because the stress field is multi-axial, the von Mises strain is used for both the peak and far-field strain. The use of the von Mises strain allows for consistency in comparisons with the total elongation reduced by the ductility ratio to predict the onset of tearing. In this form, the onset of tearing is predicted when:

$$\epsilon_{peak} > \frac{TE}{\beta}$$

where:

$TE = \text{Total Elongation}$

$$\beta = \frac{1}{2^{(1-TF)}} = \frac{1}{\text{Ductility Ratio}}, \text{ Biaxiality Coefficient}$$

$$TF = \frac{\sqrt{2} (\sigma_1 + \sigma_2 + \sigma_3)}{\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}}, \text{ Davis Triaxiality Factor}$$

$$\epsilon_{peak} = \frac{1}{\sqrt{3}} \sqrt{(\epsilon_1 - \epsilon_2)^2 + (\epsilon_2 - \epsilon_3)^2 + (\epsilon_3 - \epsilon_1)^2}, \text{ von Mises Strain}$$

There is evidence that suggests membrane strain correlates better with a tearing failure than local-bending strain (EPRI, 1989). Clearly, the far-field strain

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distribution is primarily biaxial membrane-strain. For this reason the von Mises strain is computed as the average through the thickness. In locations where the shear strain dominates the strain field, it is not clear that averaging through the thickness is appropriate. For these cases, the strain concentration factor is computed at a single integration point. The three general models are intended to represent the dome geometry of the 241-SY-101 waste tank where such discontinuities are present. It should be noted that the reinforced concrete backing is neglected, the liner-stud connections are not considered and the weld geometries are idealized in this effort. For these reasons, the significance of the discontinuities should be compared relative to each other. It is not appropriate to apply the strain concentration factors developed herein to a global model containing the reinforced concrete. The dome geometry is semiellipsoidal with major and minor axes of 480 and 180 in., respectively. The region of interest is at a location 72 in. radially from the centerline of the tank. The model boundary is selected to be approximately 174 in. radially from the centerline of the tank. In a spherical coordinate system, the boundary would be located at an angle of 81.669° with the horizontal. From the dome apex to the model boundary the dome is nearly spherical. A sphere of radius 1200 in. will concede a maximum difference in radius of 0.434 in. at the boundary as shown in Figure 2.1. This is sufficiently small to consider the dome geometry as part of a sphere. This assumption makes the modeling effort more convenient and allows for the interpretation of results to be slightly more intuitive. The location selected to represent the far-field is at the same location used in WHC-SD-WM-TI-465 (Juryk, et al., 1991), i.e., a radial coordinate of approximately 147 in. from the centerline of the tank.

Figure 2.1 Dome Geometry

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3.0 MODEL DESCRIPTIONS

Prior to the final model development, a sensitivity study was performed with respect to mesh density. Three mesh schemes were tested on a flat-plate plane-strain geometry of the 1/2" to 3/8" thickness transition region. The first mesh used three elements through the thickness with an aspect ratio of 6, the second mesh used four elements through the thickness with an aspect ratio of 6, and the third mesh used three elements through the thickness with an aspect ratio of 3. The meshes are depicted in Figure 3.1. No appreciable difference was detected when subjecting these models to membrane stress. Therefore, the first mesh with three elements through the thickness and maximum aspect ratio of 6 was used as a goal for the final models.

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FIGURE 3.1

Calculation Sheet

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3.1 Thickness Transition Model

The first general model represents the 1/2" to 3/8" thickness transition in the 241-SY-101 tank dome. It is clear that if this is the only discontinuity in a sphere, it can be represented axisymmetrically. The weld as specified in the tank drawings indicates no weld preparation, a violation of standard practice. Therefore, it is assumed that the liner material as been prepared such that the two plates have a 45° angle at the weld, and the weld material fills the groove flush as shown in Figure 3.2. Table 3.1 and Figure 3.3 describe the mesh and boundary conditions employed for this model.

A uniform pressure is applied to the inside surface of the liner in this model (and in the models described in Sections 3.2 and 3.3).

Figure 3.2 Thickness Change Geometry

Calculation Sheet

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TABLE 3.1

Axisymmetric Thickness Transition Model Description				
Element Numbers	Length (in.)	Thickness (in.)	Horizontal Angle (to-from)	Region Description
1000-1132 3000-3132 5000-5132	0.993	0.1667	86.82361 - 90.0	From center of dome to beginning of dense mesh on 1/2 " Plate.
1134-1148 3134-3148 5134-5148	0.625	0.1667	86.58487 - 86.82361	First stage of dense mesh to beginning of thickness transition.
1150-1156 3150-3156 5150-5156	0.219	0.1667 to 0.125	86.54310 - 86.58487	Thickness transition region.
1158-1176 3158-3176 5158-5176	0.500	0.125	86.30436 - 86.54310	From thickness transition to end of dense mesh on 3/8 " Plate.
1178-1430 3178-3430 5178-5430	0.764	0.125	81.669 - 86.30436	From end of dense mesh to far field location.

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$$\theta_4 = 86.561 + \frac{0.5 \cdot 180}{1200 \pi} = 86.58487$$

$$\theta_3 = 86.561 - \frac{10.375 \cdot 180}{1200} \pi = 86.54310$$

$$\theta_1 = 81.669$$

$$\theta_E = 86.561 + \frac{5.5}{12.00} \left(\frac{150}{\pi} \right) = 86.82361$$

$$\theta_2 = 86.561 - \frac{5.375}{12m} \left(\frac{180}{\pi} \right) = 86.30436$$

NODE-ELEMENT CONNECTIVITY

8-NODE ISO PARAMETRIC ELEMENTS (CAX8R)
WITH REDUCED INTEGRATION (4 INTG. PTS.)

Calculation Sheet

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The liner material specification is ASTM A516 Grade 65 (Julyk, et al., 1991) for which the modulus of elasticity is 29.1×10^6 psi at 70°F and Poisson's ratio is 0.3. All of the analyses were carried out with the ABAQUS finite element program assuming an operating temperature of 70°F. ABAQUS requires that the true stress versus true plastic strain curve be used to properly address the plasticity. Figure 3.4 illustrates the best-estimate behavior as reported in WHC-SD-WM-TI-465 (Julyk, et al., 1991).

Nominal Stress (psi)	Nominal Strain (%)	True Stress (psi)	Plastic Strain (%)	True Plastic Strain (%)
44,000	0.15	44,066	0.00	0.00
44,100	1.00	44,541	0.85	0.85
54,500	6.00	57,770	5.85	5.69
60,300	10.00	66,330	9.85	9.39
65,000	15.00	74,750	14.85	13.85

Figure 3.4 ASTM A516 Grade 65 Material Data

Calculation Sheet

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3.2 4 in. Dome Penetration Model

The second general model isolates the 4 in. Sch. 40 pipe penetration discontinuity as shown in Figure 3.5. The liner is modeled with a constant 3/8 in. thickness. Idealizing the dome as a perfect sphere with the penetration perpendicular to the surface of the sphere, an axisymmetric representation can be used, aligning the polar axis with the centerline of the penetration. The 241-SY-101 dome penetration is actually aligned vertically making an angle of approximately 86.6° with the tangent to the dome surface. The model was idealized by neglecting the 3.4° departure from the normal. The pipe was modeled to extend 6 in. above and 6 in. below the liner for a total length of 12.375 in., an adequate distance to attenuate local peak strains stemming from the discontinuity. Three elements through the thickness were used in the liner, and two elements through the thickness were used in the pipe. The mesh and boundary conditions are described in more detail in Table 3.2 and Figure 3.6.

The Sch. 40 pipe is fabricated from ASTM A53 according to the tank drawings. This material has a minimum specified yield strength of 35,000 psi which is the same as that for the liner material. The minimum ultimate tensile strength is reported as 60,000 psi for the pipe material and 65,000 psi for the liner material. It is clear that the two materials are similar. Since a different stress-strain relationship would add an additional variable to the parametric study and best-estimate properties are being employed, it is sufficient for this effort to use the same material properties for both the liner and the pipe.

Figure 3.5 4 in. Penetration Geometry with No Thickness Change

Calculation Sheet

Project	LANIL STRAIN CONCENTRATION DEV.		Prepared By:	<i>Alvin Ryz</i>	Date	11/14/92
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8-NODE ISOPARAMETRIC ELEMENTS
WITH REDUCED INTEGRATION (4 INTEG. PTS.)

Calculation Sheet

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Strain Concentration Development
Subject Nonlinear Analysis
Prepared By: *M. H. R. R.* Date 11/14/92
Reviewed By: _____ Date _____

System 241-SY-101 Dome Discontinuities Job No. 92007 File No. 92007.1.1

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TABLE 3.2

Axisymmetric 4 in. Penetration Model Description				
Element Numbers	Length (in.)	Thickness (in.)	Horizontal Angle (to-from)	Region Description
1-10, 33-42	1.00	0.1185	90.0 - 89.893	Bottom and Top of pipe (coarse mesh).
11-12, 31-32	0.50	0.1185	90.0 - 89.893	Pipe, medium-coarse mesh.
13-14, 29-30	0.25	0.1185	90.0 - 89.893	Pipe, medium dense mesh.
15-28	0.125	0.1185	90.0 - 89.893	Pipe, dense mesh at plate interface.
43-46, 58-61, 73-76	0.1989	0.125	89.893 - 89.856	Plate, dense mesh at penetration interface.
47-50, 62-65, 77-80	0.4972	0.125	89.856 - 89.761	Plate, medium dense mesh.
51-57, 66-72, 81-87	0.7626	0.125	89.761 - 89.506	Plate, coarse mesh in local region.
935, 1135, 1285 3000-3240 * 5000-5240 * 7000-7240 *	0.7550	0.125	89.506 - 85.108	Plate, coarse mesh from end local region to boundary.

* At element increment of two.

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3.3 3-D Penetration and Thickness Transition

The third general model represents the combined penetration and thickness transition discontinuity as shown in figure 3.7. The center of penetration (pipe) is located at a radial coordinate of 72 in. from the center line of the tank. The 3-D solid element mesh, described in detail on the next several pages, extends approximately 10 in. North and South of the penetration in the meridional direction. It also extends over a sector spanning 6.25° in the hoop direction. The penetration is modeled with its centerline parallel to the vertical direction as it is indicated on the construction drawings. The displacement boundary condition are specified such that the boundary nodes are free to move in the radial direction of a spherical coordinate system. Half symmetry is taken through the penetration. Because the penetration is only on one side of the tank, no other symmetry is theoretically admissible. However, the penetration is relatively small compared to the dome and it is argued that the effect of the penetration has little influence on the global response of the dome which is clearly axisymmetric. This permits modeling the 6.5° sector with boundary conditions that prohibit hoop direction displacements.

Figure 3.7 4-in. Penetration Intersecting the Dome Thickness Transition

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Three dimensional 20-node quadratic reduced-integration brick-elements (ABAQUS "C3D20R") were used to model tank dome liner and the penetration. The finite-element model of the dome liner (1/2 in. and 3/8 in. thick including the thickness transition) and the penetration (4" Sch. 40 pipe) is shown in Figure 3.8. The nodes shown on Figure 3.8 correspond to the elements along the bottom layer of the dome. The dome liner is modeled with three equal layers of elements and the pipe is modeled with two shown in Figure 3.19 and 3.20. The element numbers corresponding to the bottom layer of the dome liner are shown in Figure 3.9. The dome is modeled in a spherical coordinate system with a constant radius of 1200 in. Figure 3.10 shows the cross section of the model and its coordinates along the plane of symmetry. Since the pipe is constructed to be vertical, the angle between the axis of pipe and dome tangent is not perpendicular. The penetration of the dome appears to be circular from a plan view and ovalar from a view in the radial direction of the dome. To model this complex geometry all the nodes along the interface of pipe and dome are defined manually. The procedure used to calculate the spherical coordinates (θ and ϕ) of the interface nodes are illustrated in Figures 3.11 and 3.12. Figure 3.12 shows the coordinates of the dome nodes near the penetration in the local spherical coordinate system. Figures 3.15 and 3.16 show the geometry and the nodes at the intersection of pipe and thickness transition. The nodal coordinate calculations of the various key nodes are listed in Table 3.1.1.

The pipe element nodes (below the dome liner, above the dome liner and at the liner interface) are generated in a local cylindrical coordinate system as shown on Figures 3.17 and 3.18. The pipe elements on top of the liner are intentionally modeled with a stepped pattern to limit the element aspect ratio as the dome liner changes thickness.

ABAQUS plots of the model are shown in Figures 3.20 through 3.24. A three dimensional mesh of the entire model being viewed from two opposite directions are shown in Figures 3.19 and 3.20. The mesh showing the dome liner and the pipe elevation is listed in Figure 3.21. The dome liner and pipe mesh in plan-view is shown in Figure 3.22. A detail shown in an elevation of the dome liner elements at the penetration and the thickness transition are shown in Figure 3.23. Figure 3.24 shows a three dimensional section of a pipe, 1/2" dome liner, 3/8" dome liner and the dome liner (with elements removed for clarity) at the thickness transition.

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FIGURE 3.8

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FIGURE 3.9

DOME ELEMENTS : (20 NODE QUADRATIC DISPLACEMENT BRICK ELEMENTS : C3D20)

Layer	1001	1010	1020	1030	1040	1050	1060	1070	1080	1090	1100	1110	1120	1130	1140	1150	1160	1170	1180	1190	1200	1210	1220	1230	1240	1250	1260	1270	1280	1290	1300	1310	1320	1330	1340	1350	1360	1370	1380	1390	1400	1410	1420	1430	1440	1450	1460	1470	1480	1490	1500	1510	1520	1530	1540	1550	1560	1570	1580	1590	1600	1610	1620	1630	1640	1650	1660	1670	1680	1690	1700	1710	1720	1730	1740	1750	1760	1770	1780	1790	1800	1810	1820	1830	1840	1850	1860	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2110	2120	2130	2140	2150	2160	2170	2180	2190	2200	2210	2220	2230	2240	2250	2260	2270	2280	2290	2300	2310	2320	2330	2340	2350	2360	2370	2380	2390	2400	
BOTTOM LAYER	-	1001	1010	1020	1030	1040	1050	1060	1070	1080	1090	1100	1110	1120	1130	1140	1150	1160	1170	1180	1190	1200	1210	1220	1230	1240	1250	1260	1270	1280	1290	1300	1310	1320	1330	1340	1350	1360	1370	1380	1390	1400	1410	1420	1430	1440	1450	1460	1470	1480	1490	1500	1510	1520	1530	1540	1550	1560	1570	1580	1590	1600	1610	1620	1630	1640	1650	1660	1670	1680	1690	1700	1710	1720	1730	1740	1750	1760	1770	1780	1790	1800	1810	1820	1830	1840	1850	1860	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2110	2120	2130	2140	2150	2160	2170	2180	2190	2200	2210	2220	2230	2240	2250	2260	2270	2280	2290	2300	2310	2320	2330	2340	2350	2360	2370	2380	2390	2400
MIDDLE LAYER	-	1501	1510	1520	1530	1540	1550	1560	1570	1580	1590	1600	1610	1620	1630	1640	1650	1660	1670	1680	1690	1700	1710	1720	1730	1740	1750	1760	1770	1780	1790	1800	1810	1820	1830	1840	1850	1860	1870	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2110	2120	2130	2140	2150	2160	2170	2180	2190	2200	2210	2220	2230	2240	2250	2260	2270	2280	2290	2300	2310	2320	2330	2340	2350	2360	2370	2380	2390	2400																																																		
TOP LAYER	-	2001	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2110	2120	2130	2140	2150	2160	2170	2180	2190	2200	2210	2220	2230	2240	2250	2260	22																																																																																																																	

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DOME & PIPE INTERSECTION

FIGURE 3.11

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PIPE & DOME INTERSECTION CONT'D.

The spherical coordinates on any point along the intersection of dome with the 4" SCH 40 pipe shall be calculated as below.

$$\theta = \tan^{-1} \left[\frac{2.25 \sin \theta_1}{72 + 2.25 \cos \theta_1} \right] \quad (180^\circ \leq \theta \leq 0)$$

$$\phi = 90 - \sin^{-1} \left[\left\{ (2.25 \sin \theta_1)^2 + (72 + \cos \theta_1)^2 \right\}^{1/2} \div R \right]$$

where, R = dome radius = 1200"

FIGURE 3.12

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>[Signature]</i>	Date	10-25-92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	20	Rev. No.	0

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Handwritten signature</i>	Date	10-25-92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	21	Rev. No.	0

FIGURE 3.14

$$A = \tan^{-1} \left[\frac{2.487 \sin 45}{(72 - 2.487 \cos 45)} \right] = 1.4341659$$

$$B = 180 - \sin^{-1} \left(\frac{72 \sin A}{3.013} \right) = 143.26695$$

$$C = 180 - A - B = 35.298886$$

$$h_1 = 72 \sin C / \sin B = 69.562738''$$

$$h_2 = 72 \sin C' / \sin B' = 74.456014''$$

$$A' = \tan^{-1} \left[\frac{2.487 \sin 45}{(72 + 2.487 \cos 45)} \right] = 1.3658'$$

$$B' = \sin^{-1} \left(\frac{72 \sin A'}{3.013} \right) = 34.721263 ; C' = 180 - A' - B' = 143.91294$$

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By: <i>[Signature]</i>	Date	10-25-92
Subject	Nonlinear Analysis	Reviewed By:	Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No. 92007.1.1
Client Calc. No.	N/A	Sheet No.	22	Rev. No. 0

$$\theta = \frac{0.875}{2.25} \times \frac{180}{\pi}$$

$$= 22.282^\circ$$

$$\theta_1 = \frac{0.875}{2.487} \times \frac{180}{\pi}$$

$$= 20.158^\circ$$

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>[Signature]</i>	Date	10-25-92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	23	Rev. No.	0

GLOBAL (SPHERICAL) COORDINATES:

TABLE 3.1.1

NODE NO.	θ (degrees)	ϕ (degrees)
101	0	$90 - \sin^{-1}\left(\frac{72}{1200}\right) + \frac{12.013}{1200} \times \frac{180}{\pi}$ $= 87.133765$
1501	2.25	
2301	6.25	
1523	2.25	$90 - \sin^{-1}\left(\frac{h_1}{1200}\right) = 86.677$ $(h_1 = 69.563", \text{ see fig. 3.14})$
2323	6.25	
1527	2.25	
2327	6.25	$- \sin^{-1}\left(\frac{1}{1200} \left[(2.487 \sin 135)^2 + (72 + 2.487 \cos 135)^2 \right]^{1/2}\right) + 90$ $= 86.643$
3712	2.25	
3720	6.25	
4512	2.25	$90 - \sin^{-1}\left(\frac{71.5625}{1200}\right) = 86.533$ <p>where, 71.5625" is the horizontal length from dome apex to the end of 1/2" R.</p> $90 - \sin^{-1}\left(\frac{71.5625 + 0.875}{1200}\right) = 86.539$
4520	6.25	
1545	2.25	
2345	6.25	$90 - \sin^{-1}\left(\frac{1}{1200} \left[(2.487 \sin 45)^2 + (72 + 2.487 \cos 45)^2 \right]^{1/2}\right)$ $= 86.475$

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>[Signature]</i>	Date	10-25-92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	24	Rev. No.	0

Contd.. GLOBAL (SPHERICAL) COORDINATE TABLE 3.1.1 (Contd..)

