S

JUN 19 2003 (25) 6
STATION 4

ENGINEERING DATA TRANSMITTAL

1. EDT 637303

2. To: (Receiving Organization) Distribution	3. From: (Originating Organization) Design Engineering	4. Related EDT No.: N/A
5. Proj./Prog./Dept./Div.: Dome Load	6. Design Authority/Design Agent/Cog. Engr.: L.J. Julyk	7. Purchase Order No.: N/A
8. Originator Remarks: To release document		9. Equip./Component No.: Single-Shell Tanks
		10. System/Bldg./Facility: SX Tank Farm
		12. Major Assm. Dwg. No.: N/A
11. Receiver Remarks: None	11A. Design Baseline Document? ○ Yes ◉ No	13. Permit/Permit Application No.: N/A
		14. Required Response Date: N/A

15. DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	(F) Approval Designator	(G) Reason for Transmittal	(H) Originator Disposition	(I) Receiver Disposition
1	RPP-13992	N/A	0	Sample AOR Calculation	N/A	1	1	1
				using ANSYS Slice				
				Parametric Model for Tank				
				SST-SX				

16. KEY

Approval Designator (F)	Reason for Transmittal (G)		Disposition (H) & (I)	
E, S, Q, D OR N/A (See WHC-CM-3-5, Sec. 12.7)	1. Approval 2. Release 3. Information	4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment	4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION (See Approval Designator for required signatures)

(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN
		Design Authority									
1	1	Design Agent L.J. Julyk	L.J. Julyk	6/17/03	R1-14						
		Cog. Eng.									
1	1	Cog. Mgr. C. Defigh-Price	C. Defigh-Price	6-19-03	R2-58						
		QA									
		Safety									
		Env.									

18.	19.	20.	21. DOE APPROVAL (if required)
L.J. Julyk 6/17/03 Signature of EDT Originator — Date	T.C. Mackey 6/19/03 Authorized Representative for Receiving Organization — Date	C. Defigh-Price 6-19-03 Design Authority/ Cognizant Manager — Date	Ctrl No. N/A ○ Approved ○ Approved w/comments ○ Disapproved w/comments

BD-7400-172-2 (10/97)

BD-7400-172-1

DISTRIBUTION SHEET

To	From	Page 1 of 1
Distribution	Design Engineering	Date 6/17/03
Project Title/Work Order		EDT No. 637303
Sample AOR Calculation using ANSYS Slice Parametric Model for Tank SST-SX (RPP-13992 Rev. 0)		ECN No.

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
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Sample AOR Calculation using ANSYS Slice Parametric Model for Tank SST-SX

L.J. Julyk/T.C. Mackey
CH2M HILL Hanford Group, Inc.
Richland, WA 99352
U.S. Department of Energy Contract DE-AC27-99RL14047

EDT/ECN: 637303 UC: N/A
Cost Center: 7G120 Charge Code: 102607
B&R Code: N/A Total Pages: 88

Key Words: single-shell tanks, SX farm, dome load, ANSYS, analysis of record

Abstract: This document documents the ANSYS slice parametric model for single-shell tank SX and provides sample calculation for analysis-of-record mechanical load conditions.

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6/19/03
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RPP-13992
Revision 0

Sample AOR Calculation using ANSYS Slice Parametric Model for Tank SST-SX

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

CH2MHILL
Hanford Group, Inc.
Richland, Washington
Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC06-99RL14047

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Sample AOR Calculation using ANSYS Slice Parametric Model for Tank SST-SX

L. J. Julyk / T. C. Mackey
CH2MHILL Hanford Group, Inc.

Xianghong Li / Jim Radochia
JLR The Engineering Solutions Company

Date Published
May 2003

CH2MHILL
Hanford Group, Inc.

P. O. Box 1500
Richland, Washington

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The subject document has been reviewed by the undersigned.
The reviewer reviewed and verified the following items as applicable.