NODE NO.	θ (Degrees)	ϕ (Degrees)
1549	2.25	$90 - \sin^{-1}(h_2/1200) = 86.443$ where, $h_2 = 74.456"$, see fig. B.14
2349	6.25	
1571	2.25	$90 - \sin^{-1}(72/1200) - \frac{12.013}{1200} \times \frac{180}{\pi} = 85.9866$
2371	6.25	

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>any</i>	Date	10-25-92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	25	Rev. No.	0

DOME THICKNESS TRANSITION: (Approximated as below)

The thickness at a distance x is,

$$= 0.375 + \frac{(0.5 - 0.375)}{0.875} \cdot x$$

$$(0 \leq x \leq 0.875)$$

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>[Signature]</i>	Date	10-25-92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	26	Rev. No.	0

PIPE ELEMENTS BELOW THE
DOME BOTTOM

FIGURE 3.17

2 @ 0.1185"
= 0.237" (TYP)

LOCAL COORD.
(CYLINDRICAL)

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>[Signature]</i>	Date	10-25-92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	27	Rev. No.	0

PIPE @ DOME AND ABOVE THE DOME

FIGURE 3.18

PIPE ELEM. NOS. @ DOME = 4353 TO 4484
PIPE ELEM. NOS. ABOVE DOME = 4485 TO 4836

TANK DOME AND PIPE PENETRATION MODEL INCLUDING DOME THICKNESS TRAN
RADIUS VERSION 4-0-1 DATE: 10/24/82 TIME: 19:08:31

Figure 3.19

TANK DOME AND PIPE PENETRATION MODEL INCLUDING DOME THICKNESS TRAN
REBARUS VERSION 4-9-1 DATE: 10/24/92 TIME: 19:08:31

Figure 3.20

TANK DOME AND PIPE PENETRATION MODEL INCLUDING DOME THICKNESS TRAN
 ABAQUS VERSION 4-9-1 DATE: 10/24/92 TIME: 19:08:31

Figure 3.21

TANK DOME AND PIPE PENETRATION MODEL INCLUDING DOME THICKNESS TRAN
 ABAQUS VERSION 4-9-1 DATE: 10/24/92 TIME: 19:08:31

Figure 3.22

TANK DOME AND PIPE PENETRATION MODEL INCLUDING DOME THICKNESS TRAN
 ABRIOUS VERSION 4-9-1 DATE: 10/24/92 TIME: 19:08:31

Figure 3.23

3
1
TANK DOME AND PIPE PENETRATION MODEL INCLUDING DOME THICKNESS TRAN
ABRIOUS VERSION 4-9-1 DATE: 10/24/92 TIME: 19:08:31

Figure 3.24

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Went Nye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	34	Rev. No.	0

4.0 DISCUSSION OF RESULTS

4.1 Thickness Transition Model Results

The first general model (thickness transition in the dome) applies the RIKS solution procedure option in ABAQUS which allows the pressure load to be treated as a solution variable. This solution technique significantly aids the stability of the solution while the model undergoes large plastic deformation. Use of the large displacement option is critical because of the geometric eccentricity created by the thickness change. If small displacement theory were employed, the eccentricity would continue to exist regardless of the plastic deformation and could lead to an erroneous result. An added advantage is that initial minor inaccuracies in the mesh geometry are reduced as the model attempts to become spherical under internal pressure loading. The analysis was terminated when the internal pressure load reached 35.0 psi with a maximum meridional strain of approximately 9% and direction cosines of: $\cos x = 0.999$ $\cos y = -0.027$ $\cos z = 0.000$.

ABAQUS allows storage of the component strains at each integration point. A section through the liner thickness at the element with the maximum equivalent plastic strain was selected to determine the peak von Mises (effective) strain as shown in Figure 4.1. The principal strains for the given section are computed from the average through-thickness component strains as shown below.

$$\overline{\epsilon_{ij}} = \frac{\epsilon_{ij-int1-elem1} + \epsilon_{ij-int3-elem1} + \epsilon_{ij-int1-elem2} + \epsilon_{ij-int3-elem2} + \epsilon_{ij-int1-elem3} + \epsilon_{ij-int3-elem3}}{6}$$

where $\overline{\epsilon_{ij}}$ = average through-thickness component strain

$\epsilon_{ij-int1-elem1}$ = component strain at the first integration point of the first element

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>W. Hunt Rye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	35	Rev. No.	0

Figure 4.1 Through-Thickness Integration Point Averaging

The principal strains are computed from these equivalent membrane component strains in two dimensions as follows:

$$\bar{\varepsilon}_1 = \frac{\bar{\varepsilon}_{11} + \bar{\varepsilon}_{22}}{2} + \sqrt{\left(\frac{\bar{\varepsilon}_{11} - \bar{\varepsilon}_{22}}{2}\right)^2 + \left(\frac{\bar{\varepsilon}_{12}}{2}\right)^2}$$

$$\overline{\varepsilon}_2 = \frac{\overline{\varepsilon}_{11} + \overline{\varepsilon}_{22}}{2} - \sqrt{\left(\frac{\overline{\varepsilon}_{11} - \overline{\varepsilon}_{22}}{2}\right)^2 + \left(\frac{\overline{\varepsilon}_{12}}{2}\right)^2}$$

$$\overline{\varepsilon_3} = \overline{\varepsilon_{33}}$$

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Ryz</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	36	Rev. No.	0

The von Mises strain in 2 dimensions is computed from the principal strains computed above. The peak strains are obtained from Elements 1158, 3158, and 5158 at integration points 1 and 3. This location is the first line of integration points through the 3/8 in. plate just beyond the weld (Figure 4.1). The far-field elements are taken to be Elements 1360, 3360, and 5360. The resulting von Mises (effective) strain concentration factor as a function of far-field strain is shown in Figure 4.2. The meridional strain concentration factor is also shown for comparison purposes. The maximum von Mises and meridional strain concentration factors are roughly 2.25 and 3.2, respectively. This is a significant departure from the curve reported in WHC-SD-WM-TI-465 (Juryk, et al., 1991) for the thickness transition region. In order to understand the differences, a model was developed to duplicate the one used by Juryk, et al., 1991.

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert R. J.</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	37	Rev. No.	0

Figure 4.2 SY-101 Dome Thickness Transition (1/2" to 3/8")

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Rye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	38	Rev. No.	0

The local model geometry used by Julyk, et al., 1991 is summarized below.

Table 4.1

R and Z Coordinates for Top Row of Nodes					
Node	R (in)	Z (in)	Node	R (in)	Z (in)
5000	0	593.613	5048	75.22	591.389
5002	15.180	593.522	5050	79.22	591.145
5004	30.360	593.252	5052	87.22	590.617
5006	45.540	592.801	5054	95.749	589.996
5008	60.720	592.167	5056	110.778	588.754
5010	67.095	591.846	5058	125.808	587.321
5012	69.22	591.732	5060	140.837	585.692
5014	69.72	591.704	5062	155.866	583.861
5018	70.22	591.676	5064	170.895	581.821
5022	70.595	591.656	5066	185.925	579.564
5026	70.72	591.650	5068	200.954	577.082
5034	70.97	591.635	5070	215.983	574.365
5038	71.22	591.621	5072	231.012	571.400
5042	71.72	591.592	5074	246.042	568.172
5044	72.22	591.564	5076	261.071	564.665
5046	73.22	591.507	5078	276.100	560.859

Figure 4.3 WHC-SD-WM-TI-465 Model Mesh

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Rye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	39	Rev. No.	0

Table 4.2

R and Z Coordinates for Bottom Row of Nodes					
Node	R (in)	Z (in)	Node	R (in)	Z (in)
1000	0	594.113	1048	75.242	591.762
1002	15.186	594.022	1050	79.243	591.517
1004	30.372	593.752	1052	87.246	590.988
1006	45.558	593.300	1054	95.778	590.367
1008	60.743	592.665	1056	110.812	589.124
1010	67.122	592.343	1058	125.846	587.689
1012	69.248	592.229	1060	140.881	586.058
1014	69.747	592.201	1062	155.915	584.225
1018	70.247	592.174	1064	170.949	582.182
1022	70.614	592.061	1066	185.984	579.923
1026	70.742	592.021	1068	201.018	577.439
1034	70.991	592.007	1070	216.053	574.718
1038	71.241	591.993	1072	231.087	571.750
1042	71.742	591.965	1074	246.121	568.519
1044	72.241	591.937	1076	261.156	565.008
1046	73.242	591.879	1078	276.190	561.200

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Rye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	40	Rev. No.	0

There are several differences between the modeling and calculation methods employed here and those used by Julyk, et.al, 1991. The differences are summarized below:

Table 4.3

Modeling Difference	WHC-SD-TI-WM-465 Thickness Transition Model	ADVENT Thickness Transition Model
Mesh	Two elements through the thickness, 4 to 1 weld taper, 78 meridional elements from the dome apex to the model boundary at x=276.19".	Three elements through the thickness, 7 to 1 weld taper, 430 meridional elements from the dome apex to the model boundary at x=173.83".
Boundary Conditions	Vertically free at the dome apex, prescribed x and y displacements at the far boundary corresponding to the predicted global response.	Vertically free at the dome apex and radial only at the far boundary.
Solution Procedure	Direct=NOSTOP with PTOL=1000., override equilibrium convergence after the maximum number of iterations is reached (maximum number of iterations never reached).	RIKS with PTOL=100., allows the pressure load to be treated as a solution variable.
Location of Far-Field Strain	Far boundary element where displacement boundary conditions are applied (very sensitive to location selected as far-field even at boundary).	Coincides with far-field location of global model in WHC-SD-TI-WM-465 (not sensitive to location 22" beyond the discontinuity).
Strain Concentration Factor Definition	Peak meridional strain/far-field meridional strain. *	Peak von Mises strain/far-field von Mises strain.**

* Based on average meridional strain considering top two integration points in top element and bottom two integration points in bottom element.

** Based on average through-thickness component strains.

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Rye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	41	Rev. No.	0

As expected, the results of this model (Figure 4.4) are very similar to that reported by Julyk.

Other models were used to assess the relative contribution of each of the primary differences, reported in Table 4.3, to the drastic differences in calculated strain concentration factors. One model removed the prescribed displacement boundary conditions, another tested the solution procedure. Methods used to define the membrane strain were assessed, as well as the location chosen to represent the far-field. All of these effects are illustrated in Figures 4.5 through 4.8. The mesh has a relatively small effect; the solution procedure in this case has essentially no effect. The most significant effect is the selection of the far-field location in combination with the prescribed boundary conditions. The boundary chosen as the far-field element is excessively constrained in the WHC-SD-TI-WM-465 model (all degrees of freedom prescribed at one end) and is a very conservative choice for determining a strain concentration factor. The strain concentration factor curve in Figure 4.2 is appropriate for comparisons with the other models reported herein. The pressure loading and resulting radial displacements are consistent for the thickness transition model, the 4 in. penetration model and the combined 3-D model.

The response of the axisymmetric thickness transition model is typified in Figure 4.9 where a contour plot of the equivalent plastic strain is illustrated. The response is dominated by peak meridional strain as shown by comparing the contour plot of the meridional strains in Figure 4.10 to the hoop strain contour plot in Figure 4.11.

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Rop</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	42	Rev. No.	0

Figure 4.4 SY-101 Dome Thickness Transition (1/2" to 3/8")

- ☐ SY101 global displacement boundary conditions
- ☐ Direct=NOSTOP solution procedure
- ☐ WHC-SD-WM-TI-465 local mesh (2-el. thru thickness)
- ☐ Uses element at boundary as far-field
- ☐ Averages top and bottom two integration points for membrane effect

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>W. A. Rye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	43	Rev. No.	0

Figure 4.5 SY-101 Dome Thickness Transition (1/2" to 3/8")

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Rye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	44	Rev. No.	0

Figure 4.6 SY-101 Dome Thickness Transition (1/2" to 3/8")

EPDM60.XLC

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Rye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	45	Rev. No.	0

Figure 4.7 SY-101 Dome Thickness Transition (1/2" to 3/8")

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Rye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	46	Rev. No.	0

Figure 4.8 SY-101 Dome Thickness Transition (1/2" to 3/8")

EPDM2060.XLC

Figure 4.9 Axisymmetric Thickness Transition Model- von Mises Plastic Strain

Figure 4.10 Axisymmetric Thickness Transition Model- Meridional Strain

Figure 4.11 Axisymmetric Thickness Transition Model- Hoop Strain

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Hye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	50	Rev. No.	0

4.2 4 in. Penetration Model Results

The RIKS solution procedure and the large displacement option were applied for the second general model (4 in. penetration in 3/8" liner). The analysis was terminated at a maximum pressure of 30.0 psi with a maximum strain of approximately 12 % (Figure 4.12) and direction cosines of $\cos x = 0.0663$, $\cos y = 0.998$, $\cos z = 0.000$. The response of the axisymmetric 4 in. penetration model is completely different from that of the thickness transition model. The normal stress at the inside surface of the 4 in. pipe is by definition equal to the the internal pressure. The stress in the meridional direction eventually reaches $P_r/2t$ in the far-field. The hoop direction stress is required to resist the pressure load even at the discontinuity as demonstrated by the hoop strain contour plot in Figure 4.13. Therefore, a Poisson effect creates compressive strains at the pipe/dome interface as shown in Figure 4.14 which is not entirely intuitive. The dome converts the pressure stress into meridional and hoop membrane forces which attempt to enlarge the penetration diameter in achieving equilibrium. The pipe above and below the dome juncture is essentially stress free. There are no forces acting along the length of the pipe to enlarge the diameter uniformly. The result is a bulge at the penetration/dome juncture dominated by shear strains as shown in Figure 4.15. The bulging tendency of the pipe at the dome liner connection is illustrated by the deformed shape plot in Figure 4.12. The equivalent plastic strain contour plot in Figure 4.16 illustrates the complex response. The strain concentration factors at integration points corresponding to the maximum meridional, hoop, and shear strains are plotted as a function of the far-field von Mises strain in Figure 4.17. The maximum strain concentration factor of 3.0 corresponds to the location of maximum shear strain. In addition, two sections were taken to develop membrane-based strain concentration factors. One section is taken through the pipe and the other is taken through the dome liner. The corresponding strain concentration factors are plotted as a function of the far-field strain in Figure 4.18. The maximum strain concentration factor of approximately 2.25 exists at the through-liner location. While the shape of these strain concentration factor curves are similar to those reported by the Sandia 1/6 scale model predictions and testing (Clauss, 1989), the magnitude is significantly lower than that for penetrations tested at Sandia. The Sandia test report attributes most of the strain concentration to concrete/liner interaction which is completely omitted in this effort.

Figure 4.12 Axisymmetric 4-in. Penetration Model- Deformed Shape

U
MAG. FACTOR = +1.0E+00

DEFORMED SHAPE

TIME COMPLETED IN THIS STEP +4.170E+02

TOTAL ACCUMULATED TIME +4.170E+02

STEP 1 INCREMENT 417

Figure 4.13 Axisymmetric 4-in. Penetration Model- Hoop Strain

Figure 4.14 Axisymmetric 4-in. Penetration Model- Meridional Strain

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Figure 4.15 Axisymmetric 4-in. Penetration Model- Shear Strain

Figure 4.16 Axisymmetric 4-in. Penetration Model- von Mises Plastic Strain

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Ryz</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	56	Rev. No.	0

Figure 4.17 Strain Concentration for 4 in. Dome Penetration

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Rye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	57	Rev. No.	0

4.3 3-D Combination 4 in. Penetration-Thickness Transition Model Results

The third model combines the effects of both structural discontinuities. The RIKS solution procedure was applied along with the large displacement option. Since ABAQUS only reports global strain components, the principal strain and direction cosines were calculated externally.

The **Principal strains** are calculated by solving the roots of the following:

$$\begin{aligned} \epsilon_n^3 - (\epsilon_{xx} + \epsilon_{yy} + \epsilon_{zz})\epsilon_n^2 \\ + (\epsilon_{xx}\epsilon_{yy} + \epsilon_{yy}\epsilon_{zz} + \epsilon_{zz}\epsilon_{xx} - \gamma_{xy}^2/4 - \gamma_{yz}^2/4 - \gamma_{zx}^2/4)\epsilon_n \\ - (\epsilon_{xx}\epsilon_{yy}\epsilon_{zz} - \epsilon_{xx}\gamma_{yz}^2/4 - \epsilon_{yy}\gamma_{zx}^2/4 - \epsilon_{zz}\gamma_{xy}^2/4 + \gamma_{xy}\gamma_{yz}\gamma_{zx}/4) = 0 \end{aligned}$$

Where, ϵ_n = Principal strains (ϵ_{n1} , ϵ_{n2} , and ϵ_{n3}).
 ϵ_x , ϵ_y , ϵ_z = Cartesian strain components.
 γ_{xy} , γ_{yz} , γ_{zx} = Cartesian shear strain components.

The **Principal directions** (direction cosines for any root) are obtained by solving the following homogeneous linear equations:

$$\begin{aligned} (\epsilon_{xx} - \epsilon_n) \cos(n,x) + \gamma_{yx} \cos(n,y) + \gamma_{zx} \cos(n,z) &= 0 \\ \gamma_{xy} \cos(n,x) + (\epsilon_{yy} - \epsilon_n) \cos(n,y) + \gamma_{zy} \cos(n,z) &= 0 \\ \gamma_{xz} \cos(n,x) + \gamma_{yz} \cos(n,y) + (\epsilon_{zz} - \epsilon_n) \cos(n,z) &= 0 \end{aligned}$$

$$\text{and } \cos^2(n,x) + \cos^2(n,y) + \cos^2(n,z) = 1$$

where, $\cos(n,x)$, $\cos(n,y)$ and $\cos(n,z)$ = direction cosine of the principal strain ϵ_n with respect to global x-axis, y-axis and z-axis, respectively.

The direction cosines for any principal stresses is calculated by solving any two of homogeneous equation listed above and the cosine identity.

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Went Rye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	58	Rev. No.	0

The analysis was terminated at a maximum pressure of 30 psi and a maximum von Mises strain of 10% with direction cosines of $\cos x = 0.132$, $\cos y = -0.193$, $\cos z = 0.972$. The structural integrity of this model is similar to that of the penetration-only model. The one major difference is that the eccentricity caused by the thickness change causes the penetration to rotate as shown in the deformed shape plot in Figure 4.19 (scale factor = 10). The response of the thickness change region adjacent to the penetration is as expected (Figure 4.20), where the thin plate displaces more than the thick plate.

The maximum equivalent plastic strains are concentrated on the 3/8" side of the penetration plate connection as shown in Figure 4.21, where a view is taken of the pressure side of the dome. It is evident from Figure 4.21 that the strain magnitude remains relatively constant at distances greater than a penetration diameter from the center of the penetration. Thus, the far-field strain could be calculated much closer to the penetration. As was the case for the penetration-only model, the shear strains are the major contributors to the large von Mises strains. In consideration of the arguments made in Section 4.2, through-thickness averaging of the peak strains was not judged to be appropriate. The von Mises strain concentration factor is plotted as a function of the far-field strain in Figure 4.22. Four integration points were selected as summarized below.

Element	Integration Point	Relevance
4435	8	Maximum out of plane shear strain and maximum compressive radial strain
4524	1	Large in-plane shear and larger out-of-plane shear than 4524_3.
4524	3	Maximum in-plane shear strain and large out-of-plane shear.
4479	4	Maximum meridional strain and large shear strains

The maximum peak strain occurs at Element 4435 (integration point 8).