Document Reviewed: RPP-13992, Rev. 0, Sample AOR Calculation using ANSYS Slice Parametric Model for Tank SST-SX

Analysis performed by: Xianghong Li / Jim Radochia
JLR The Engineering Solutions Company

- Design Input*
- Basic Assumption
- Approach/Design Methodology
- Related Information
- Conclusion/Result Interpretation

*Default values of changeable parameters in model are for example only. User of model must confirm proper input of parameter values for specific application of model.

An electronic version of model is available from undersigned. See attached ERATA sheet for any known problems with model.

Reviewer/Approver (print) L. J. Julyk / Design Engineering

Reviewer/Approver (signature) LJulyk 6/17/03
Date

CHECKLIST FOR INDEPENDENT REVIEW

Document Reviewed: RPP-13992, Rev. 0, Sample AOR Calculation using ANSYS Slice Parametric Model for Tank SST-SX

Author: Xianghong Li / Jim Radochia
JLR The Engineering Solutions Company

Yes	No	N/A	
[X]	[ ]	[ ]	Problem completely defined.
[X]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[X]	[ ]	[ ]	Computer codes and data files documented.
[X]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[X]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[X]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[X]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[X]	[ ]	[ ]	Hand calculations checked for errors.
[X]	[ ]	[ ]	Code run streams correct and consistent with analysis documentation.
[X]	[ ]	[ ]	Code output consistent with input and with results reported in analysis documentation.
[ ]	[ ]	[X] *	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[ ]	[ ]	[X] *	Safety margins consistent with good engineering practices.
[X]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[X]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.

* Sample Calculation / Model Development

B. V. Winkel (M&D) B. V. Winkel 6-10-03
Reviewer Date

L. J. Julyk (CHG) L. J. Julyk 6/17/03
Reviewer Date

ERRATA

ANSYS Macro	Tracking #	Issue Description	Recommended Action
Parm_sx.mac	1	Material properties are set at default values that may or may not be appropriate for specific analysis.	Verify material input values appropriate for specific analysis.
Parm_sx.mac and Sst_sx_slice.mac (see set material properties)	2	Concrete creep coefficients listed are incorrectly specified for implicit user-defined creep. Solid65 elements can only use explicit creep. Error is in report listing only; actual macro files are correct.	See RPP-13990 for proper creep coefficient specification and usage.

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1.0 OBJECTIVE/PURPOSE

The purpose of this calculation is to develop a parametric model for the single shell tank (SST) SX, and provide a sample analysis of the SST-SX tank based on analysis of record (AOR) loads. The SST-SX model is based on buyer-supplied as-built drawings and information for the AOR for SSTs, encompassing the existing tank load conditions, and evaluates stresses and deformations throughout the tank and surrounding soil mass.

These sample calculations in this document are not to be used for assessing the structural integrity of the SST-SX tanks at the Hanford site.

2.0 METHODS OF ANALYSIS

1. A 3-degree slice 3D model of the SST-SX tanks was first developed using the ANSYS Parametric Design Language (APDL) in ANSYS 7.0, a general purpose finite element analysis program [Ref_1]. Compared with the linear model reported in RPP-13991 [Ref_5], the 3D slice model includes some non-linear characteristics of the analysis, such as a) contact between the soil and tank with friction, b) plastic soil material. Also, the reinforcement bars embedded in the concrete tank were included for this analysis.

2. The parametric model of the SST-SX tank was then analyzed based on AOR loads. Contour plots showing stress and displacement are provided, as well as path plots showing section force/moment.

3.0 INPUT DATA

The geometry of the SST-SX tank is provided in drawing H-2-39511 [Ref_4], and is shown in Figure 1. The parametric model includes material properties for the tank, and nominal soil material properties. For purposes of this calculation, the soil overburden (at the top of the tank dome) is 8.52 feet [Ref_3], with a unit weight of 125 pcf and Poisson ratio of 0.27. The soil is divided into three layers as shown in Figure 2. Each layer has a different elastic modulus. Material properties for structural concrete and soil are the same as those in document RPP-14249 [Ref_2]. The concrete reinforcing bar properties are also specified. All linear material properties are listed in Table 1.

Table 1. Linear Material Properties [Ref_2]

Material	Elastic Modulus (ksi)	Poisson's Ratio	Density (lb/ft³)
Structural Concrete	3,100	0.2	150
Top Soil *	7	0.27	125
Mid-Soil*	13	0.27	125
Bottom Soil*	20	0.27	125
Tank Rebar Steel	27,700	0.3	490
Slab Rebar Steel	27,700	0.3	490

*Drucker-Prager plasticity is used for soil, and the friction angle is 35.4 degrees for all three layers of soil.

The concrete tank is modeled with 3D solid elements SOLID65, and the soil is modeled with SOLID45 elements. Figures 3 through 5 show the finite element mesh used for this calculation. The tank is divided into small volumes of 1" wide according the location of the steel reinforcing bars (Figures 6 to 8). Real constants are assigned to tank elements to represent the rebar volume ratios and rebar orientations (Figure 9). The volume ratio is calculated using Excel spreadsheets listed in Tables 2 to 6. In the dome and slab, the volume ratio of the radial rebars increases linearly with decreasing radius. Given this variety of rebar volume ratio, the average radius was used during the calculation of the real constants for the radial rebars in the dome and slab. There are 3 element coordinate systems used to orient the rebars, and they are listed in Table 7. Figure 10 shows the rebar elements colored by element coordinate systems. Figure 11 to 13 depict the rebar orientations at various locations of the concrete tank. Standard contact with a friction coefficient of 0.3 is defined between the tank and the surrounding soil.

The AOR loads for the SST-SX tank include a uniform pressure load of 40 lbf/ft² on the soil surface and a concentrated load of 200 kip over a circular region with a radius of 10 ft. The concentrated load is applied to the soil surface as a uniform pressure load in this calculation. A vacuum load of -6 in. water gage is also applied to the inside surface of the tank. Boundary conditions are applied to the model so that both ends of the slice are constrained in the circumferential direction, the outside radius surface of the soil is fixed in the radial direction, and the bottom surface of the soil is fixed in the vertical direction. Gravity is also included in the calculation.

The parametric inputs used in this calculation are summarized in the attachments. The files and their functions are listed in Table 8.

Table 2. Calculation of Steel Reinforcement Ratios for Slab

SST-SX - Steel Reinforcement Ratios for Slab - Ref H-2-39512 100

Description	Elevation (in)	Radius (in)	Bottom / Meridional Size	Spacing	Area Ratio	Volume Ratio	Bottom / Circumferential Size	Spacing	Area Ratio	Volume Ratio	Real Constant
Slab Center		0.0									
			5	12.00	0.0256	0.0256	5	12	0.0256	0.0256	100
Mid of overlapping		372.0									
			6	6.19	0.0714	0.0714	5	12	0.0256	0.0256	101
end of overlapping		390.0									
			6	6.58	0.0671	0.0671	5	12	0.0256	0.0256	102
6' from rebar end		420.5									
			6	7.10	0.0622	0.0622	5	12	0.0256	0.0256	103
start of curved rbar		453.4									
			6	7.50	0.0589	0.0589	5	12	0.0256	0.0256	104
end of curved rbar		470.4									
			6	7.82	0.0565	0.0565	5	12	0.0256	0.0256	105
Slab Outside Radius		492.5									

SST-SX - Steel Reinforcement Ratios for Slab - Ref H-2-39512 100

Description	Elevation (in)	Radius (in)	Top / Meridional Size	Spacing (in)	Area Ratio	Volume Ratio	Top / Circumferential Size	Spacing (in)	Area Ratio	Volume Ratio	Real Constant
Slab Center		0.0									
		282.0									
			6	5.17	0.0855	0.0855	5	12	0.0256	0.0256	106
		354.0									
			6	6.56	0.0674	0.0674	5	12	0.0256	0.0256	107
Start of curved rbar		453.4									
			6	7.50	0.0589	0.0589	5	12	0.0256	0.0256	108
End of curved rbar		470.4									
			6	7.82	0.0565	0.0565	5	12	0.0256	0.0256	109
Slab Outside Radius		492.5									