Figure 4.19 3-D Combination 4-in. Penetration/Thickness Transition Model at Penetration

Figure 4.20 3-D Combination 4-in. Penetration/Thickness Transition Model at Thickness Transition

Figure 4.21 3-D Combination 4-in. Penetration/Thickness Transition Model- von Mises Plastic Strain

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Rye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	62	Rev. No.	0

Figure 4.22 4 in. Penetration and Thickness Transition
3-D Model

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Dye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	63	Rev. No.	0

5.0 CONCLUSIONS/RECOMMENDATIONS

The relative significance of the 1/2" to 3/8" thickness transition, 4-in. penetration, and combined penetration and thickness transition has been the focus of this effort. It could be misleading to report just the maximum strain concentration factors for each geometry. It is much more important to know the maximum peak strain as a function of far-field strain. Large strain concentration factors at low far-field strains maybe less significant than low strain concentration factors at large far-field strains. The thickness transition is much more of a global discontinuity than the penetration. The attenuation of the peak strain field associated with the penetration is smaller than that associated with the thickness transition. The peak strain is more easily redistributed in the thickness transition model resulting in a smaller difference between the far-field and peak strain than that demonstrated by the penetration-only model. The peak strains associated with the penetration are much more localized.

When these two discontinuities are combined there is some degree of interaction, demonstrated by the response of the 3-D model. In Figure 5.1 the peak strains for each of the discontinuities is plotted as a function of the far-field strain. It is obvious from this figure that the peak strains of the 3-D composite model become excessive at lower far-field strains than for either the penetration-only or thickness transition model. The more localized the discontinuity is, the less tendency there is for stress/strain redistribution. It is not clear from this effort that any general expression can be used reliably to combine strain concentration factors that were derived independently. One unexpected observation was that the strain concentration factors are often sensitive to what is selected as the far-field strain. Even within the three general models developed in this effort, there was no obvious correlation between the far-field strain responses. There is a natural willingness to believe that the far-field response behaves as the free-field would. However, as was noted in Section 4.1, global boundary constraints on a sphere can change the far-field; not unlike a thick plate would provide a connecting thin plate.

In order to make practical use of strain concentrations factors predicted by local models, more detail associated with the actual construction including liner/concrete interaction response must be addressed. As a minimum, the stiffness of the reinforced concrete should be represented, and it would be appropriate to model the stud/liner interface. This is especially true for penetrations where concrete/liner interaction is significant.

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Rye</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	64	Rev. No.	0

Figure 5.1 Comparison of the 4 in. Penetration, Thickness Transition, and 3-D Composite Model

Calculation Sheet

Project	Los Alamos National Laboratory Strain Concentration Development	Prepared By:	<i>Albert Ryz</i>	Date	11/14/92
Subject	Nonlinear Analysis	Reviewed By:		Date	
System	241-SY-101 Dome Discontinuities	Job No.	92007	File No.	92007.1.1
Client Calc. No.	N/A	Sheet No.	65	Rev. No.	0

6.0 REFERENCES

Julyk, L.J., et al., 1991, Structural Integrity Evaluation of Double-Shell Waste Tank 241-SY-101 Under a Postulated Hydrogen Burn, WHC-SD-WM-TM-465, Rev.0.

EPRI, 1989, Criteria and Guidelines for Predicting Concrete Containment Leakage, EPRI NP-6260-M, Interim Report.

Clauss, D.B., 1989, Round-Robin Analyses of the Behavior of a 1:6-Scale Reinforced Concrete Containment Model Pressurized to Failure: Posttest Evaluations, NUREG/CR-5341, SAND89-0349, Sandia National Laboratories, Albuquerque, New Mexico.

axiextrk.inp - axisymmetric thickness transition only model.
axipl.inp - axisymmetric penetration only model.
dload.inp - combined 3-d model with thickness change and penetration.
dome20.inp - model developed to duplicate the WHC thickness change model.
dome.inp - same as dome20 with a automatic time step control.
mesh366.inp - mesh sensitivity model 3 el thru thick and aspect ratio of 6.
mesh466.inp - mesh sensitivity model 4 el thru thick and aspect ratio of 6.
mesh333.inp - mesh sensitivity model 3 el thru thick and aspect ratio of 3.
Any questions can be refered to Albert Dyrness of ADVENT at (510) 743-7777.

FILENAME: dometran.inp

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1010,67.095 ,591.846
1012,69.22 ,591.732
1014,69.72 ,591.704

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1022,70.595 ,591.656
1026,70.72 ,591.650
1034,70.97 ,591.635
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1044,72.22 ,591.564
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DOME-20 MODEL 3/8-1/2 THICKNESS TRANSITION

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FILENAME: dome.inp

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121.0, 0.1924,	126.0, 0.2079,	131.0, 0.2187,	136.0, 0.2291,
141.0, 0.2377,	146.0, 0.2481,	151.0, 0.2566,	156.0, 0.2675,
161.0, 0.2795,	166.0, 0.2959,	171.0, 0.3097,	176.0, 0.3226,
181.0, 0.3330,	186.0, 0.3439,	191.0, 0.3548,	196.0, 0.3542,
201.0, 0.3629,	206.0, 0.3710,	211.0, 0.3777,	216.0, 0.3899,
221.0, 0.4044,	226.0, 0.4221,	231.0, 0.4350,	236.0, 0.4514,
241.0, 0.4585,	246.0, 0.4712,	251.0, 0.4846,	256.0, 0.4994,
261.0, 0.5146,	266.0, 0.5306,	271.0, 0.5472,	276.0, 0.5642,
281.0, 0.5819,	286.0, 0.6000,	291.0, 0.6191,	296.0, 0.6401,

**

*AMPLITUDE, TIME=A, NAME=CUTU2

1.000, -0.1510,	2.000, -1.0552E-02,	3.000, -1.5988E-03,	4.000, 7.3504E-03,
5.000, 1.6296E-02,	6.000, 2.5238E-02,	7.000, 3.4178E-02,	8.000, 4.3121E-02,
9.000, 5.2059E-02,	10.00, 6.1006E-02,	11.00, 7.0077E-02,	12.00, 7.9177E-02,
13.00, 8.8365E-02,	14.00, 9.7632E-02,	15.00, 0.1069,	16.00, 0.1159,
17.00, 0.1311,	18.00, 0.1661,	19.00, 0.2575,	20.00, 0.3289,
21.00, 0.3744,	22.00, 0.4305,	23.00, 0.4807,	24.00, 0.5256,
25.00, 0.5750,	26.00, 0.6318,	27.00, 0.6826,	28.00, 0.7372,
29.00, 0.8055,	30.00, 0.8544,	31.00, 0.9217,	32.00, 0.9863,
33.00, 1.0410,	34.00, 1.0920,	35.00, 1.1440,	36.00, 1.198,
37.00, 1.2520,	38.00, 1.3200,	39.00, 1.3910,	40.00, 1.455,
41.00, 1.5190,	42.00, 1.5700,	43.00, 1.6200,	44.00, 1.666,
45.00, 1.7060,	46.00, 1.7450,	47.00, 1.7830,	48.00, 1.827,
49.00, 1.8750,	50.00, 1.9220,	51.00, 1.9700,	52.00, 2.024,
53.00, 2.0830,	54.00, 2.1650,	55.00, 2.2550,	56.00, 2.363,
58.00, 2.5410,	60.00, 2.7290,	62.00, 2.9740,	64.00, 3.215,
66.00, 3.4400,	68.00, 3.6580,	70.00, 3.8670,	72.00, 4.068,
74.00, 4.2770,	76.00, 4.4760,	78.00, 4.6790,	80.00, 4.961,
82.00, 5.2230,	84.00, 5.4720,	86.00, 5.7480,	88.00, 6.018,
90.00, 6.3020,	92.00, 6.5680,	94.00, 6.8150,	96.00, 7.051,
101.0, 7.2770,	106.0, 7.4900,	111.0, 7.6970,	116.0, 7.965,
121.0, 8.2980,	126.0, 8.5880,	131.0, 8.8740,	136.0, 9.151,
141.0, 9.4340,	146.0, 9.6930,	151.0, 9.9400,	156.0, 10.19,
161.0, 10.450,	166.0, 10.720,	171.0, 10.980,	176.0, 11.23,
181.0, 11.470,	186.0, 11.710,	191.0, 11.940,	196.0, 12.20,
201.0, 12.420,	206.0, 12.630,	211.0, 13.500,	216.0, 13.66,
221.0, 13.810,	226.0, 13.960,	231.0, 14.090,	236.0, 14.27,
241.0, 14.390,	246.0, 14.540,	251.0, 14.690,	256.0, 14.87,
261.0, 15.060,	266.0, 15.280,	271.0, 15.510,	276.0, 15.82,
281.0, 16.130,	286.0, 16.440,	291.0, 16.750,	296.0, 17.11,

**

*AMPLITUDE, TIME=A, NAME=SYMU2

1.000, -0.2993,	2.000, -2.1507E-03,	3.000, -4.1066E-03,	4.000, 1.3279E-02,
5.000, 3.0651E-02,	6.000, 4.8008E-02,	7.000, 6.5351E-02,	8.000, 8.2686E-02,
9.000, 0.1000,	10.00, 0.1173,	11.00, 0.1346,	12.00, 0.1520,
13.00, 0.1693,	14.00, 0.1865,	15.00, 0.2037,	16.00, 0.2474,
17.00, 0.5402,	18.00, 0.8908,	19.00, 0.9916,	20.00, 1.0290,
21.00, 1.0920,	22.00, 1.159,	23.00, 1.229,	24.00, 1.2960,
25.00, 1.3630,	26.00, 1.440,	27.00, 1.515,	28.00, 1.5870,
29.00, 1.6340,	30.00, 1.704,	31.00, 1.790,	32.00, 1.8740,
33.00, 1.9480,	34.00, 2.013,	35.00, 2.082,	36.00, 2.1520,
37.00, 2.2240,	38.00, 2.296,	39.00, 2.375,	40.00, 2.4580,
41.00, 2.5440,	42.00, 2.619,	43.00, 2.686,	44.00, 2.7500,
45.00, 2.8090,	46.00, 2.867,	47.00, 2.924,	48.00, 2.9850,
49.00, 3.0510,	50.00, 3.117,	51.00, 3.183,	52.00, 3.2600,
53.00, 3.3400,	54.00, 3.444,	55.00, 3.556,	56.00, 3.6870,
58.00, 3.8790,	60.00, 4.092,	62.00, 4.363,	64.00, 4.6330,
66.00, 4.8930,	68.00, 5.152,	70.00, 5.412,	72.00, 5.6740,
74.00, 5.9390,	76.00, 6.202,	78.00, 6.471,	80.00, 6.8340,
82.00, 7.1800,	84.00, 7.542,	86.00, 7.919,	88.00, 8.3170,
90.00, 8.7210,	92.00, 9.125,	94.00, 9.501,	96.00, 9.8690,
101.0, 10.230,	106.0, 10.59,	111.0, 10.95,	116.0, 11.390,

FILENAME: dome.inp

121.0,	11.910	,	126.0,	12.39	,	131.0,	12.87	,	136.0,	13.350,
141.0,	13.890	,	146.0,	14.37	,	151.0,	14.88	,	156.0,	15.390,
161.0,	15.880	,	166.0,	16.38	,	171.0,	16.90	,	176.0,	17.420,
181.0,	17.930	,	186.0,	18.45	,	191.0,	18.98	,	196.0,	19.580,
201.0,	20.100	,	206.0,	20.62	,	211.0,	21.81	,	216.0,	22.260,
221.0,	22.740	,	226.0,	23.31	,	231.0,	23.75	,	236.0,	24.250,
241.0,	24.680	,	246.0,	25.12	,	251.0,	25.57	,	256.0,	26.050,
261.0,	26.550	,	266.0,	27.08	,	271.0,	27.62	,	276.0,	28.240,
281.0,	28.850	,	286.0,	29.46	,	291.0,	30.07	,	296.0,	30.720

**

*RESTART,WRITE,FREQ=1001

*STEP,AMPLITUDE=RAMP,CYCL=5,INC=1000,NLGEOM

FIRST STEP

*STATIC,PTOL=1000.

.1,1.

*DLOAD,AMPLITUDE=DEAD

EALL,BZ,-.2827

*BOUNDARY,AMPLITUDE=CUTU1

FARIGHT,1,1,1.

*BOUNDARY,AMPLITUDE=CUTU2

FARIGHT,2,2,1.

*BOUNDARY,AMPLITUDE=SYMU2

FARLEFT,2,2,1.

*BOUNDARY

FARLEFT,1,1,0.

*EL FILE,ELSET=EALL,FREQ=20

S

E

PE

SINV

LOADS

*NODE FILE,NSET=NALL,FREQ=20

U

RF

*EL PRINT,ELSET=EALL,FREQ=100

E

*NODE PRINT,NSET=FARIGHT,FREQ=20,GLOBAL=YES,TOTALS=YES

U

RF

*NODE PRINT,NSET=FARLEFT,FREQ=20,GLOBAL=YES,TOTALS=YES

U

RF

*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=20

DISPLACED SHAPE

,,6.,6.,4.,,1.5,1.5,7.5

.12,.25,7.5

*DETAIL,ELSET=FOCUS

*DISPLACED

U

*END STEP

*STEP,AMPLITUDE=RAMP,CYCL=8,INC=1000,NLGEOM

SECOND STEP

*STATIC,PTOL=1000.

1.,55.,.001,1.

*DLOAD,AMPLITUDE=LIVE

EBOT,P1,1.0

*BOUNDARY,AMPLITUDE=CUTU1

FARIGHT,1,1,1.

*BOUNDARY,AMPLITUDE=CUTU2

FARIGHT,2,2,1.

*BOUNDARY,AMPLITUDE=SYMU2

FARLEFT,2,2,1.

*BOUNDARY

FARLEFT,1,1,0.

*EL FILE,ELSET=EALL,FREQ=2

S

E

PE

SINV

LOADS

FILENAME: dome.inp

```

*NODE FILE,NSET=NALL,FREQ=2
U
RF
*EL PRINT,ELSET=EALL,FREQ=100
E
*NODE PRINT,NSET=FARIGHT,FREQ=2,GLOBAL=YES,TOTALS=YES
U,RF
*NODE PRINT,NSET=FARLEFT,FREQ=2,GLOBAL=YES,TOTALS=YES
U
RF
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=20
EQUIVELENT PLASTIC STRAIN
15,,9,9,5,1,.1,.1
.3
*DETAIL,ELSET=FOCUS
*CONTOUR,FACTOR=.01
PEEQ,6
*END STEP
*STEP,AMPLITUDE=RAMP,CYCL=8,INC=2000,NLGEOM
THIRD STEP
*STATIC,PTOL=1000.
1.,40.,.001,1.
*DLOAD,AMPLITUDE=LIVE
EBOT,P1,1.0
*BOUNDARY,AMPLITUDE=CUTU1
FARIGHT,1,1,1.
*BOUNDARY,AMPLITUDE=CUTU2
FARIGHT,2,2,1.
*BOUNDARY,AMPLITUDE=SYMU2
FARLEFT,2,2,1.
*BOUNDARY
FARLEFT,1,1,0.
*EL FILE,ELSET=EALL,FREQ=2
S
E
PE
SINV
LOADS
*NODE FILE,NSET=NALL,FREQ=2
U
RF
*EL PRINT,ELSET=EALL,FREQ=100
E
*NODE PRINT,NSET=FARIGHT,FREQ=2,GLOBAL=YES,TOTALS=YES
U,RF
*NODE PRINT,NSET=FARLEFT,FREQ=2,GLOBAL=YES,TOTALS=YES
U
RF
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=20
EQUIVELENT PLASTIC STRAIN
15,,9,9,5,1,.1,.1
.3
*DETAIL,ELSET=FOCUS
*CONTOUR,FACTOR=.01
PEEQ,6
*END STEP
*STEP,AMPLITUDE=RAMP,CYCL=10,INC=1000,NLGEOM
FOURTH STEP
*STATIC,PTOL=1000.
0.5,200.,.001,1.
*DLOAD,AMPLITUDE=LIVE
EBOT,P1,1.0
*BOUNDARY,AMPLITUDE=CUTU1
FARIGHT,1,1,1.
*BOUNDARY,AMPLITUDE=CUTU2
FARIGHT,2,2,1.
*BOUNDARY,AMPLITUDE=SYMU2
FARLEFT,2,2,1.
*BOUNDARY
FARLEFT,1,1,0.

```

FILENAME: dome.inp

```
*EL FILE,ELSET=EALL,FREQ=2
S
E
PE
SINV
LOADS
*NODE FILE,NSET=NALL,FREQ=2
U
RF
*EL PRINT,ELSET=EALL,FREQ=100
E
*NODE PRINT,NSET=FARIGHT,FREQ=2,GLOBAL=YES,TOTALS=YES
U,RF
*NODE PRINT,NSET=FARLEFT,FREQ=2,GLOBAL=YES,TOTALS=YES
U
RF
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=20
EQUIVALENT PLASTIC STRAIN
15,,9,9,5,1,.1,.1
.3
*DETAIL,ELSET=FOCUS
*CONTOUR,FACTOR=.01
PEEQ,6
*END STEP
```


FILENAME: dload.inp

*HEADING
TANK DOME AND PIPE PENETRATION MODEL INCLUDING DOME THICKNESS TRANSITION

**

*NODE,NSET=DOMBOT,SYSTEM=S

101,1200.,0.,87.133766
122,1200.,0.,86.715984
150,1200.,0.,86.40439
171,1200.,0.,85.986609
1171,1200.,1.3658,85.986609
1101,1200.,1.4341659,87.133765

**

141,1200.0,0.000000,86.452558
241,1200.0,0.136236,86.452879
341,1200.0,0.271706,86.453843
441,1200.0,0.405649,86.455443
541,1200.0,0.537308,86.457670
641,1200.0,0.665935,86.460511
741,1200.0,0.790796,86.463952
841,1200.0,0.911173,86.467971
941,1200.0,1.026365,86.472547
1041,1200.0,1.135693,86.477653
1141,1200.0,1.238505,86.483260

**

131,1200.0,0.000000,86.667805
231,1200.0,0.144997,86.667462
331,1200.0,0.289013,86.666437
431,1200.0,0.431073,86.664737
531,1200.0,0.570222,86.662372
631,1200.0,0.705527,86.659360
731,1200.0,0.836089,86.655719
831,1200.0,0.961050,86.651475
931,1200.0,1.079595,86.646657
1031,1200.0,1.190965,86.641295
1131,1200.0,1.294458,86.635426

**

3004,1200.0,1.389434,86.629088
3104,1200.0,1.475318,86.622324
3204,1200.0,1.551608,86.615176
3304,1200.0,1.617870,86.607692
3404,1200.0,1.673745,86.599920
3504,1200.0,1.718949,86.591909
3604,1200.0,1.753269,86.583710

**

3704,1200.0,1.766862,86.579354
3804,1200.0,1.778996,86.574174
3904,1200.0,1.786880,86.568964
4004,1200.0,1.790515,86.563737
4104,1200.0,1.789911,86.558506
4204,1200.0,1.785089,86.553283
4304,1200.0,1.776079,86.548080
4404,1200.0,1.762922,86.542909
4504,1200.0,1.745666,86.537783

**

4604,1200.0,1.727889,86.533485
4704,1200.0,1.686086,86.525423
4804,1200.0,1.634208,86.517582
4904,1200.0,1.572629,86.510010
5004,1200.0,1.501776,86.502750
5104,1200.0,1.422120,86.495845
5204,1200.0,1.334178,86.489336

**

*NODE,NSET=XPOINT,SYSTEM=RC

2,0.,0.,1198.4988
3,0.,0.,1197.0573

**

*NGEN,NSET=DOMBOT,SYSTEM=S

101,122,1
150,171,1

**

*NGEN,NSET=DOMBOT,SYSTEM=S,LINE=C

FILENAME: dload.inp

```
101,1101,100,2
171,1171,100,3
**
**
*SYSTEM
0.,0.,0.,1.,0.,-0.06009
0.,1.,0.
**
*NODE,NSET=XPOINT,SYSTEM=RC
1,0.,0.,1199.997
**
*NODE,NSET=DOBOT,SYSTEM=S
123,1200.,180.,89.85614
127,1200.,180.,89.881255
145,1200., 0.,89.881255
149,1200., 0.,89.85614
1123,1200.,145.53104,89.85614
1127,1200.,135.,89.881255
1145,1200., 45.,89.881255
1149,1200.,36.087068,89.85614
**
**
*NGEN,NSET=DOBOT,SYSTEM=S
123,127,1
127,131,1
1123,1127,1
1127,1131,1
**
141,145,1
145,149,1
1141,1145,1
1145,1149,1
**
**
*NGEN,NSET=DOBOT,SYSTEM=S,LINE=C
123,1123,100,1
124,1124,100,1
125,1125,100,1
126,1126,100,1
127,1127,100,1
128,1128,100,1
129,1129,100,1
130,1130,100,1
**
142,1142,100,1
143,1143,100,1
144,1144,100,1
145,1145,100,1
146,1146,100,1
147,1147,100,1
148,1148,100,1
149,1149,100,1
**
**
*SYSTEM
*NGEN,NSET=DOBOT,SYSTEM=S
249,271,1
349,371,1
449,471,1
549,571,1
649,671,1
749,771,1
849,871,1
949,971,1
1049,1071,1
1149,1171,1
**
201,223,1
301,323,1
401,423,1
```

FILENAME: dload.inp

501,523,1
601,623,1
701,723,1
801,823,1
901,923,1
1001,1023,1
1101,1123,1

**

**

*SYSTEM

0.,0.,0.,1.,0.,-0.06009

0.,1.,0.