SST-SX - Steel Reinforcement Ratios for Slab - Ref H-2-39512 100

Description	Elevation (in)	Radius (in)	Meridional Size	Spacing (in)	Area Ratio	Volume Ratio	Circumferential Size	Spacing (in)	Area Ratio	Volume Ratio	Real Constant
Curved rebars											
			6	8	0.0552	0.0552	0	0	0.0000	0.0000	110-116

Table 3. Calculation of Steel Reinforcement Ratios for Wall

SST-SX - Steel Reinforcement Ratios for Wall - Ref H-2-39512 200

Description	Elevation (in)	Radius (in)	Interior / Meridional Size	Spacing (in)	Area Ratio	Volume Ratio	Interior / Circumferential Size	Spacing (in)	Area Ratio	Volume Ratio	Real Constant
Dome Tangent Line	0.0										
			6	16.0	0.0276	0.0276	0	0	0.0000	0.0000	213
	3.0										
			6	16.0	0.0276	0.0276	8	4	0.1963	0.1963	200
	7.0										
			6	16.0	0.0276	0.0276	8	11	0.0714	0.0714	201
	18.0										
			6	16.0	0.0276	0.0276	8	5	0.1571	0.1571	202
	23.0										
			6	16.0	0.0276	0.0276	8	8	0.0982	0.0982	203
	79.0										
			6	16.0	0.0276	0.0276	8	6	0.1309	0.1309	204
Start of thickness trans.	139.0										
			6	16.0	0.0276	0.0276	8	4.5	0.1745	0.1745	205
End of thickness trans	205.0										
			6	8.0	0.0552	0.0552	8	4.5	0.1745	0.1745	206
Mid of overlapping	357.6										
			6	8.0	0.0552	0.0552	8	4.5	0.1745	0.1745	207
End of horizontal bar	368.5										
			6	8.0	0.0552	0.0552	6	8	0.0552	0.0552	208
Top of Slab	375.6										

SST-SX - Steel Reinforcement Ratios for Wall - Ref H-2-39512 200

Description	Elevation (in)	Radius (in)	Exterior / Meridional Size	Spacing (in)	Area Ratio	Volume Ratio	Exterior / Circumferential Size	Spacing (in)	Area Ratio	Volume Ratio	Real Constant
Dome Tangent Line	0.0										
			6	16.0	0.0276	0.0276	0	0	0.0000	0.0000	213
	3.0										
			6	16.0	0.0276	0.0276	8	4	0.1963	0.1963	200
	7.0										
			6	16	0.0276	0.0276	8	11	0.0714	0.0714	201
	18.0										
			6	16	0.0276	0.0276	8	9	0.0873	0.0873	209
	27.0										
			6	16	0.0276	0.0276	8	8	0.0982	0.0982	203
	75.0										
			6	16	0.0276	0.0276	8	7	0.1122	0.1122	210
	82.0										
			6	16	0.0276	0.0276	8	6	0.1309	0.1309	204
	136.0										
			6	16	0.0276	0.0276	8	5.25	0.1496	0.1496	211
	141.3										
			6	16	0.0276	0.0276	8	4.5	0.1745	0.1745	212
End of thickness trans	205.0										
			6	8	0.0552	0.0552	8	4.5	0.1745	0.1745	206
Mid of overlapping	357.6										
			6	8	0.0552	0.0552	8	4.5	0.1745	0.1745	207
End of horizontal bar	370.8										
			6	8	0.0552	0.0552	6	8	0.0552	0.0552	208
Top of Slab	375.6										

Table 4. Calculation of Steel Reinforcement Ratios for Dome

SST-SX - Steel Reinforcement Ratios for Dome - Ref H-2-39512, H-2-39513 300

Description	Elevation (in)	Radius (in)	External / Meridional Size	Spacing (in)	Area Ratio	Volume Ratio	External / Circumferential Size	Spacing (in)	Area Ratio	Volume Ratio	Real Constant
Dome Center		0.0									
			6	6.0	0.0736	0.0736	6	6	0.0736	0.0736	300
		75.0									
			6	10.2	0.0433	0.0433	6	12	0.0368	0.0368	301
		120.0									
			6	18.8	0.0234	0.0469	6	12	0.0368	0.0368	302
			6	18.8	0.0234						
		240.0									
			6	30.6	0.0144	0.0577	6	12	0.0368	0.0368	303
			6	30.6	0.0144						
			6	15.3	0.0288						
Curve/Straight Line Joint		345.0									
			6	37.9	0.0117	0.0467	8	12.00	0.0654	0.0654	304
			6	37.9	0.0117						
			6	18.9	0.0233						
		378.0									
			6	41.5	0.0106	0.0426	11	9.00	0.1735	0.1735	305
			6	41.5	0.0106						
			6	20.8	0.0213						
			6	10.4	0.0426						
Dome/Haunch Joint		415.0									

SST-SX - Steel Reinforcement Ratios for Dome - Ref H-2-39512, H-2-39513 300

Description	Elevation (in)	Radius (in)	Internal / Meridional Size	Spacing (in)	Area Ratio	Volume Ratio	Internal / Circumferential Size	Spacing (in)	Area Ratio	Volume Ratio	Real Constant
Dome Center		0.0									
			6	6	0.0736	0.0736	6	6	0.0736	0.0736	300
		75.0									
			6	10.2	0.0433	0.0433	6	12	0.0368	0.0368	301
		120.0									
			6	18.8	0.0234	0.0469	6	12	0.0368	0.0368	302
			6	18.8	0.0234						
		240.0									
			6	30.6	0.0144	0.0577	6	12	0.0368	0.0368	303
			6	30.6	0.0144						
			6	15.3	0.0288						
Curve/Straight Line Joint		345.0									
			6	37.9	0.0117	0.0467	8	12	0.0654	0.0654	304
			6	37.9	0.0117						
			6	18.9	0.0233						
		378.0									
			6	41.5	0.0106	0.0426	11	9	0.1735	0.1735	306
			6	41.5	0.0106						
			6	20.8	0.0213						
Dome/Haunch Joint		415.0									

Table 5. Calculation of Steel Reinforcement Ratios for Haunch

SST-SX - Steel Reinforcement Ratios for Haunch - Ref H-2-39513 400

Description	Elevation (in)	Radius (in)	External / Meridional Size	Spacing (in)	Area Ratio	Volume Ratio	External / Circumferential Size	Spacing (in)	Area Ratio	Volume Ratio	Real Constant
Dome/Haunch Joint		415.0									
			6	45.7	0.0097	0.0773	11	7.125	0.2192	0.2192	400
			6	45.7	0.0097						
			6	22.9	0.0193						
			6	11.4	0.0386						
			6	11.4	0.0386						
Haunch Corner	54.1	466.0									
			6	16.0	0.0276	0.0276	11	4.875	0.3203	0.3203	401
Wall/Haunch Joint	0"										

SST-SX - Steel Reinforcement Ratios for Haunch - Ref H-2-39513 400

Description	Elevation (in)	Radius (in)	Internal /Meridional Size	Spacing (in)	Area Ratio	Volume Ratio	Internal / Circumferential Size	Spacing (in)	Area Ratio	Volume Ratio	Real Constant
Dome/Haunch Joint		415.0									
			6	45.7	0.0097	0.0386	11	10.8571	0.1438	0.1438	402
			6	45.7	0.0097						
			6	22.9	0.0193						
Wall/Haunch Joint	0.0										

Table 6. Calculation of Steel Reinforcement Ratios for Haunch Core

SST-SX - Steel Reinforcement Ratios for Haunch Interior - Ref H-2-39513 500

Description	Circumferential Size	Quantity	Bar area (in^2)	Haunch area (in^2)	Volume Ratio	Diagonal Ties Size	Quantity	Bar area	Area (in^2)	Volume Ratio	Real Constant
Haunch Interior											
	11	2	3.1229	1610.4000	0.0349	5	7	2.1476	1968.0000	0.0011	500
	11	3	4.6844								
	11	4	6.2458								
	11	5	7.8073								
	11	6	9.3687								
	11	7	10.9302								
	11	9	14.0531								