**

**

*NODE,NSET=DOMBOT1,SYSTEM=S

3008,1200.,130.5,89.881255

3608,1200.,103.5,89.881255

**

3708,1200.,100.131900,89.881255

4508,1200.,79.868104,89.881255

**

4608,1200.,76.5,89.881255

5208,1200.,49.5,89.881255

**

*NGEN,NSET=DOMBOT1,SYSTEM=S,LINE=C

3008,3608,100,1

3708,4508,100,1

4608,5208,100,1

**

**

*NGEN,NSET=DOMBOT1,SYSTEM=S

3004,3008,1

3604,3608,1

4604,4608,1

5204,5208,1

**

3704,3708,1

4504,4508,1

**

**

*NGEN,NSET=DOMBOT1,SYSTEM=S,LINE=C

3005,3605,100,1

3006,3606,100,1

3007,3607,100,1

**

3705,4505,100,1

3706,4506,100,1

3707,4507,100,1

**

4605,5205,100,1

4606,5206,100,1

4607,5207,100,1

**

**

**

*SYSTEM

**

*NODE,NSET=XPOINT,SYSTEM=RC

4,0.,0.,1197.9846

5,0.,0.,1197.9423

6,0.,0.,1197.8643

7,0.,0.,1197.8117

8,0.,0.,1197.7313

9,0.,0.,1197.6896

**

**

*NODE,NSET=DOMBOT1,SYSTEM=S

1501,1200.,2.25,87.133765

1523,1200.,2.25,86.678857

FILENAME: dload.inp

```
1527,1200.,2.25,86.644129
**
3712,1200.,2.25,86.581114
4512,1200.,2.25,86.53926
**
1545,1200.,2.25,86.476287
1549,1200.,2.25,86.443987
1571,1200.,2.25,85.986609
**
** FOLLOWING TWO DUMMY NODES ARE AT THE SAME LOCATIONS OF 1527 AND 1545.
** THEY ARE DEFINED TO GENERATE THE NODES BETWEEN THEM.
**
2912,1200.,2.25,86.644129
5312,1200.,2.25,86.476287
**
*NGEN,NSET=DOMBOT1,SYSTEM=S,LINE=C
1101,1501,100,2
1123,1523,100,4
1127,1527,100,5
**
1145,1545,100,8
1149,1549,100,9
1171,1571,100,3
**
**
*NGEN,NSET=DOMBOT1,SYSTEM=S
3708,3712,1
4508,4512,1
**
1201,1223,1
1223,1227,1
1301,1323,1
1323,1327,1
1401,1423,1
1423,1427,1
**
1501,1523,1
1523,1527,1
**
2912,3712,100
3712,4512,100
4512,5312,100
**
1245,1249,1
1249,1271,1
1345,1349,1
1349,1371,1
1445,1449,1
1449,1471,1
1545,1549,1
1549,1571,1
**
**
*NGEN,NSET=DOMBOT1,SYSTEM=S,LINE=C
3008,3012,1,5
5208,5212,1,8
**
**
*NGEN,NSET=DOMBOT1,SYSTEM=S
**
3009,3709,100
3709,4509,100
4509,5209,100
**
3010,3710,100
3710,4510,100
4510,5210,100
**
3011,3711,100
3711,4511,100
```

FILENAME: dload.inp

4511,5211,100

**

**

** -----

**

** NODE SETS BOTMIDA THROUGH BOTMIDG CONTAINS THE BOTTOM NODES AT
 ** THICKNESS TRANSITION.

**

*NSET,NSET=BOTMIDA,GENERATE

3804,3812,1

*NSET,NSET=BOTMIDB,GENERATE

3904,3912,1

*NSET,NSET=BOTMIDC,GENERATE

4004,4012,1

*NSET,NSET=BOTMIDD,GENERATE

4104,4112,1

*NSET,NSET=BOTMIDE,GENERATE

4204,4212,1

*NSET,NSET=BOTMIDF,GENERATE

4304,4312,1

*NSET,NSET=BOTMIDG,GENERATE

4404,4412,1

**

**

** GENERATING THE TOP NODES AT THICKNESS TRANSITION

** (NODE SETS TOPMIDA THRU TOPMIDG)

**

*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BOTMIDA,NEWSET=TOPMIDA

0.,0.,0.484375

0.,0.,0.,0.,0.,1.0

*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BOTMIDB,NEWSET=TOPMIDB

0.,0.,0.46875

0.,0.,0.,0.,0.,1.0

*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BOTMIDC,NEWSET=TOPMIDC

0.,0.,0.453125

0.,0.,0.,0.,0.,1.0

*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BOTMIDD,NEWSET=TOPMIDD

0.,0.,0.4375

0.,0.,0.,0.,0.,1.0

*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BOTMIDE,NEWSET=TOPMIDE

0.,0.,0.421875

0.,0.,0.,0.,0.,1.0

*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BOTMIDF,NEWSET=TOPMIDF

0.,0.,0.40625

0.,0.,0.,0.,0.,1.0

*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BOTMIDG,NEWSET=TOPMIDG

0.,0.,0.390625

0.,0.,0.,0.,0.,1.0

**

**

*NFILL,NSET=TRANS

** ALL NODES AT THICKNESS TRANSITION

BOTMIDA,TOPMIDA,6,10000

BOTMIDB,TOPMIDB,6,10000

BOTMIDC,TOPMIDC,6,10000

BOTMIDD,TOPMIDD,6,10000

BOTMIDE,TOPMIDE,6,10000

BOTMIDF,TOPMIDF,6,10000

BOTMIDG,TOPMIDG,6,10000

**

**

*NSET,NSET=LBOTPL,GENERATE

**

** BOTTOM NODES OF 0.5" PLATE

**

101,131,1

201,231,1

301,331,1

401,431,1

501,531,1

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601,631,1
701,731,1
801,831,1
901,931,1
1001,1031,1
1101,1131,1

**

1201,1227,1
1301,1327,1
1401,1427,1
1501,1527,1

**

3004,3012,1
3104,3112,1
3204,3212,1
3304,3312,1
3404,3412,1
3504,3512,1
3604,3612,1
3704,3712,1

**

**

*NSET,NSET=RBOTPL,GENERATE

**

** BOTTOM NODES OF 0.375" PLATE

**

141,171,1
241,271,1
341,371,1
441,471,1
541,571,1
641,671,1
741,771,1
841,871,1
941,971,1
1041,1071,1
1141,1171,1

**

1245,1271,1
1345,1371,1
1445,1471,1
1545,1571,1

**

4504,4512,1
4604,4612,1
4704,4712,1
4804,4812,1
4904,4912,1
5004,5012,1
5104,5112,1
5204,5212,1

**

**

*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=LBOTPL,NEWSET=LTOPPL

**

**

** TOP NODES OF 0.5" PLATE

**

0.,0.,0.5
0.,0.,0.,0.,0.,1.0,0.

**

*NODE,NSET=XPOINT,SYSTEM=RC

22,0.,0.,1198.9982

**

*NODE,NSET=LTOPPL,SYSTEM=S

60101,1200.5,0.,87.133766

61101,1200.5,1.4341659,87.133765

61501,1200.5,2.25,87.133765

**

*NGEN,NSET=LTOPPL,SYSTEM=S,LINE=C

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```

60101,61101,100,22
61101,61501,100,22
**
*NFILL,NSET=THICKPL
**
** GENERATING NODES BETWEEN TOP AND BOTTOM LAYER FOR 0.5" PLATE
**
LBOTPL,LTOPPL,6,10000
**
**
*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=RBOTPL,NEWSET=RTOPPL
**
** TOP NODES OF 0.375" PLATE
**
0.,0.,0.375
0.,0.,0.,0.,0.,1.0,0.
**
*NODE,NSET=XPOINT,SYSTEM=RC
23,0.,0.,1197.4313
**
*NODE,NSET=RTOPPL,SYSTEM=S
60171,1200.375,0.,85.986609
61171,1200.375,1.3658,85.986609
61571,1200.375,2.25,85.986609
**
*NGEN,NSET=LTOPPL,SYSTEM=S,LINE=C
60171,61171,100,23
61171,61571,100,23
**
*NFILL,NSET=THINPL
**
RBOTPL,RTOPPL,6,10000
**
** *****
** EXTENDING THE MODEL FROM TETA=2.25 DEGREES TO TETA=6.25 DEGREES
** *****
*NSET,NSET=LR1,GENERATE
  1501, 1527,1
11501,11527,1
21501,21527,1
31501,31527,1
41501,41527,1
51501,51527,1
61501,61527,1
**
  1529, 1571,1
11529,11571,1
21529,21571,1
31529,31571,1
41529,41571,1
51529,51571,1
61529,61571,1
**
**
*NSET,NSET=M1,GENERATE
  3012, 5212,100
13112,15112,100
23012,25212,100
33112,35112,100
43012,45212,100
53112,55112,100
63012,65212,100
**
**
*NCOPY,CHANGE NUMBER=100,OLDSET=LR1,NEWSET=LR2,SHIFT,MULTIPLE=8
0.,0.,0.
0.,0.,0.,0.,0.,1300.0,0.5
**
*NCOPY,CHANGE NUMBER=1,OLDSET=M1,NEWSET=M2,SHIFT,MULTIPLE=8
0.,0.,0.

```

FILENAME: dload.inp

0.,0.,0.,0.,0.,1300.0,0.5

**

**

**

*ELEMENT,TYPE=C3D20R,ELSET=DOME1

**

** 20 NODE, QUADRATIC DISPLACEMENT BRICK (0.5" PLATE)

** DEFINE NODAL CONNECTIVITY IN FREE FORMAT (1615 PER LINE)

**

1001,101,103,303,301,20101,20103,20303,20301,102,203,302,201,20102,20203,20302,
20201,10101,10103,10303,10301

**

1076,141,143,343,341,20141,20143,20343,20341,142,243,342,241,20142,20243,20342,
20241,10141,10143,10343,10341

**

*ELGEN,ELSET=DOME1

1001,15,2,1,5,200,15,3,20000,500

1076,15,2,1,5,200,15,3,20000,500

**

**

*ELEMENT,TYPE=C3D20R,ELSET=DOME2

** FIXED FORMAT (1615)

1151 1131 3104 3106 112921131231042310621129 3004 3105 3006 1130230042310523006
2113011131131041310611129

**

1152 3104 3304 3306 310623104233042330623106 3204 3305 3206 3105232042330523206
23105,13104,13304,13306,13106

**

1162 5104 1141 1143 510625104211412114325106 5204 1142 5206 5105252042114225206
25105,15104,11141,11143,15106

**

1163 1129 3106 3108 112721129231062310821127 3006 3107 3008 1128230062310723008
21128,11129,13106,13108,11127

**

1174 5106 1143 1145 510825106211432114525108 5206 1144 5208 5107252062114425208
25107,15106,11143,11145,15108

**

*ELGEN,ELSET=DOME2

1152,10,200,1,2,2,12,3,20000,500

**

**

**

*ELEMENT,TYPE=C3D20R,ELSET=DOME3

**

1175 1101 1103 1303 130121101211032130321301 1102 1203 1302 1201211022120321302
21201,11101,11103,11303,11301

**

1189 3108 3308 3310 311023108233082331023110 3208 3309 3210 3109232082330923210
23109,13108,13308,13310,13110

**

1200 1145 1147 1347 134521145211472134721345 1146 1247 1346 1245211462124721346
21245,11145,11147,11347,11345

**

**

1188 1127 3108 3110 132721127231082311021327 3008 3109 3010 1227230082310923010
21227,11127,13108,13110,113271226 1327 3110 3112 152721327231102311221527 3010 3111 3012 1427230102311123012
21427,11327,13110,13112,115271264 1527 3112 3114 172721527231122311421727 3012 3113 3014 1627230122311323014
21627,11527,13112,13114,117271302 1727 3114 3116 192721727231142311621927 3014 3115 3016 1827230142311523016
21827,11727,13114,13116,119271340 1927 3116 3118 212721927231162311822127 3016 3117 3018 2027230162311723018
22027,11927,13116,13118,121271378 2127 3118 3120 232722127231182312022327 3018 3119 3020 2227230182311923020
22227,12127,13118,13120,12327

**

1199 5108 1145 1345 511025108211452134525110 5208 1245 5210 5109252082124525210
25109,15108,11145,11345,15110

1237 5110 1345 1545 511225110213452154525112 5210 1445 5212 5111252102144525212

FILENAME: dload.inp

```

25111,15110,11345,11545,15112
1275 5112 1545 1745 511425112215452174525114 5212 1645 5214 5113252122164525214
25113,15112,11545,11745,15114
1313 5114 1745 1945 511625114217452194525116 5214 1845 5216 5115252142184525216
25115,15114,11745,11945,15116
1351 5116 1945 2145 511825116219452214525118 5216 2045 5218 5117252162204525218
25117,15116,11945,12145,15118
1389 5118 2145 2345 512025118221452234525120 5218 2245 5220 5119252182224525220
25119,15118,12145,12345,15120
**
**
*ELSET,ELSET=XELEM1,GENERATE
1188,1378,38
1199,1389,38
**
*ELCOPY,OLDSET=XELEM1,NEWSET=XELEM2,ELEMENT SHIFT=500,SHIFT NODES=20000
*ELCOPY,OLDSET=XELEM2,NEWSET=XELEM3,ELEMENT SHIFT=500,SHIFT NODES=20000
**
**
*ELGEN,ELSET=DOME3
1175,13, 2,1,6,200,38,3,20000,500
1189,10,200,1,6, 2,38,3,20000,500
1200,13, 2,1,6,200,38,3,20000,500
**
*ELSET,ELSET=DOME
DOME1,DOME2,DOME3,XELEM1,XELEM2,XELEM3
**
**
*MATERIAL,NAME=STEEL
*DENSITY
.0007324
*ELASTIC
29.0E6,0.30
*PLASTIC
44066.,0.
44541.,.008461
57770.,.056515
66330.,.093439
74750.,.137833
*SOLID SECTION,MATERIAL=STEEL,ELSET=DOME
**
** #####
** PIPE MODEL
** #####
*SYSTEM
72.0,0.,1197.8381,73.0,0.0,1198.8381
**
*NODE,NSET=XPOINT
10,0.,0.,-6.0
** =====
** NODES OF PIPE EXTENDED BELOW THE DOME
** =====
*NODE,NSET=PBIN,SYSTEM=C
6001,2.013,180.0 , -6.0
6018,2.013,103.5 , -6.0
6019,2.013,101.141, -6.0
6027,2.013, 78.859, -6.0
6028,2.013, 76.5 , -6.0
6045,2.013, 0.0 , -6.0
**
*NGEN,NSET=PBIN,SYSTEM=C,LINE=C
6001,6018,1,10
6019,6027,1,10
6028,6045,1,10
**
*NODE,NSET=PBOUT,SYSTEM=C
6201,2.25,180.0 , -6.0
6218,2.25,103.5 , -6.0
6219,2.25,101.141, -6.0
6227,2.25, 78.859, -6.0

```

FILENAME: dload.inp

```

6228,2.25, 76.5 , -6.0
6245,2.25, 0.0 , -6.0
**
*NGEN,NSET=PBOUT,SYSTEM=C,LINE=C
6201,6218,1,10
6219,6227,1,10
6228,6245,1,10
**
**
*NFILL,NSET=PB
PBIN,PBOUT,4,50
**
**
*NCOPY,CHANGE NUMBER=2000,SHIFT,OLDSET=PB,NEWSET=PB1
0.,0.,4.5
0.,0.,0.,0.,1.0,0.
**
*NFILL,NSET=PIPEBOT
PB,PB1,8,250
**
*NCOPY,CHANGE NUMBER=1000,SHIFT,OLDSET=PB1,NEWSET=PB2
0.,0.,0.75
0.,0.,0.,0.,1.0,0.
**
*NFILL,NSET=PIPEBOT
PB1,PB2,4,250
**
*NCOPY,CHANGE NUMBER=750,SHIFT,OLDSET=PB2,NEWSET=PB3
0.,0.,0.5
0.,0.,0.,0.,1.0,0.
**
*NFILL,NSET=PIPEBOT
PB2,PB3,3,250
**
** =====
** NODES OF PIPE EXTENDED TOP THE DOME
** =====
*NODE,NSET=XPOINT
12,0.,0.,0.75
13,0.,0.,0.625
14,0.,0.,0.5
**
*NODE,NSET=PTIN,SYSTEM=C
66001,2.013,180.0,0.75
66017,2.013,108.0,0.75
**
66018,2.013,103.5 ,0.6875
**
66019,2.013,101.141,0.625
66027,2.013, 78.859,0.625
**
66028,2.013, 76.5 ,0.5625
**
66029,2.013,72.0,0.5
66045,2.013, 0.0,0.5
**
*NGEN,NSET=PTIN,SYSTEM=C,LINE=C
66001,66017,1,12
66019,66027,1,13
66029,66045,1,14
**
*NODE,NSET=PTOUT,SYSTEM=C
66201,2.25,180.0,0.75
66217,2.25,108.0,0.75
**
66218,2.25,103.5 ,0.6875
**
66219,2.25,101.141,0.625
66227,2.25, 78.859,0.625
**

```

FILENAME: dload.inp