Vertical Ties

Size	Quantity	Bar area	Area (in^2)	Volume Ratio
5	8	2.4544	1248.0000	0.0020

Table 7. Element Coordinate Systems

CS Number	System Type	Element Axes			Covered Region
		x	y	z	
100	Spheroidal	Thickness Direction	Radial Direction	Hoop Direction	Interior rebars in dome and haunch, haunch core
101	Spheroidal	Thickness Direction	Radial Direction	Hoop Direction	Exterior rebars in dome and haunch
110	Cylindrical	Radial Direction	Hoop Direction	Vertical Direction	Rebars in wall and slab, vertical part of the exterior haunch rebar

Table 8. Input File List

Input File Name	Function	Calling For
sst_sx_slice.mac	Main input creating parametric slice model for SST-SX tank and getting solutions	parm_sx.mac sx_load_slice.mac
parm_sx.mac	Set all parametric variables used to create the parametric model	NONE
slice_load_sx.mac	Apply boundary conditions and AOR loads	NONE
pst_sx_slice.mac	Calculate section forces/moments and generate path plots, output path data to path_sx.dat file	get_res_slice.mac get_hpfrc.mac plpng.mac path_sx.plt axial_path.mac shear_path.mac hoop_path.mac moment_path.mac
get_res_slice.mac	Calculate total forces and moments at individual cross section	NONE
get_hpfrc.mac	Calculate hoop force from hoop stress results	NONE
plpng.mac	Create image hard copy in png format	NONE
path_sx.plt	View setting for path plot	NONE
axial_path.mac	Define and plot the path plot of axial force	NONE
shear_path.mac	Define and plot the path plot of shear force	NONE
hoop_path.mac	Define and plot the path plot of hoop force	NONE
moment_path.mac	Define and plot the path plot of moment	NONE

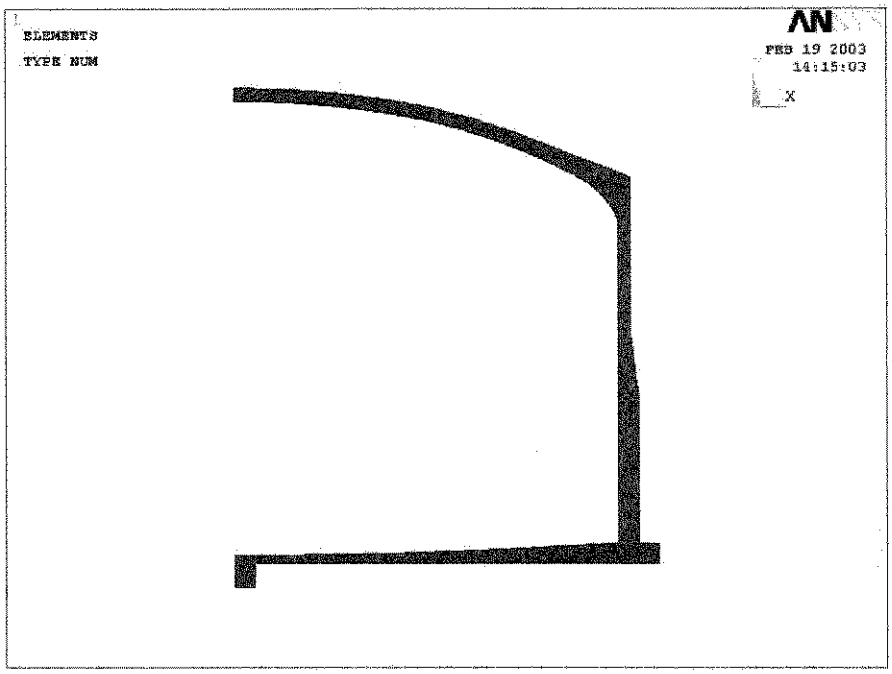

Figure 1. Geometry of SST-SX Tank

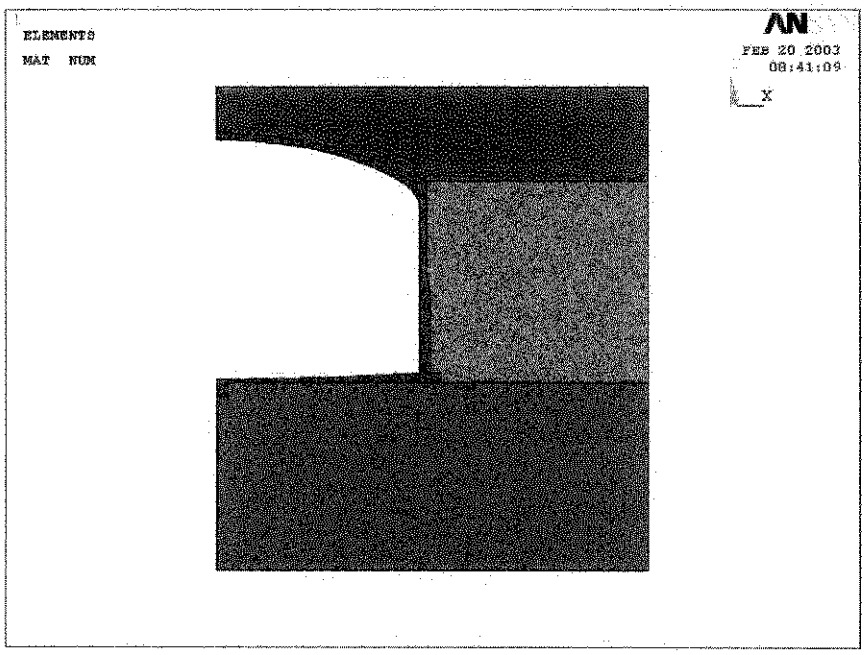

Figure 2. Soil Layers

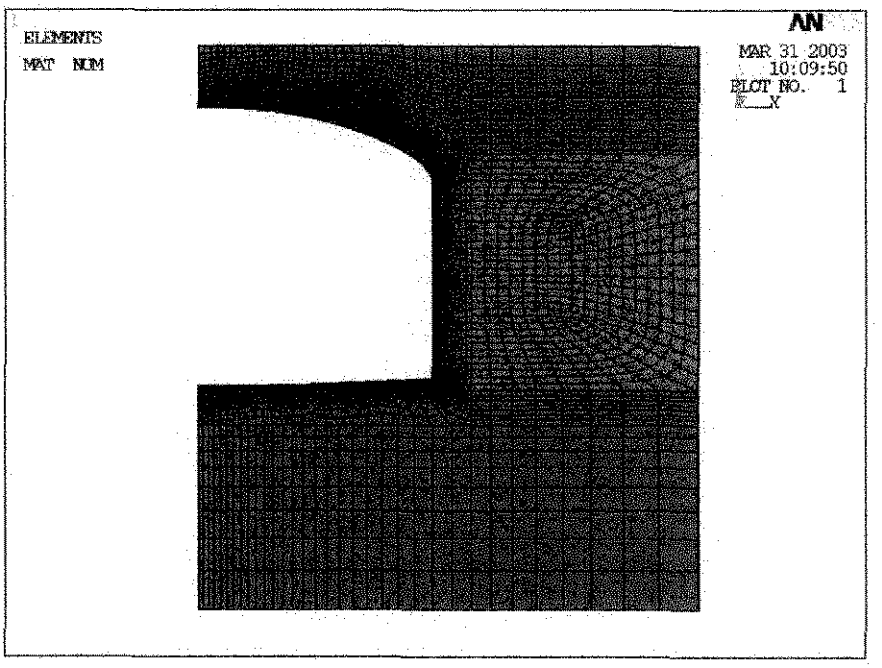

Figure 3. Finite element mesh, showing elements colored by material ID.