```

66228,2.25, 76.5 ,0.5625
**
66229,2.25,72.0,0.5
66245,2.25, 0.0,0.5
**
*NGEN,NSET=PTOUT,SYSTEM=C,LINE=C
66201,66217,1,12
66219,66227,1,12
66229,66245,1,12
**
**
*NFILL,NSET=PT
PTIN,PTOUT,4,50
**
**
*NCOPY,CHANGE NUMBER=750,SHIFT,OLDSET=PT,NEWSET=PT1
0.,0.,0.375
0.,0.,0.,0.,1.0,0.
**
*NFILL,NSET=PIPETOP
PT,PT1,3,250
**
*NCOPY,CHANGE NUMBER=1000,SHIFT,OLDSET=PT1,NEWSET=PT2
0.,0.,1.0
0.,0.,0.,0.,1.0,0.
**
*NFILL,NSET=PIPETOP
PT1,PT2,4,250
**
*NCOPY,CHANGE NUMBER=2000,SHIFT,OLDSET=PT2,NEWSET=PT3
0.,0.,4.5
0.,0.,0.,0.,1.0,0.
**
*NFILL,NSET=PIPETOP
PT2,PT3,8,250
**
**
** =====
** ELEMENT GENERATION
** =====
*ELEMENT,TYPE=C3D20R,ELSET=PIPEBOT
4001,6101,6001,6003,6103,6601,6501,6503,6603,6051,6002,6053,6102,6551,6502,6553,
6602,6351,6251,6253,6353
**
*ELGEN,ELSET=PIPEBOT
4001,22,2,1,2,100,22,7,500,44
**
**
*ELGEN,ELSET=PIPETOP
** GEN. ELEM. NO. 4529
4001,2,60250,528,
4529,22,2,1,2,100,22,7,500,44
**
** ++++++
*SYSTEM
72.0,0.,1197.8381,73.0,0.0,1198.8381
**
** =====
** NODES OF PIPE AT INTERSECTION OF DOME
** =====
*NODE,NSET=PMIN,SYSTEM=C
11,0.,0.,0.
135,2.013,180.0 ,0.
1135,2.013,135.0 ,0.
3000,2.013,130.5 ,0.
3600,2.013,103.5 ,0.
3700,2.013,101.141,0.
4500,2.013, 78.859,0.
4600,2.013, 76.5 ,0.
5200,2.013, 49.5 ,0.

```

FILENAME: dload.inp

1137,2.013, 45.0 ,0.
 137,2.013, 0.0 ,0.

**

**

** PIPE NODES AT DOME THICKNESS 0.5"

**

*NGEN,NSET=PMINL,SYSTEM=C,LINE=C

135,1135,100,11

*NGEN,NSET=PMINCL,SYSTEM=C,LINE=C

3000,3600,100,11

**

**

*NSET,NSET=ML1,GENERATE

131,1131,100

*NSET,NSET=ML2,GENERATE

3004,3604,100

**

**

*NFILL,NSET=PMIDL

ML1,PMINL,4,1

**

*NFILL,NSET=PMIDL

PMINCL,ML2,4,1

**

**

*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=PMIDL,NEWSET=PMIDLT

0.,0.,0.5

0.,0.,0.,0.,0.,1.0,0.

**

*NFILL,NSET=PMID

PMIDL,PMIDLT,6,10000

**

**

** PIPE NODES AT DOME THICKNESS 0.375"

**

*NGEN,NSET=PMINR,SYSTEM=C,LINE=C

4600,5200,100,11

137,1137,100,11

**

**

*NSET,NSET=MR,GENERATE

4604,5204,100

141,1141,100

**

**

*NFILL,NSET=PMIDR

PMINR,MR,4,1

**

*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=PMIDR,NEWSET=PMIDRT

0.,0.,0.375

0.,0.,0.,0.,0.,1.0,0.

**

*NFILL,NSET=PMID

PMIDR,PMIDRT,6,10000

**

**

** PIPE NODES AT DOME THICKNESS TRANSITION

**

*NGEN,NSET=PMINC,SYSTEM=C,LINE=C

3700,4500,100,11

**

**

*NSET,NSET=MC,GENERATE

3704,4504,100

**

**

*NFILL,NSET=PTRANS

PMINC,MC,4,1

**

** NODE SETS BMA THROUGH BMI CONTAINS BOTTOM NODES AT

FILENAME: dload.inp

** THICKNESS TRANSITION.
**

*NSET,NSET=BMA,GENERATE
3700,3704,1
*NSET,NSET=BMB,GENERATE
3800,3804,1
*NSET,NSET=BMC,GENERATE
3900,3904,1
*NSET,NSET=BMD,GENERATE
4000,4004,1
*NSET,NSET=BME,GENERATE
4100,4104,1
*NSET,NSET=BMF,GENERATE
4200,4204,1
*NSET,NSET=BMG,GENERATE
4300,4304,1
*NSET,NSET=BMH,GENERATE
4400,4404,1
*NSET,NSET=BMI,GENERATE
4500,4504,1
**
**

** GENERATING TOP NODES AT THICKNESS TRANSITION
** (NODE SETS TMA THRU TMI)
**

*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BMA,NEWSET=TMA
0.,0.,0.5
0.,0.,0.,0.,0.,1.0,0.
*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BMB,NEWSET=TMB
0.,0.,0.484375
0.,0.,0.,0.,0.,1.0
*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BMC,NEWSET=TMC
0.,0.,0.46875
0.,0.,0.,0.,0.,1.0
*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BMD,NEWSET=TMD
0.,0.,0.453125
0.,0.,0.,0.,0.,1.0
*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BME,NEWSET=TME
0.,0.,0.4375
0.,0.,0.,0.,0.,1.0
*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BMF,NEWSET=TMF
0.,0.,0.421875
0.,0.,0.,0.,0.,1.0
*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BMG,NEWSET=TMG
0.,0.,0.40625
0.,0.,0.,0.,0.,1.0
*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BMH,NEWSET=TMH
0.,0.,0.390625
0.,0.,0.,0.,0.,1.0
*NCOPY,CHANGE NUMBER=60000,SHIFT,OLDSET=BMI,NEWSET=TMI
0.,0.,0.375
0.,0.,0.,0.,0.,1.0
**

*NFILL,NSET=PTRANS
BMA,TMA,6,10000
BMB,TMB,6,10000
BMC,TMC,6,10000
BMD,TMD,6,10000
BME,TME,6,10000
BMF,TMF,6,10000
BMG,TMG,6,10000
BMH,TMH,6,10000
BMI,TMI,6,10000
**
**

** =====
** ELEMENT GENERATION
** =====

*ELEMENT,TYPE=C3D20R,ELSET=PIPEMID
** FIXED FORMAT (1615)

FILENAME: dload.inp

```

**
4353,133,135,335,333,20133,20135,20335,20333,134,235,334,233,20134,20235,20334,
20233,10133,10135,10335,10333
**
4358 1135 3100 3102 113321135231002310221133 3000 3101 3002 1134230002310123002
21134,11135,13100,13102,11133
**
4359 3100 3300 3302 310223100233002330223102 3200 3301 3202 3101232002330123202
23101,13100,13300,13302,13102
**
4369 5100 1137 1139 510225100211372113925102 5200 1138 5202 5101252002113825202
25101,15100,11137,11139,15102
**
4380 1133 3102 3104 113121133231022310421131 3002 3103 3004 1132230022310323004
21132,11133,13102,13104,11131
**
4391 5102 1139 1141 510425102211392114125104 5202 1140 5204 5103252022114025204
25103,15102,11139,11141,15104
**
4374,137,139,339,337,20137,20139,20339,20337,138,239,338,237,20138,20239,20338,
20237,10137,10139,10339,10337
**
*ELGEN,ELSET=PIPEMID
4353,5,200,1,2,-2,22,3,20000,44
4374,5,200,-1,2,2,22,3,20000,44
**
4358,3,20000,44,
4380,3,20000,44,
4359,10,200,1,2,2,22,3,20000,44
4369,3,20000,44,
4391,3,20000,44,
**
** =====
** INTERSECTION PIPE ELEMENTS BETWEEN PIPE AT DOME AND THE PIPE BELOW THE DOME
** ELEMENT NOS. 4309 THROUGH 4352
** ELEMENT CONNECTIVITY IS INPUT IN FREE FORMAT
** =====
*ELEMENT,TYPE=C3D20R,ELSET=PIPEDOME
4309,9601,9501,9503,9603, 133, 135, 335, 333,9551,9502,9553,9602, 134, 235, 334
233,9851,9751,9753,9853
4310,9603,9503,9505,9605, 333, 335, 535, 533,9553,9504,9555,9604, 334, 435, 534
433,9853,9753,9755,9855
4311,9605,9505,9507,9607, 533, 535, 735, 733,9555,9506,9557,9606, 534, 635, 734
633,9855,9755,9757,9857
4312,9607,9507,9509,9609, 733, 735, 935, 933,9557,9508,9559,9608, 734, 835, 934
833,9857,9757,9759,9859
4313,9609,9509,9511,9611, 933, 935,1135,1133,9559,9510,9561,9610, 934,1035,1134
1033,9859,9759,9761,9861
**
4314,9611,9511,9513,9613,1133,1135,3100,3102,9561,9512,9563,9612,1134,3000,3101
3002,9861,9761,9763,9863
**
4315,9613,9513,9515,9615,3102,3100,3300,3302,9563,9514,9565,9614,3101,3200,3301
3202,9863,9763,9765,9865
4316,9615,9515,9517,9617,3302,3300,3500,3502,9565,9516,9567,9616,3301,3400,3501
3402,9865,9765,9767,9867
4317,9617,9517,9519,9619,3502,3500,3700,3702,9567,9518,9569,9618,3501,3600,3701
3602,9867,9767,9769,9869
4318,9619,9519,9521,9621,3702,3700,3900,3902,9569,9520,9571,9620,3701,3800,3901
3802,9869,9769,9771,9871
4319,9621,9521,9523,9623,3902,3900,4100,4102,9571,9522,9573,9622,3901,4000,4101
4002,9871,9771,9773,9873
4320,9623,9523,9525,9625,4102,4100,4300,4302,9573,9524,9575,9624,4101,4200,4301
4202,9873,9773,9775,9875
4321,9625,9525,9527,9627,4302,4300,4500,4502,9575,9526,9577,9626,4301,4400,4501
4402,9875,9775,9777,9877
4322,9627,9527,9529,9629,4502,4500,4700,4702,9577,9528,9579,9628,4501,4600,4701
4602,9877,9777,9779,9879
4323,9629,9529,9531,9631,4702,4700,4900,4902,9579,9530,9581,9630,4701,4800,4901
4802,9879,9779,9781,9881

```

FILENAME: dload.inp

4324,9631,9531,9533,9633,4902,4900,5100,5102,9581,9532,9583,9632,4901,5000,5101
5002,9881,9781,9783,9883

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4325,9633,9533,9535,9635,5102,5100,1137,1139,9583,9534,9585,9634,5101,5200,1138
5202,9883,9783,9785,9885

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4326,9635,9535,9537,9637,1139,1137, 937, 939,9585,9536,9587,9636,1138,1037, 938
1039,9885,9785,9787,9887

4327,9637,9537,9539,9639, 939, 937, 737, 739,9587,9538,9589,9638, 938, 837, 738
839,9887,9787,9789,9889

4328,9639,9539,9541,9641, 739, 737, 537, 539,9589,9540,9591,9640, 738, 637, 538
639,9889,9789,9791,9891

4329,9641,9541,9543,9643, 539, 537, 337, 339,9591,9542,9593,9642, 538, 437, 338
439,9891,9791,9793,9893

4330,9643,9543,9545,9645, 339, 337, 137, 139,9593,9544,9595,9644, 338, 237, 138
239,9893,9793,9795,9895

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4331,9701,9601,9603,9703, 131, 133, 333, 331,9651,9602,9653,9702, 132, 233, 332
231,9951,9851,9853,9953

4332,9703,9603,9605,9705, 331, 333, 533, 531,9653,9604,9655,9704, 332, 433, 532

431,9953,9853,9855,9955

4333,9705,9605,9607,9707, 531, 533, 733, 731,9655,9606,9657,9706, 532, 633, 732

631,9955,9855,9857,9957

4334,9707,9607,9609,9709, 731, 733, 933, 931,9657,9608,9659,9708, 732, 833, 932

831,9957,9857,9859,9959

4335,9709,9609,9611,9711, 931, 933,1133,1131,9659,9610,9661,9710, 932,1033,1132

1031,9959,9859,9861,9961

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4336,9711,9611,9613,9713,1131,1133,3102,3104,9661,9612,9663,9712,1132,3002,3103

3004,9961,9861,9863,9963

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4337,9713,9613,9615,9715,3104,3102,3302,3304,9663,9614,9665,9714,3103,3202,3303
3204,9963,9863,9865,9965

4338,9715,9615,9617,9717,3304,3302,3502,3504,9665,9616,9667,9716,3303,3402,3503

3404,9965,9865,9867,9967

4339,9717,9617,9619,9719,3504,3502,3702,3704,9667,9618,9669,9718,3503,3602,3703

3604,9967,9867,9869,9969

4340,9719,9619,9621,9721,3704,3702,3902,3904,9669,9620,9671,9720,3703,3802,3903

3804,9969,9869,9871,9971

4341,9721,9621,9623,9723,3904,3902,4102,4104,9671,9622,9673,9722,3903,4002,4103

4004,9971,9871,9873,9973

4342,9723,9623,9625,9725,4104,4102,4302,4304,9673,9624,9675,9724,4103,4202,4303

4204,9973,9873,9875,9975

4343,9725,9625,9627,9727,4304,4302,4502,4504,9675,9626,9677,9726,4303,4402,4503

4404,9975,9875,9877,9977

4344,9727,9627,9629,9729,4504,4502,4702,4704,9677,9628,9679,9728,4503,4602,4703

4604,9977,9877,9879,9979

4345,9729,9629,9631,9731,4704,4702,4902,4904,9679,9630,9681,9730,4703,4802,4903

4804,9979,9879,9881,9981

4346,9731,9631,9633,9733,4904,4902,5102,5104,9681,9632,9683,9732,4903,5002,5103

5004,9981,9881,9883,9983

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4347,9733,9633,9635,9735,5104,5102,1139,1141,9683,9634,9685,9734,5103,5202,1140

5204,9983,9883,9885,9985

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4348,9735,9635,9637,9737,1141,1139, 939, 941,9685,9636,9687,9736,1140,1039, 940

1041,9985,9885,9887,9987

4349,9737,9637,9639,9739, 941, 939, 739, 741,9687,9638,9689,9738, 940, 839, 740

841,9987,9887,9889,9989

4350,9739,9639,9641,9741, 741, 739, 539, 541,9689,9640,9691,9740, 740, 639, 540

641,9989,9889,9891,9991

4351,9741,9641,9643,9743, 541, 539, 339, 341,9691,9642,9693,9742, 540, 439, 340

441,9991,9891,9893,9993

4352,9743,9643,9645,9745, 341, 339, 139, 141,9693,9644,9695,9744, 340, 239, 140

241,9993,9893,9895,9995

**

**

** =====

** INTERSECTION PIPE ELEMENTS BETWEEN THE PIPE AT DOME AND THE PIPE ABOVE DOME

** ELEMENT NOS. 4485 THROUGH 4528

FILENAME: dload.inp

** ELEMENT CONNECTIVITY IS INPUT IN FIXED FORMAT (1615)

```
** =====  
4485601336013560335603336635166251662536635360134602356033460233663016625266303  
66352,66101,66001,66003,66103  
**  
4486603336033560535605336635366253662556635560334604356053460433663036625466305  
66354,66103,66003,66005,66105  
**  
4487605336053560735607336635566255662576635760534606356073460633663056625666307  
66356,66105,66005,66007,66107  
**  
4488607336073560935609336635766257662596635960734608356093460833663076625866309  
66358,66107,66007,66009,66109  
**  
4489609336093561135611336635966259662616636160934610356113461033663096626066311  
66360,66109,66009,66011,66111  
**  
**  
4490611336113563100631026636166261662636636361134630006310163002663116626266313  
66362,66111,66011,66013,66113  
**  
**  
4491631026310063300633026636366263662656636563101632006330163202663136626466315  
66364,66113,66013,66015,66115  
**  
4492633026330063500635026636566265662676636763301634006350163402663156626666317  
66366,66115,66015,66017,66117  
**  
4493635026350063700637026636766267662696636963501636006370163602663176626866319  
66368,66117,66017,66019,66119  
**  
4494637026370063900639026636966269662716637163701638006390163802663196627066321  
66370,66119,66019,66021,66121  
**  
4495639026390064100641026637166271662736637363901640006410164002663216627266323  
66372,66121,66021,66023,66123  
**  
4496641026410064300643026637366273662756637564101642006430164202663236627466325  
66374,66123,66023,66025,66125  
**  
4497643026430064500645026637566275662776637764301644006450164402663256627666327  
66376,66125,66025,66027,66127  
**  
4498645026450064700647026637766277662796637964501646006470164602663276627866329  
66378,66127,66027,66029,66129  
**  
4499647026470064900649026637966279662816638164701648006490164802663296628066331  
66380,66129,66029,66031,66131  
**  
4500649026490065100651026638166281662836638364901650006510165002663316628266333  
66382,66131,66031,66033,66133  
**  
**  
4501651026510061137611396638366283662856638565101652006113865202663336628466335  
66384,66133,66033,66035,66135  
**  
**  
4502611396113760937609396638566285662876638761138610376093861039663356628666337  
66386,66135,66035,66037,66137  
**  
4503609396093760737607396638766287662896638960938608376073860839663376628866339  
66388,66137,66037,66039,66139  
**  
4504607396073760537605396638966289662916639160738606376053860639663396629066341  
66390,66139,66039,66041,66141  
**  
4505605396053760337603396639166291662936639360538604376033860439663416629266343  
66392,66141,66041,66043,66143  
**  
4506603396033760137601396639366293662956639560338602376013860239663436629466345
```


FILENAME: dload.inp

66394,66143,66043,66045,66145
**
**
**
4507601316013360333603316645166351663536645360132602336033260231664016635266403
66452,66201,66101,66103,66203
**
4508603316033360533605316645366353663556645560332604336053260431664036635466405
66454,66203,66103,66105,66205
**
4509605316053360733607316645566355663576645760532606336073260631664056635666407
66456,66205,66105,66107,66207
**
4510607316073360933609316645766357663596645960732608336093260831664076635866409
66458,66207,66107,66109,66209
**
4511609316093361133611316645966359663616646160932610336113261031664096636066411
66460,66209,66109,66111,66211
**
**
4512611316113363102631046646166361663636646361132630026310363004664116636266413
66462,66211,66111,66113,66213
**
**
4513631046310263302633046646366363663656646563103632026330363204664136636466415
66464,66213,66113,66115,66215
**
4514633046330263502635046646566365663676646763303634026350363404664156636666417
66466,66215,66115,66117,66217
**
4515635046350263702637046646766367663696646963503636026370363604664176636866419
66468,66217,66117,66119,66219
**
4516637046370263902639046646966369663716647163703638026390363804664196637066421
66470,66219,66119,66121,66221
**
4517639046390264102641046647166371663736647363903640026410364004664216637266423
66472,66221,66121,66123,66223
**
4518641046410264302643046647366373663756647564103642026430364204664236637466425
66474,66223,66123,66125,66225
**
4519643046430264502645046647566375663776647764303644026450364404664256637666427
66476,66225,66125,66127,66227
**
4520645046450264702647046647766377663796647964503646026470364604664276637866429
66478,66227,66127,66129,66229
**
4521647046470264902649046647966379663816648164703648026490364804664296638066431
66480,66229,66129,66131,66231
**
4522649046490265102651046648166381663836648364903650026510365004664316638266433
66482,66231,66131,66133,66233
**
**
4523651046510261139611416648366383663856648565103652026114065204664336638466435
66484,66233,66133,66135,66235
**
**
4524611416113960939609416648566385663876648761140610396094061041664356638666437
66486,66235,66135,66137,66237
**
4525609416093960739607416648766387663896648960940608396074060841664376638866439
66488,66237,66137,66139,66239
**
4526607416073960539605416648966389663916649160740606396054060641664396639066441
66490,66239,66139,66141,66241
**
4527605416053960339603416649166391663936649360540604396034060441664416639266443
66492,66241,66141,66143,66243

FILENAME: dload.inp

```

**
4528603416033960139601416649366393663956649560340602396014060241664436639466445
66494,66243,66143,66145,66245
**

```

```

** ***** ROTATING THE BOUNDARY NODES *****

```

```

*NSET,NSET=LEFT,GENERATE

```

```

101, 2301,100
10101,12301,100
20101,22301,100
30101,32301,100
40101,42301,100
50101,52301,100
60101,62301,100

```

```

**
*NSET,NSET=RIGHT,GENERATE

```

```

171, 2371,100
10171,12371,100
20171,22371,100
30171,32371,100
40171,42371,100
50171,52371,100
60171,62371,100

```

```

**
*NSET,NSET=SOUTH,GENERATE

```

```

101, 135,1
10101,10135,1
20101,20135,1
30101,30135,1
40101,40135,1
50101,50135,1
60101,60135,1

```

```

**
137, 171,1
10137,10171,1
20137,20171,1
30137,30171,1
40137,40171,1
50137,50171,1
60137,60171,1

```

```

**
*NSET,NSET=NORTH,GENERATE

```

```

2301, 2327,1
12301,12327,1
22301,22327,1
32301,32327,1
42301,42327,1
52301,52327,1
62301,62327,1

```

```

**
2345, 2371,1
12345,12371,1
22345,22371,1
32345,32371,1
42345,42371,1
52345,52371,1
62345,62371,1

```

```

**
3020, 5220,100
13120,15120,100
23020,25220,100
33120,35120,100
43020,45220,100
53120,55120,100
63020,65220,100

```

```

**
*NSET,NSET=NODTRAN
LEFT,RIGHT,SOUTH,NORTH
**

```

FILENAME: dload.inp

```
**
*TRANSFORM,NSET=NODTRAN,TYPE=S
0.,0.,0.,0.,0.,1.0
**
**
*ELSET,ELSET=DBOTTOM,GENERATE
1001,1402,1
**
*ELSET,ELSET=DTOP,GENERATE
4793,4836,1
*ELSET,ELSET=PIPE
PIPEBOT,PIPETOP,PIPEMID,PIPEDOME
**
*MATERIAL,NAME=STEEL
*DENSITY
.0007324
*ELASTIC
29.0E6,0.30
*PLASTIC
44066.,0.
44541.,.008461
57770.,.056515
66330.,.093439
74750.,.137833
*SOLID SECTION,MATERIAL=STEEL,ELSET=PIPE
1.
**
*NSET,NSET=YSYM,GENERATE
101,135,1
10101,10135,1
20101,20135,1
30101,30135,1
40101,40135,1
50101,50135,1
60101,60135,1
**
137,171,1
10137,10171,1
20137,20171,1
30137,30171,1
40137,40171,1
50137,50171,1
60137,60171,1
**
6001,9751,250
6051,9801,250
6101,9851,250
6151,9901,250
6201,9951,250
**
6045,9795,250
6095,9845,250
6145,9895,250
6195,9945,250
6245,9995,250
**
66001,69751,250
66051,69801,250
66101,69851,250
66151,69901,250
66201,69951,250
**
66045,69795,250
66095,69845,250
66145,69895,250
66195,69945,250
66245,69995,250
*BOUNDARY
YSYM,2,2
NORTH,2,2
```

FILENAME: dload.inp

```
LEFT,3,3
RIGHT,3,3
*ELSET,ELSET=DISTORT
1009,1010,1011,1073,1189,1190,1197,1198,1509,1510,1511,1573,1689,1690,
1697,1698,2009,2010,2073,2189,2190,2197,2198,4498
** //////////////// END OF MODEL GENERATION ////////////////
**
**
*PLOT,COLORS=16,OUTPUT=BINARY
**
*ELSET,ELSET=FULMODEL
PIPE,DOME
**
**
*ELSET,ELSET=SEC1,GENERATE
4309,4528,1
**
1014,1074,15
1015,1075,15
1076,1136,15
1077,1137,15
1155,1158,1
1167,1170,1
1192,1195,1
1230,1233,1
**
1514,1574,15
1515,1575,15
1576,1636,15
1577,1637,15
1655,1658,1
1667,1670,1
1692,1695,1
1730,1733,1
**
2014,2074,15
2015,2075,15
2076,2136,15
2077,2137,15
2155,2158,1
2167,2170,1
2192,2195,1
2230,2233,1
**
**
*ELSET,ELSET=SEC2,GENERATE
1264,1275,1
1302,1313,1
1340,1351,1
1378,1389,1
**
1764,1775,1
1802,1813,1
1840,1851,1
1878,1889,1
**
2264,2275,1
2302,2313,1
2340,2351,1
2378,2389,1
**
**
*ELSET,ELSET=SEC3,GENERATE
4309,4528,1
**
1014,1074,15
1015,1075,15
1076,1136,15
1077,1137,15
1151,1174,1
```

FILENAME: dload.inp

```
1187,1200,1
1225,1237,1
**
1514,1574,15
1515,1575,15
1576,1636,15
1577,1637,15
1651,1674,1
1687,1700,1
1725,1737,1
**
2151,2174,1
2187,2200,1
2225,2237,1
2014,2074,15
2015,2075,15
2076,2136,15
2077,2137,15
**
**
*VIEWPOINT
1.,1.,1.,0.,0.,1.
**
*DETAIL,ELSET=DISTORT
*DRAW,HIDE,ELNUM
*DETAIL,ELSET=PIPE
*DRAW,HIDE
*DETAIL,ELSET=SEC1
*DRAW,HIDE
*DETAIL,ELSET=SEC2
*DRAW,HIDE
**
*VIEWPOINT
0.,0.,1.,0.,1.,0.
**
*DETAIL,ELSET=FULMODEL
*DRAW,HIDE
*DETAIL,ELSET=SEC3
*DRAW,HIDE
**
*VIEWPOINT
1.,1.,1.,0.,0.,1.
**
*DETAIL,ELSET=DISTORT
*DRAW,HIDE
*DETAIL,ELSET=SEC1
*DRAW,HIDE
**
*VIEWPOINT
1.,-1.,1.,0.,0.,1.
**
*DETAIL,ELSET=FULMODEL
*DRAW,HIDE
*DETAIL,ELSET=PIPE
*DRAW,HIDE
*DETAIL,ELSET=SEC1
*DRAW,HIDE
*DETAIL,ELSET=SEC2
*DRAW,HIDE
**
*VIEWPOINT
-1.,1.,1.,0.,0.,1.
**
*DETAIL,ELSET=FULMODEL
*DRAW,HIDE
*DETAIL,ELSET=SEC1
*DRAW,HIDE
**
*RESTART,WRITE,FREQ=50
*STEP,AMPLITUDE=RAMP,CYCL=8,INC=1000,NLGEOM,MONOTONIC
```

FILENAME: dload.inp

```
INTERNAL PRESSURE LOADING 0 - 33.0 PSI
*STATIC,PTOL=100.,RIKS
1.,31.,.00001,2.,1.
*DLOAD
DBOTTOM,P1,31.0
DTOP,P2,-124.333
*EL FILE,ELSET=FULMODEL,FREQ=4
S
E
PE
SINV
LOADS
*EL PRINT,ELSET=FULMODEL,FREQ=50
E
*NODE FILE,FREQ=4
U
RF
*NODE PRINT,NSET=NODTRAN,FREQ=50,GLOBAL=YES,TOTALS=YES
U
RF
*NODE PRINT,NSET=NODTRAN,FREQ=50,GLOBAL=NO,TOTAL=YES
U
RF
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=10
EQUIVALENT PLASTIC STRAIN
15.,9,9,5,1,-1,.1
.3
*VIEWPOINT
0.,0.,1.,0.,1.,0.
*DETAIL,ELSET=FULMODEL
*CONTOUR,FACTOR=.01
PEEQ,6
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=10
DEFORMED SHAPE
*VIEWPOINT
0.,1.,0.,0.,0.,1.
*DETAIL,ELSET=FULMODEL
*DISPLACED
U,1.
*END STEP
```

FILENAME: axiextrk.inp

*HEADING

Axisymmetric Mesh EXT 3x6x6 Model-1 3/8 to 1/2 in. transition in SY101 Dome

**-----
** Node number, x, y coordinates**-----
*NODE,NSET=BOT,SYSTEM=C

1000,1200.0,90.000
1001,1200.0,89.976
1002,1200.0,89.953
1003,1200.0,89.929
1004,1200.0,89.905
1005,1200.0,89.881
1006,1200.0,89.858
1007,1200.0,89.834
1008,1200.0,89.810
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FILENAME: axiextrk.inp

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FILENAME: axiextrk.inp

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7236,1200.375,85.246
7237,1200.375,85.228
7238,1200.375,85.209
7239,1200.375,85.191
7240,1200.375,85.173
7241,1200.375,85.155
7242,1200.375,85.136
7243,1200.375,85.118
7244,1200.375,85.100
7245,1200.375,85.082
7246,1200.375,85.063
7247,1200.375,85.045
7248,1200.375,85.027
7249,1200.375,85.009
7250,1200.375,84.990
7251,1200.375,84.972
7252,1200.375,84.954
7253,1200.375,84.936
7254,1200.375,84.917
7255,1200.375,84.899
7256,1200.375,84.881
7257,1200.375,84.863
7258,1200.375,84.844
7259,1200.375,84.826

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7260,1200.375,84.808
7261,1200.375,84.790
7262,1200.375,84.771
7263,1200.375,84.753
7264,1200.375,84.735
7265,1200.375,84.717
7266,1200.375,84.698
7267,1200.375,84.680
7268,1200.375,84.662
7269,1200.375,84.644
7270,1200.375,84.625
7271,1200.375,84.607
7272,1200.375,84.589
7273,1200.375,84.571
7274,1200.375,84.552
7275,1200.375,84.534
7276,1200.375,84.516
7277,1200.375,84.498
7278,1200.375,84.479
7279,1200.375,84.461
7280,1200.375,84.443
7281,1200.375,84.425
7282,1200.375,84.406
7283,1200.375,84.388
7284,1200.375,84.370
7285,1200.375,84.352
7286,1200.375,84.333
7287,1200.375,84.315
7288,1200.375,84.297
7289,1200.375,84.279
7290,1200.375,84.260
7291,1200.375,84.242
7292,1200.375,84.224
7293,1200.375,84.206
7294,1200.375,84.187
7295,1200.375,84.169
7296,1200.375,84.151
7297,1200.375,84.133
7298,1200.375,84.114
7299,1200.375,84.096
7300,1200.375,84.078
7301,1200.375,84.060
7302,1200.375,84.041
7303,1200.375,84.023
7304,1200.375,84.005
7305,1200.375,83.987
7306,1200.375,83.968
7307,1200.375,83.950
7308,1200.375,83.932
7309,1200.375,83.914
7310,1200.375,83.895
7311,1200.375,83.877
7312,1200.375,83.859
7313,1200.375,83.841
7314,1200.375,83.822
7315,1200.375,83.804
7316,1200.375,83.786
7317,1200.375,83.768
7318,1200.375,83.749
7319,1200.375,83.731
7320,1200.375,83.713
7321,1200.375,83.695
7322,1200.375,83.676
7323,1200.375,83.658
7324,1200.375,83.640
7325,1200.375,83.622
7326,1200.375,83.603
7327,1200.375,83.585
7328,1200.375,83.567
7329,1200.375,83.549

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7330,1200.375,83.530
7331,1200.375,83.512
7332,1200.375,83.494
7333,1200.375,83.476
7334,1200.375,83.457
7335,1200.375,83.439
7336,1200.375,83.421
7337,1200.375,83.403
7338,1200.375,83.384
7339,1200.375,83.366
7340,1200.375,83.348
7341,1200.375,83.330
7342,1200.375,83.311
7343,1200.375,83.293
7344,1200.375,83.275
7345,1200.375,83.257
7346,1200.375,83.238
7347,1200.375,83.220
7348,1200.375,83.202
7349,1200.375,83.184
7350,1200.375,83.165
7351,1200.375,83.147
7352,1200.375,83.129
7353,1200.375,83.111
7354,1200.375,83.092
7355,1200.375,83.074
7356,1200.375,83.056
7357,1200.375,83.038
7358,1200.375,83.019
7359,1200.375,83.001
7360,1200.375,82.983
7361,1200.375,82.965
7362,1200.375,82.946
7363,1200.375,82.928
7364,1200.375,82.910
7365,1200.375,82.892
7366,1200.375,82.873
7367,1200.375,82.855
7368,1200.375,82.837
7369,1200.375,82.819
7370,1200.375,82.800
7371,1200.375,82.782
7372,1200.375,82.764
7373,1200.375,82.746
7374,1200.375,82.727
7375,1200.375,82.709
7376,1200.375,82.691
7377,1200.375,82.673
7378,1200.375,82.654
7379,1200.375,82.636
7380,1200.375,82.618
7381,1200.375,82.600
7382,1200.375,82.581
7383,1200.375,82.563
7384,1200.375,82.545
7385,1200.375,82.527
7386,1200.375,82.508
7387,1200.375,82.490
7388,1200.375,82.472
7389,1200.375,82.454
7390,1200.375,82.435
7391,1200.375,82.417
7392,1200.375,82.399
7393,1200.375,82.381
7394,1200.375,82.362
7395,1200.375,82.344
7396,1200.375,82.326
7397,1200.375,82.308
7398,1200.375,82.289
7399,1200.375,82.271

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7400,1200.375,82.253
 7401,1200.375,82.235
 7402,1200.375,82.216
 7403,1200.375,82.198
 7404,1200.375,82.180
 7405,1200.375,82.162
 7406,1200.375,82.143
 7407,1200.375,82.125
 7408,1200.375,82.107
 7409,1200.375,82.089
 7410,1200.375,82.070
 7411,1200.375,82.052
 7412,1200.375,82.034
 7413,1200.375,82.016
 7414,1200.375,81.997
 7415,1200.375,81.979
 7416,1200.375,81.961
 7417,1200.375,81.943
 7418,1200.375,81.924
 7419,1200.375,81.906
 7420,1200.375,81.888
 7421,1200.375,81.870
 7422,1200.375,81.851
 7423,1200.375,81.833
 7424,1200.375,81.815
 7425,1200.375,81.797
 7426,1200.375,81.778
 7427,1200.375,81.760
 7428,1200.375,81.742
 7429,1200.375,81.724
 7430,1200.375,81.705
 7431,1200.375,81.687
 7432,1200.375,81.669

*NFILL,NSET=NULL

**-----
 ** NFILL, first boundary node set, last boundary node set, intervals
 ** along each line, increment in node number
 **-----

BOT,TOP,6,1000

*ELEMENT,TYPE=CAX8R,ELSET=EALL

**-----
 ** Element number,first,second,third,and forth nodes (CCW)
 **-----

1000,1000,1002,3002,3000,1001,2002,3001,2000

*ELGEN,ELSET=EALL

**-----
 ** Master element number, num elements in 1st row, incr. in node num,
 ** incr. in element num, number of row defined, incr. in node,
 ** incr. in element number
 **-----

1000,3,2000,2000,216,2,2

*ELSET,ELSET=POINT1,GENERATE

1400,5400,2000

*MATERIAL,NAME=STEEL

*DENSITY

.0007324

*ELASTIC

29.0E6,0.30

*PLASTIC

44066.,0.

44541.,.008461

57770.,.056515

66330.,.093439

74750.,.137833

*SOLID SECTION,MATERIAL=STEEL,ELSET=EALL

1.0

*NSET,NSET=FAIRLEFT,GENERATE

1000,7000,1000

*NSET,NSET=FAIRIGHT,GENERATE

1432,7432,1000

FILENAME: axiextrk.inp

```

*TRANSFORM,NSET=NALL,TYPE=C
0.,0.,0.,0.,0.,1.
*SYSTEM
*BOUNDARY
**-----
** Coordinate system x=1, y=2, z=3
** NODE/NAME,FIRST DOF,SECOND DOF
**-----
FARIGHT,2,2
FARLEFT,2,2
*ELSET,ELSET=FOCUS,GENERATE
1144,1158,2
3144,3158,2
5144,5158,2
*ELSET,ELSET=BFOCUS,GENERATE
1134,1168,2
3134,3168,2
5134,5168,2
*ELSET,ELSET=EBOT,GENERATE
1000,1432,2
*PLOT,COLORS=16,OUTPUT=BINARY
*DETAIL,ELSET=EALL
*DRAW
*DETAIL,ELSET=BFOCUS
*DRAW
*DETAIL,ELSET=FOCUS
*DRAW
*RESTART,WRITE,FREQ=1001
*STEP,AMPLITUDE=RAMP,CYCL=8,INC=2000,NLGEOM,MONOTONIC
INTERNAL PRESSURE LOADING 0 - 40 PSI
*STATIC,PTOL=100.,RIKS.
1.,40.,.00000001,1.,1.
*DLOAD
EBOT,P1,40.
*ELSET,ELSET=ESTORE
FOCUS
*ELSET,ELSET=ESTORE,GENERATE
1360,5360,1000
1362,5362,1000
1364,5364,1000
1358,5358,1000
*EL FILE,ELSET=ESTORE,FREQ=5
E,PE
*EL FILE,ELSET=EALL,FREQ=20
S
E
PE
SINV
LOADS
*EL PRINT,ELSET=EALL,FREQ=100
E
*NODE FILE,NSET=FARLEFT,FREQ=5
U
*NODE FILE,NSET=FARIGHT,FREQ=5
U
*NODE FILE,NSET=NALL,FREQ=20
U
RF
*NODE PRINT,NSET=FARIGHT,FREQ=200,GLOBAL=YES,TOTALS=YES
U
*NODE PRINT,NSET=FARLEFT,FREQ=200,GLOBAL=YES,TOTALS=YES
U
*NODE PRINT,NSET=FARIGHT,FREQ=200,GLOBAL=NO,TOTAL=YES
U
*NODE PRINT,NSET=FARLEFT,FREQ=200,GLOBAL=NO,TOTALS=YES
U
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=50
EQUIVALENT PLASTIC STRAIN
*DETAIL,ELSET=FOCUS
*CONTOUR,FACTOR=.01

```

FILENAME: axiextrk.inp

PEEQ,6
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=50
DEFORMED SHAPE
*DETAIL,ELSET=EALL
*DISPLACED
U
*END STEP

FILENAME: axipl.inp

*HEADING
AXI-SYMMETRIC TANK PENETRATION MODEL NO THICKNESS TRANSITION
**

*NODE,NSET=PIPEIN,SYSTEM=RC

1,2.013,1194,
501,2.013,1199,
601,2.013,1199.50,
701,2.013,1199.75,
1401,2.013,1200.625,
1501,2.013,1200.875,
1601,2.013,1201.375,
2101,2.013,1206.375,
**

*NODE,NSET=PIPEOUT,SYSTEM=RC

5,2.25,1194,
505,2.25,1199,
605,2.25,1199.50,
705,2.25,1199.75,
1405,2.25,1200.625,
1505,2.25,1200.875,
1605,2.25,1201.375,
2105,2.25,1206.375,
**

*NGEN,NSET=PIPEIN,SYSTEM=RC

1, 501,50
501, 701,50
701,1401,50
1401,1601,50
1601,2101,50
**

*NGEN,NSET=PIPEOUT,SYSTEM=RC

5, 505,50
505, 705,50
705,1405,50
1405,1605,50
1605,2105,50
**

*NFILL,NSET=PIPE
PIPEIN,PIPEOUT,4,1
**

*NODE,NSET=BOT,SYSTEM=C

**905,1200.0, 89.893
906,1200.0, 89.888
907,1200.0, 89.883
908,1200.0, 89.879
909,1200.0, 89.874
910,1200.0, 89.870
911,1200.0, 89.865
912,1200.0, 89.861
913,1200.0, 89.856
914,1200.0, 89.844
915,1200.0, 89.832
916,1200.0, 89.820
917,1200.0, 89.808
918,1200.0, 89.796
919,1200.0, 89.785
920,1200.0, 89.773
921,1200.0, 89.761
922,1200.0, 89.742
923,1200.0, 89.724
924,1200.0, 89.706
925,1200.0, 89.688
926,1200.0, 89.670
927,1200.0, 89.652
928,1200.0, 89.633
929,1200.0, 89.615
930,1200.0, 89.597
931,1200.0, 89.579
932,1200.0, 89.561
933,1200.0, 89.542

FILENAME: axipl.inp

```
934,1200.0, 89.524
935,1200.0, 89.506
936,1200.0, 89.488
*NODE,NSET=TOP,SYSTEM=C
**1205,1200.375,89.893
1206,1200.375,89.888
1207,1200.375,89.883
1208,1200.375,89.879
1209,1200.375,89.874
1210,1200.375,89.870
1211,1200.375,89.865
1212,1200.375,89.861
1213,1200.375,89.856
1214,1200.375,89.844
1215,1200.375,89.832
1216,1200.375,89.820
1217,1200.375,89.808
1218,1200.375,89.796
1219,1200.375,89.785
1220,1200.375,89.773
1221,1200.375,89.761
1222,1200.375,89.742
1223,1200.375,89.724
1224,1200.375,89.706
1225,1200.375,89.688
1226,1200.375,89.670
1227,1200.375,89.652
1228,1200.375,89.633
1229,1200.375,89.615
1230,1200.375,89.597
1231,1200.375,89.579
1232,1200.375,89.561
1233,1200.375,89.542
1234,1200.375,89.524
1235,1200.375,89.506
1236,1200.375,89.488
**
*NFILL,NSET=PLATE
BOT,TOP,6,50
**
** ADDED NODES FOR FAR FIELD
*NODE,NSET=NEWBOT,SYSTEM=C
3000,1200.,89.469590,
3242,1200.,85.10800,
**
*NODE,NSET=NEWTOP,SYSTEM=C
9000,1200.375,89.469590,
9242,1200.375,85.10800,
**
*NGEN,NSET=NEWBOT,LINE=C
3000,3242,1,,0.,0.,0.
**
*NGEN,NSET=NEWTOP,LINE=C
9000,9242,1,,0.,0.,0.
**
*NFILL,NSET=PLATE
NEWBOT,NEWTOP,6,1000
**
*ELEMENT,TYPE=CAX8R,ELSET=ELNO
** 8 NODE BIQUADRATIC, REDUCED INTEGRATION
1,1,3,103,101,2,53,102,51
43,905,907,1007,1005,906,957,1006,955
*ELEMENT,TYPE=CAX8R,ELSET=ELPLATE
935,935,3000,5000,1035,936,4000,1036,985
1035,1035,5000,7000,1135,1036,6000,1136,1085
1135,1135,7000,9000,1235,1136,8000,1236,1185
3000,3000,3002,5002,5000,3001,4002,5001,4000
**
*ELGEN,ELSET=ELPIPE
1,2,2,1,21,100,2,
```

FILENAME: axipl.inp

```

*ELGEN,ELSET=ELPLATE
43,15,2,1,3,100,15,
3000,3,2000,2000,121,2,2
**
*NSET,NSET=FARIGHT,GENERATE
3242,9242,1000
**
*TRANSFORM,NSET=FARIGHT,TYPE=C
0.,0.,0.,0.,0.,1.0
**
*BOUNDARY
FARIGHT,2,2
**
*NSET,NSET=NALL
PIPE,PLATE,NEWTOP,NEWBOT
**
*ELSET,ELSET=FOCUS,GENERATE
13,32,1
43,50,1
58,65,1
73,80,1
*ELSET,ELSET=BFOCUS,GENERATE
1,87,1
935,1135,100
3000,3010,2
5000,5010,2
7000,7010,2
*ELSET,ELSET=PRESEN,GENERATE
19,21,2
*ELSET,ELSET=PRESDOM,GENERATE
43,57,1
3000,3242,2
*ELSET,ELSET=PRESDOM
935
*ELSET,ELSET=PRESEND,GENERATE
1,2,1
*ELSET,ELSET=PRESBEG,GENERATE
41,42,1
*ELSET,ELSET=EALL
ELNO,ELPLATE,ELPIPE
**
*MATERIAL,NAME=STEEL
*DENSITY
.0007324
*ELASTIC
29.0E6,0.30
*PLASTIC
44066.,0.
44541.,.008461
57770.,.056515
66330.,.093439
74750.,.137833
*SOLID SECTION,MATERIAL=STEEL,ELSET=EALL
1.0
**
*PLOT,COLORS=16,OUTPUT=BINARY
*VIEWPOINT
0.,0.,1.,0.,1.,0.
*DETAIL,ELSET=EALL
*DRAW
*DETAIL,ELSET=BFOCUS
*DRAW
*DETAIL,ELSET=FOCUS
*DRAW
*RESTART,WRITE,FREQ=1001
*STEP,AMPLITUDE=RAMP,CYCL=8,INC=2000,NLGEOM,MONOTONIC
PRESSURE LOADING 0 - 30 PSI
*STATIC,PTOL=100.,RIKS
1.,30.,.00000001,1.,1.
*DLOAD

```


FILENAME: axipl.inp

```
PRESIN,P4,30.0
PRESDOM,P1,30.0
PRESEND,P1,30.0
PRESBEG,P3,120.322
*EL FILE,ELSET=EALL,FREQ=20
S
E
PE
SINV
LOADS
*EL PRINT,ELSET=EALL,FREQ=200
E
*ELSET,ELSET=FARFIELD,GENERATE
3168,7168,1000
3170,7170,1000
3172,7172,1000
*EL FILE,ELSET=FARFIELD,FREQ=5
E,PE
*EL FILE,ELSET=FOCUS,FREQ=5
E,PE
*NODE FILE,NSET=NALL,FREQ=20
U
RF
*NODE PRINT,NSET=FARIGHT,FREQ=1000,GLOBAL=YES,TOTAL=YES
U
RF
*NODE PRINT,NSET=FARIGHT,FREQ=1000,GLOBAL=NO,TOTAL=YES
U
RF
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=500
EQUIVALENT PLASTIC STRAIN
15,,9,9,5,1,.1,.1
.3
*DETAIL,ELSET=FOCUS
*CONTOUR,FACTOR=.01
PEEQ,6
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=500
MERIDIONAL STRAIN
15,,9,9,5,1,.1,.1
.3
*DETAIL,ELSET=FOCUS
*CONTOUR
E11,6
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=500
DEFORMED SHAPE
*DETAIL,ELSET=EALL
*DISPLACED
U
*END STEP
```

FILENAME: dome20.inp

*HEADING

DOME-20 MODEL 3/8-1/2 THICKNESS TRANSITION

*NODE,NSET=BOT,SYSTEM=RC

1000,0. ,593.613
1002,15.18 ,593.522
1004,30.36 ,593.252
1006,45.54 ,592.801
1008,60.720 ,592.167
1010,67.095 ,591.846
1012,69.22 ,591.732
1014,69.72 ,591.704

**

1018,70.22 ,591.676
1022,70.595 ,591.656
1026,70.72 ,591.650
1034,70.97 ,591.635
1038,71.22 ,591.621
1042,71.72 ,591.592
1044,72.22 ,591.564
1046,73.22 ,591.507
1048,75.22 ,591.389
1050,79.22 ,591.145
1052,87.22 ,590.617
1054,95.749 ,589.996
1056,110.778,588.754
1058,125.808,587.321
1060,140.837,585.692
1062,155.866,583.861
1064,170.895,581.821
1066,185.925,579.564
1068,200.954,577.082
1070,215.983,574.365
1072,231.012,571.400
1074,246.042,568.172
1076,261.071,564.665
1078,276.100,560.859

*NODE,NSET=TOP,SYSTEM=RC

**

5000,0. ,594.113
5002,15.186 ,594.022
5004,30.372 ,593.752
5006,45.558 ,593.300
5008,60.743 ,592.665
5010,67.122 ,592.343
5012,69.248 ,592.229
5014,69.747 ,592.201

**

5018,70.247 ,592.174
5022,70.614 ,592.061
5026,70.742 ,592.021
5034,70.991 ,592.007
5038,71.241 ,591.993
5042,71.742 ,591.965
5044,72.241 ,591.937
5046,73.242 ,591.879
5048,75.242 ,591.762
5050,79.243 ,591.517
5052,87.246 ,590.988
5054,95.778 ,590.367
5056,110.812,589.124
5058,125.846,587.689
5060,140.881,586.058
5062,155.915,584.225
5064,170.949,582.182
5066,185.984,579.923
5068,201.018,577.439
5070,216.053,574.718
5072,231.087,571.750
5074,246.121,568.519
5076,261.156,565.008

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5078,276.190,561.200

**

*NGEN,NSET=BOT

1000,1002,1

1004,1006,1

1008,1010,1

1012,1014,1

1018,1022,1

1026,1034,1

1038,1042,1

1044,1046,1

1050,1052,1

1054,1056,1

1058,1060,1

1062,1064,1

1066,1068,1

1070,1072,1

1074,1076,1

**

1002,1004,1

1006,1008,1

1010,1012,1

1014,1018,1

1022,1026,1

1034,1038,1

1042,1044,1

1046,1048,1

1048,1050,1

1052,1054,1

1056,1058,1

1060,1062,1

1064,1066,1

1068,1070,1

1072,1074,1

1076,1078,1

**

*NGEN,NSET=TOP

5000,5002,1

5004,5006,1

5008,5010,1

5012,5014,1

5018,5022,1

5026,5034,1

5038,5042,1

5044,5046,1

5050,5052,1

5054,5056,1

5058,5060,1

5062,5064,1

5066,5068,1

5070,5072,1

5074,5076,1

**

5002,5004,1

5006,5008,1

5010,5012,1

5014,5018,1

5022,5026,1

5034,5038,1

5042,5044,1

5046,5048,1

5048,5050,1

5052,5054,1

5056,5058,1

5060,5062,1

5064,5066,1

5068,5070,1

5072,5074,1

5076,5078,1

*NFILL,NSET=NALL

FILENAME: dome20.inp

```

BOT, TOP, 4, 1000
*ELEMENT, TYPE=CAX8R, ELSET=EALL
1000, 1000, 1002, 3002, 3000, 1001, 2002, 3001, 2000
*ELGEN, ELSET=EALL
1000, 2, 2000, 2000, 39, 2, 2
*MATERIAL, NAME=STEEL
*DENSITY
.0007324
*ELASTIC
29.0E6, 0.30
*PLASTIC
44066., 0.
44541., .008461
57770., .056515
66330., .093439
74750., .137833
*SOLID SECTION, MATERIAL=STEEL, ELSET=EALL
1.0
*ELSET, ELSET=EBOT, GENERATE
1000, 1076, 2
*ELSET, ELSET=PLOT1, GENERATE
1000, 1020, 2
*ELSET, ELSET=PLOT2, GENERATE
1022, 1032, 2
*ELSET, ELSET=PLOT3, GENERATE
1034, 1046, 2
*ELSET, ELSET=PLOT4, GENERATE
1048, 1060, 2
*ELSET, ELSET=PLOT5, GENERATE
1062, 1076, 2
*ELSET, ELSET=FOCUS, GENERATE
1024, 1038, 2
*PLOT, COLORS=8, OUTPUT=BINARY
MESH PLOTS
15., 9, 9, 5, 1, .1, .1
.3
*DETAIL, ELSET=PLOT1
*DRAW, ELNUM
*DETAIL, ELSET=PLOT2
*DRAW, ELNUM
*DETAIL, ELSET=PLOT3
*DRAW, ELNUM
*DETAIL, ELSET=PLOT4
*DRAW, ELNUM
*DETAIL, ELSET=PLOT5
*DRAW, ELNUM
*NSET, NSET=FARIGHT, GENERATE
1078, 5078, 1000
*NSET, NSET=FARLEFT, GENERATE
1000, 5000, 1000
*AMPLITUDE, TIME=A, NAME=DEAD
0., 0., 1., 1., 200., 1.,
**
*AMPLITUDE, TIME=A, NAME=LIVE
0., 0., 1., 0., 2., 16., 16., 30.
56., 50., 96., 60., 196., 70., 296., 80.
**
*AMPLITUDE, TIME=A, NAME=CUTU1
1.000, -8.5110E-03, 2.000, -3.3265E-03, 3.000, -2.9918E-03, 4.000, -2.6564E-03,
5.000, -2.3204E-03, 6.000, -1.9837E-03, 7.000, -1.6464E-03, 8.000, -1.3086E-03,
9.000, -9.7009E-04, 10.00, -6.2599E-04, 11.00, -2.7044E-04, 12.00, 9.1900E-05,
13.00, 4.7673E-04, 14.00, 8.8426E-04, 15.00, 1.3022E-03, 16.00, 1.5221E-03,
17.00, 2.2173E-03, 18.00, 3.8920E-03, 19.00, 9.2918E-03, 20.00, 1.7985E-02,
21.00, 1.9698E-02, 22.00, 2.2562E-02, 23.00, 2.3905E-02, 24.00, 2.5119E-02,
25.00, 2.6828E-02, 26.00, 2.8124E-02, 27.00, 2.8834E-02, 28.00, 3.0622E-02,
29.00, 3.8339E-02, 30.00, 3.9576E-02, 31.00, 4.1044E-02, 32.00, 4.2508E-02,
33.00, 4.3686E-02, 34.00, 4.4693E-02, 35.00, 4.6560E-02, 36.00, 4.8424E-02,
37.00, 5.0064E-02, 38.00, 5.3704E-02, 39.00, 5.6898E-02, 40.00, 5.8270E-02,
41.00, 5.9150E-02, 42.00, 5.9967E-02, 43.00, 6.1629E-02, 44.00, 6.2985E-02,
45.00, 6.4311E-02, 46.00, 6.5633E-02, 47.00, 6.7023E-02, 48.00, 6.8699E-02,

```

FILENAME: dome20.inp

```

49.00, 7.0100E-02, 50.00, 7.1485E-02, 51.00, 7.2862E-02, 52.00, 7.3505E-02,
53.00, 7.4467E-02, 54.00, 7.6183E-02, 55.00, 7.8071E-02, 56.00, 7.9620E-02,
58.00, 8.2829E-02, 60.00, 8.4365E-02, 62.00, 8.5963E-02, 64.00, 8.7607E-02,
66.00, 8.9450E-02, 68.00, 9.1491E-02, 70.00, 9.3847E-02, 72.00, 9.6406E-02,
74.00, 0.1018, 76.00, 0.1044, 78.00, 0.1078, 80.00, 0.1108,
82.00, 0.1140, 84.00, 0.1176, 86.00, 0.1213, 88.00, 0.1256,
90.00, 0.1311, 92.00, 0.1365, 94.00, 0.1416, 96.00, 0.1471,
101.0, 0.1538, 106.0, 0.1605, 111.0, 0.1687, 116.0, 0.1782,
121.0, 0.1924, 126.0, 0.2079, 131.0, 0.2187, 136.0, 0.2291,
141.0, 0.2377, 146.0, 0.2481, 151.0, 0.2566, 156.0, 0.2675,
161.0, 0.2795, 166.0, 0.2959, 171.0, 0.3097, 176.0, 0.3226,
181.0, 0.3330, 186.0, 0.3439, 191.0, 0.3548, 196.0, 0.3542,
201.0, 0.3629, 206.0, 0.3710, 211.0, 0.3777, 216.0, 0.3899,
221.0, 0.4044, 226.0, 0.4221, 231.0, 0.4350, 236.0, 0.4514,
241.0, 0.4585, 246.0, 0.4712, 251.0, 0.4846, 256.0, 0.4994,
261.0, 0.5146, 266.0, 0.5306, 271.0, 0.5472, 276.0, 0.5642,
281.0, 0.5819, 286.0, 0.6000, 291.0, 0.6191, 296.0, 0.6401

```

**

*AMPLITUDE, TIME=A, NAME=CUTU2

```

1.000, -0.1510, 2.000, -1.0552E-02, 3.000, -1.5988E-03, 4.000, 7.3504E-03,
5.000, 1.6296E-02, 6.000, 2.5238E-02, 7.000, 3.4178E-02, 8.000, 4.3121E-02,
9.000, 5.2059E-02, 10.00, 6.1006E-02, 11.00, 7.0077E-02, 12.00, 7.9177E-02,
13.00, 8.8365E-02, 14.00, 9.7632E-02, 15.00, 0.1069, 16.00, 0.1159,
17.00, 0.1311, 18.00, 0.1661, 19.00, 0.2575, 20.00, 0.3289,
21.00, 0.3744, 22.00, 0.4305, 23.00, 0.4807, 24.00, 0.5256,
25.00, 0.5750, 26.00, 0.6318, 27.00, 0.6826, 28.00, 0.7372,
29.00, 0.8055, 30.00, 0.8544, 31.00, 0.9217, 32.00, 0.9863,
33.00, 1.0410, 34.00, 1.0920, 35.00, 1.1440, 36.00, 1.198,
37.00, 1.2520, 38.00, 1.3200, 39.00, 1.3910, 40.00, 1.455,
41.00, 1.5190, 42.00, 1.5700, 43.00, 1.6200, 44.00, 1.666,
45.00, 1.7060, 46.00, 1.7450, 47.00, 1.7830, 48.00, 1.827,
49.00, 1.8750, 50.00, 1.9220, 51.00, 1.9700, 52.00, 2.024,
53.00, 2.0830, 54.00, 2.1650, 55.00, 2.2550, 56.00, 2.363,
58.00, 2.5410, 60.00, 2.7290, 62.00, 2.9740, 64.00, 3.215,
66.00, 3.4400, 68.00, 3.6580, 70.00, 3.8670, 72.00, 4.068,
74.00, 4.2770, 76.00, 4.4760, 78.00, 4.6790, 80.00, 4.961,
82.00, 5.2230, 84.00, 5.4720, 86.00, 5.7480, 88.00, 6.018,
90.00, 6.3020, 92.00, 6.5680, 94.00, 6.8150, 96.00, 7.051,
101.0, 7.2770, 106.0, 7.4900, 111.0, 7.6970, 116.0, 7.965,
121.0, 8.2980, 126.0, 8.5880, 131.0, 8.8740, 136.0, 9.151,
141.0, 9.4340, 146.0, 9.6930, 151.0, 9.9400, 156.0, 10.19,
161.0, 10.450, 166.0, 10.720, 171.0, 10.980, 176.0, 11.23,
181.0, 11.470, 186.0, 11.710, 191.0, 11.940, 196.0, 12.20,
201.0, 12.420, 206.0, 12.630, 211.0, 13.500, 216.0, 13.66,
221.0, 13.810, 226.0, 13.960, 231.0, 14.090, 236.0, 14.27,
241.0, 14.390, 246.0, 14.540, 251.0, 14.690, 256.0, 14.87,
261.0, 15.060, 266.0, 15.280, 271.0, 15.510, 276.0, 15.82,
281.0, 16.130, 286.0, 16.440, 291.0, 16.750, 296.0, 17.11

```

**

*AMPLITUDE, TIME=A, NAME=SYMU2

```

1.000, -0.2993, 2.000, -2.1507E-03, 3.000, -4.1066E-03, 4.000, 1.3279E-02,
5.000, 3.0651E-02, 6.000, 4.8008E-02, 7.000, 6.5351E-02, 8.000, 8.2686E-02,
9.000, 0.1000, 10.00, 0.1173, 11.00, 0.1346, 12.00, 0.1520,
13.00, 0.1693, 14.00, 0.1865, 15.00, 0.2037, 16.00, 0.2474,
17.00, 0.5402, 18.00, 0.8908, 19.00, 0.9916, 20.00, 1.0290,
21.00, 1.0920, 22.00, 1.159, 23.00, 1.229, 24.00, 1.2960,
25.00, 1.3630, 26.00, 1.440, 27.00, 1.515, 28.00, 1.5870,
29.00, 1.6340, 30.00, 1.704, 31.00, 1.790, 32.00, 1.8740,
33.00, 1.9480, 34.00, 2.013, 35.00, 2.082, 36.00, 2.1520,
37.00, 2.2240, 38.00, 2.296, 39.00, 2.375, 40.00, 2.4580,
41.00, 2.5440, 42.00, 2.619, 43.00, 2.686, 44.00, 2.7500,
45.00, 2.8090, 46.00, 2.867, 47.00, 2.924, 48.00, 2.9850,
49.00, 3.0510, 50.00, 3.117, 51.00, 3.183, 52.00, 3.2600,
53.00, 3.3400, 54.00, 3.444, 55.00, 3.556, 56.00, 3.6870,
58.00, 3.8790, 60.00, 4.092, 62.00, 4.363, 64.00, 4.6330,
66.00, 4.8930, 68.00, 5.152, 70.00, 5.412, 72.00, 5.6740,
74.00, 5.9390, 76.00, 6.202, 78.00, 6.471, 80.00, 6.8340,
82.00, 7.1800, 84.00, 7.542, 86.00, 7.919, 88.00, 8.3170,
90.00, 8.7210, 92.00, 9.125, 94.00, 9.501, 96.00, 9.8690,
101.0, 10.230, 106.0, 10.59, 111.0, 10.95, 116.0, 11.390,

```

FILENAME: dome20.inp

121.0, 11.910	, 126.0, 12.39	, 131.0, 12.87	, 136.0, 13.350,
141.0, 13.890	, 146.0, 14.37	, 151.0, 14.88	, 156.0, 15.390,
161.0, 15.880	, 166.0, 16.38	, 171.0, 16.90	, 176.0, 17.420,
181.0, 17.930	, 186.0, 18.45	, 191.0, 18.98	, 196.0, 19.580,
201.0, 20.100	, 206.0, 20.62	, 211.0, 21.81	, 216.0, 22.260,
221.0, 22.740	, 226.0, 23.31	, 231.0, 23.75	, 236.0, 24.250,
241.0, 24.680	, 246.0, 25.12	, 251.0, 25.57	, 256.0, 26.050,
261.0, 26.550	, 266.0, 27.08	, 271.0, 27.62	, 276.0, 28.240,
281.0, 28.850	, 286.0, 29.46	, 291.0, 30.07	, 296.0, 30.720

**

*RESTART,WRITE,FREQ=1001

*STEP,AMPLITUDE=RAMP,CYCL=5,INC=1000,NLGEOM

FIRST STEP

*STATIC,PTOL=1000.,DIRECT=NOSTOP

.1,1.

*DLOAD,AMPLITUDE=DEAD

EALL,BZ,-.2827

*BOUNDARY,AMPLITUDE=CUTU1

FARIGHT,1,1,1.

*BOUNDARY,AMPLITUDE=CUTU2

FARIGHT,2,2,1.

*BOUNDARY,AMPLITUDE=SYMU2

FARLEFT,2,2,1.

*BOUNDARY

FARLEFT,1,1,0.

*EL FILE,ELSET=EALL,FREQ=20

S

E

PE

SINV

LOADS

*NODE FILE,NSET=NALL,FREQ=20

U

RF

*EL PRINT,ELSET=EALL,FREQ=100

E

*NODE PRINT,NSET=FARIGHT,FREQ=20,GLOBAL=YES,TOTALS=YES

U

RF

*NODE PRINT,NSET=FARLEFT,FREQ=20,GLOBAL=YES,TOTALS=YES

U

RF

*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=20

DISPLACED SHAPE

,,6.,6.,4.,,1.5,1.5,7.5

.12,.25,7.5

*DETAIL,ELSET=FOCUS

*DISPLACED

U

*END STEP

*STEP,AMPLITUDE=RAMP,CYCL=5,INC=1000,NLGEOM

SECOND STEP

*STATIC,PTOL=1000.,DIRECT=NOSTOP

1.,55.

*DLOAD,AMPLITUDE=LIVE

EBOT,P1,1.0

*BOUNDARY,AMPLITUDE=CUTU1

FARIGHT,1,1,1.

*BOUNDARY,AMPLITUDE=CUTU2

FARIGHT,2,2,1.

*BOUNDARY,AMPLITUDE=SYMU2

FARLEFT,2,2,1.

*BOUNDARY

FARLEFT,1,1,0.

*EL FILE,ELSET=EALL,FREQ=2

S

E

PE

SINV

LOADS

FILENAME: dome20.inp

```

*NODE FILE,NSET=NALL,FREQ=2
U
RF
*EL PRINT,ELSET=EALL,FREQ=100
E
*NODE PRINT,NSET=FARIGHT,FREQ=2,GLOBAL=YES,TOTALS=YES
U,RF
*NODE PRINT,NSET=FARLEFT,FREQ=2,GLOBAL=YES,TOTALS=YES
U
RF
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=20
EQUIVELENT PLASTIC STRAIN
15,,9,9,5,1,.1,.1
.3
*DETAIL,ELSET=FOCUS
*CONTOUR,FACTOR=.01
PEEQ,6
*END STEP
*STEP,AMPLITUDE=RAMP,CYCL=8,INC=2000,NLGEOM
THIRD STEP
*STATIC,PTOL=1000.,DIRECT=NOSTOP
1.,40.
*DLOAD,AMPLITUDE=LIVE
EBOT,P1,1.0
*BOUNDARY,AMPLITUDE=CUTU1
FARIGHT,1,1,1.
*BOUNDARY,AMPLITUDE=CUTU2
FARIGHT,2,2,1.
*BOUNDARY,AMPLITUDE=SYMU2
FARLEFT,2,2,1.
*BOUNDARY
FARLEFT,1,1,0.
*EL FILE,ELSET=EALL,FREQ=2
S
E
PE
SINV
LOADS
*NODE FILE,NSET=NALL,FREQ=2
U
RF
*EL PRINT,ELSET=EALL,FREQ=100
E
*NODE PRINT,NSET=FARIGHT,FREQ=2,GLOBAL=YES,TOTALS=YES
U,RF
*NODE PRINT,NSET=FARLEFT,FREQ=2,GLOBAL=YES,TOTALS=YES
U
RF
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=20
EQUIVELENT PLASTIC STRAIN
15,,9,9,5,1,.1,.1
.3
*DETAIL,ELSET=FOCUS
*CONTOUR,FACTOR=.01
PEEQ,6
*END STEP
*STEP,AMPLITUDE=RAMP,CYCL=10,INC=1000,NLGEOM
FOURTH STEP
*STATIC,PTOL=1000.,DIRECT=NOSTOP
1.0,200.
*DLOAD,AMPLITUDE=LIVE
EBOT,P1,1.0
*BOUNDARY,AMPLITUDE=CUTU1
FARIGHT,1,1,1.
*BOUNDARY,AMPLITUDE=CUTU2
FARIGHT,2,2,1.
*BOUNDARY,AMPLITUDE=SYMU2
FARLEFT,2,2,1.
*BOUNDARY
FARLEFT,1,1,0.

```

FILENAME: dome20.inp

*EL FILE,ELSET=EALL,FREQ=2
S
E
PE
SINV
LOADS
*NODE FILE,NSET=NALL,FREQ=2
U
RF
*EL PRINT,ELSET=EALL,FREQ=100
E
*NODE PRINT,NSET=FARIGHT,FREQ=2,GLOBAL=YES,TOTALS=YES
U,RF
*NODE PRINT,NSET=FARLEFT,FREQ=2,GLOBAL=YES,TOTALS=YES
U
RF
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=20
EQUIVALENT PLASTIC STRAIN
15,,9,9,5,1,.1,.1
.3
*DETAIL,ELSET=FOCUS
*CONTOUR,FACTOR=.01
PEEQ,6
*END STEP

FILENAME: mesh333.inp

```

*HEADING
Mesh sensitivity test 3x6x6 on the 3/8 to 1/2 in. transition in SY101 Dome
*NODE,NSET=NALL,SYSTEM=RC
**-----
** Node number, x, y coordinates
**-----
100,0.,0.
700,0.,0.5
144,10.,0.
744,10.,0.5
152,10.875,0.
752,10.875,.375
198,20.875,0.
798,20.875,.375
*NGEN,NSET=FARLEFT
**-----
** NGEN, starting node, last node, increments between
**-----
100,700,100
*NGEN,NSET=LEFT
144,744,100
*NGEN,NSET=RIGHT
152,752,100
*NGEN,NSET=FARIGHT
198,798,100
*NFill,NSET=NALL
**-----
** NFill, first boundary node set, last boundary node set, intervals
**      along each line, increment in node number
**-----
FARLEFT,LEFT,44,1
LEFT,RIGHT,8,1
RIGHT,FARIGHT,46,1
*ELEMENT,TYPE=CPE8R,ELSET=EALL
**-----
** Element number,first,second,third,and forth nodes (CCW)
**-----
100,100,102,302,300,101,202,301,200
*ELGEN,ELSET=EALL
**-----
** Master element number, num elements in 1st row, incr. in node num,
** incr. in element num, number of row defined, incr. in node,
** incr. in element number
**-----
100,3,200,200,49,2,2
*NSET,NSET=NFIXED,GENERATE
100,700,100
*ELSET,ELSET=ESTRESS,GENERATE
148,548,200
*MATERIAL,NAME=STEEL
*DENSITY
.0007324
*ELASTIC
29.0E6,0.30
*PLASTIC
44066.,0.
44541.,.008461
57770.,.056515
66330.,.093439
74750.,.137833
*SOLID SECTION,MATERIAL=STEEL,ELSET=EALL
1.0
*BOUNDARY
**-----
** Coordinate system x=1, y=2, z=3
** NODE/NAME,FIST DOF,SECOND DOF
**-----
NFIxed,1,2
*ELSET,ELSET=FOCUS,GENERATE
140,156,2

```

FILENAME: mesh333.inp

340,356,2
540,556,2
*PLOT,COLORS=16,OUTPUT=BINARY
*DETAIL,ELSET=EALL
*DRAW
*DETAIL,ELSET=FOCUS
*DRAW
*STEP,AMPLITUDE=RAMP,CYCL=6,INC=1000,NLGEOM
MEMBRANE STRESS LOADING 0 - 100 PSI
*STATIC,PTOL=100.
0.05,300.,.01,10.
*BOUNDARY
FARIGHT,1,1,0.3
*EL FILE,ELSET=EALL,FREQ=15
S
E
PE
SINV
LOADS
*ELPRINT,ELSET=ESTRESS,FREQ=15
S
SINV
E
PE
LOADS
*NODE FILE,NSET=NALL,FREQ=15
U
RF
*NODE PRINT,NSET=FARIGHT,FREQ=15
U
*NODE PRINT,NSET=FARLEFT,FREQ=15
RF
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=15
EQUIVALENT PLASTIC STRAIN
*DETAIL,ELSET=EALL
*CONTOUR,DEFORMED
PEEQ,6
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=15
EQUIVALENT PLASTIC STRAIN
*DETAIL,ELSET=FOCUS
*CONTOUR,DEFORMED
PEEQ,6
*END STEP

FILENAME: mesh366.inp

```

*HEADING
Mesh sensitivity test 3x6x6 on the 3/8 to 1/2 in. transition in SY101 Dome
*NODE,NSET=NALL,SYSTEM=RC
**-----
** Node number, x, y coordinates
**-----
100,0.,0.
700,0.,0.5
128,10.,0.
728,10.,0.5
136,10.875,0.
736,10.875,.375
164,20.875,0.
764,20.875,.375
*NGEN,NSET=FARLEFT
**-----
** NGEN, starting node, last node, increments between
**-----
100,700,100
*NGEN,NSET=LEFT
128,728,100
*NGEN,NSET=RIGHT
136,736,100
*NGEN,NSET=FARIGHT
164,764,100
*NFill,NSET=NALL
**-----
** NFill, first boundary node set, last boundary node set, intervals
**      along each line, increment in node number
**-----
FARLEFT,LEFT,28,1
LEFT,RIGHT,8,1
RIGHT,FARIGHT,28,1
*ELEMENT,TYPE=CPE8R,ELSET=EALL
**-----
** Element number,first,second,third,and forth nodes (CCW)
**-----
100,100,102,302,300,101,202,301,200
*ELGEN,ELSET=EALL
**-----
** Master element number, num elements in 1st row, incr. in node num,
** incr. in element num, number of row defined, incr. in node,
** incr. in element number
**-----
100,3,200,200,32,2,2
*NSET,NSET=NFIXED,GENERATE
100,700,100
*ELSET,ELSET=ESTRESS,GENERATE
132,532,200
*MATERIAL,NAME=STEEL
*DENSITY
.0007324
*ELASTIC
29.0E6,0.30
*PLASTIC
44066.,0.
44541.,.008461
57770.,.056515
66330.,.093439
74750.,.137833
*SOLID SECTION,MATERIAL=STEEL,ELSET=EALL
1.0
*BOUNDARY
**-----
** Coordinate system x=1, y=2, z=3
** NODE/NAME,FIST DOF,SECOND DOF
**-----
NFIxed,1,2
*ELSET,ELSET=FOCUS,GENERATE
124,140,2

```

FILENAME: mesh366.inp

324,340,2
524,540,2
*PLOT,COLORS=16,OUTPUT=BINARY
*DETAIL,ELSET=EALL
*DRAW
*DETAIL,ELSET=FOCUS
*DRAW
*STEP,AMPLITUDE=RAMP,CYCL=6,INC=1000,NLGEOM
MEMBRANE STRESS LOADING 0 - 100 PSI
*STATIC,PTOL=100.
0.05,300.,.01,10.
*BOUNDARY
FARIGHT,1,1,0.3
*EL FILE,ELSET=EALL,FREQ=15
S
E
PE
SINV
LOADS
*ELPRINT,ELSET=ESTRESS,FREQ=15
S
SINV
E
PE
LOADS
*NODE FILE,NSET=NALL,FREQ=15
U
RF
*NODE PRINT,NSET=FARIGHT,FREQ=15
U
*NODE PRINT,NSET=FARLEFT,FREQ=15
RF
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=15
EQUIVALENT PLASTIC STRAIN
*DETAIL,ELSET=EALL
*CONTOUR,DEFORMED
PEEQ,6
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=15
EQUIVALENT PLASTIC STRAIN
*DETAIL,ELSET=FOCUS
*CONTOUR,DEFORMED
PEEQ,6
*END STEP

FILENAME: mesh466.inp

*HEADING

Mesh sensitivity test 4x6x6 on the 3/8 to 1/2 in. transition in SY101 Dome

*NODE,NSET=NALL,SYSTEM=RC

**-----

** Node number, x, y coordinates

**-----

100,0.,0.

900,0.,0.5

136,10.,0.

936,10.,0.5

144,10.875,0.

944,10.875,.375

180,20.875,0.

980,20.875,.375

*NGEN,NSET=FARLEFT

**-----

** NGEN, starting node, last node, increments between

**-----

100,900,100

*NGEN,NSET=LEFT

136,936,100

*NGEN,NSET=RIGHT

144,944,100

*NGEN,NSET=FAIRIGHT

180,980,100

*NFILL,NSET=NALL

**-----

** NFILL, first boundary node set, last boundary node set, intervals

** along each line, increment in node number

**-----

FARLEFT,LEFT,36,1

LEFT,RIGHT,8,1

RIGHT,FAIRIGHT,36,1

*ELEMENT,TYPE=CPE8R,ELSET=EALL

**-----

** Element number,first,second,third,and forth nodes (CCW)

**-----

100,100,102,302,300,101,202,301,200

*ELGEN,ELSET=EALL

**-----

** Master element number, num elements in 1st row, incr. in node num,

** incr. in element num, number of row defined, incr. in node,

** incr. in element number

**-----

100,4,200,200,40,2,2

*NSET,NSET=NFIXED,GENERATE

100,900,100

*ELSET,ELSET=ESTRESS,GENERATE

140,740,200

*MATERIAL,NAME=STEEL

*DENSITY

.0007324

*ELASTIC

29.0E6,0.30

*PLASTIC

44066.,0.

44541.,.008461

57770.,.056515

66330.,.093439

74750.,.137833

*SOLID SECTION,MATERIAL=STEEL,ELSET=EALL

1.0

*BOUNDARY

**-----

** Coordinate system x=1, y=2, z=3

** NODE/NAME,FIRST DOF,SECOND DOF

**-----

NFIXED,1,2

*ELSET,ELSET=FOCUS,GENERATE

132,148,2

FILENAME: mesh466.inp

332,348,2
532,548,2
*PLOT,COLORS=16,OUTPUT=BINARY
*DETAIL,ELSET=EALL
*DRAW
*DETAIL,ELSET=FOCUS
*DRAW
*STEP,AMPLITUDE=RAMP,CYCL=6,INC=1000,NLGEOM
MEMBRANE STRESS LOADING 0 - 100 PSI
*STATIC,PTOL=100.
0.05,300.,.01,10.
*BOUNDARY
FARIGHT,1,1,0.3
*EL FILE,ELSET=EALL,FREQ=15
S
E
PE
SINV
LOADS
*ELPRINT,ELSET=ESTRESS,FREQ=15
S
SINV
E
PE
LOADS
*NODE FILE,NSET=NALL,FREQ=15
U
RF
*NODE PRINT,NSET=FARIGHT,FREQ=15
U
*NODE PRINT,NSET=FARLEFT,FREQ=15
RF
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=15
EQUIVALENT PLASTIC STRAIN
*DETAIL,ELSET=EALL
*CONTOUR,DEFORMED
PEEQ,6
*PLOT,COLORS=8,OUTPUT=BINARY,FREQ=15
EQUIVALENT PLASTIC STRAIN
*DETAIL,ELSET=FOCUS
*CONTOUR,DEFORMED
PEEQ,6
*END STEP