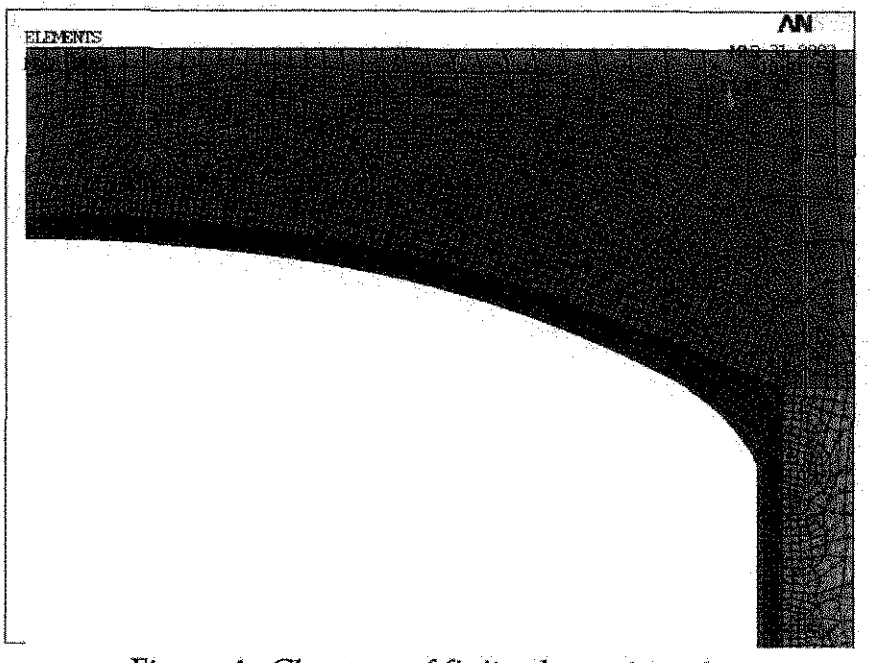

Figure 4. Close-up of finite element mesh.

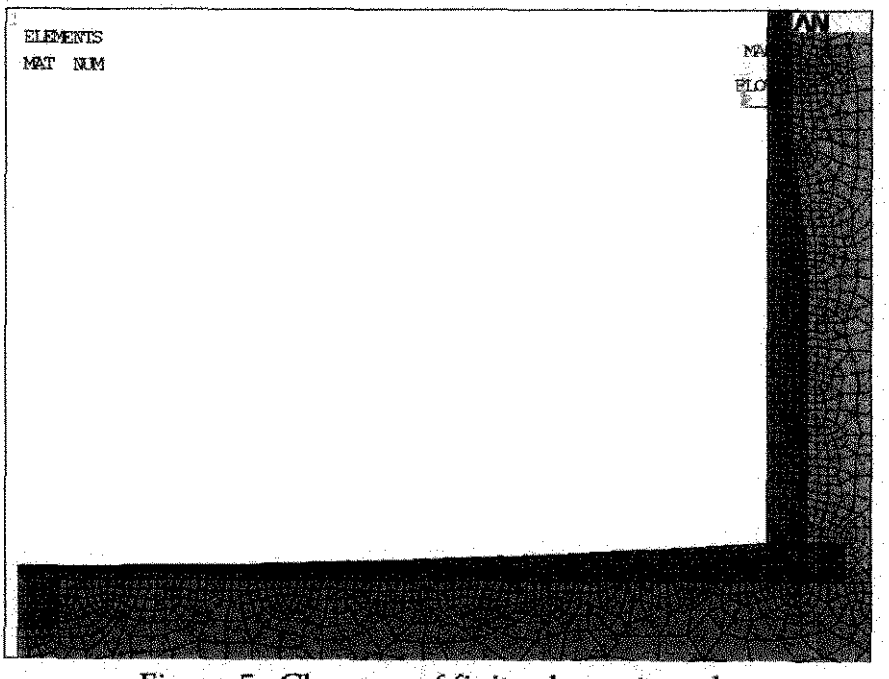

Figure 5. Close-up of finite element mesh.

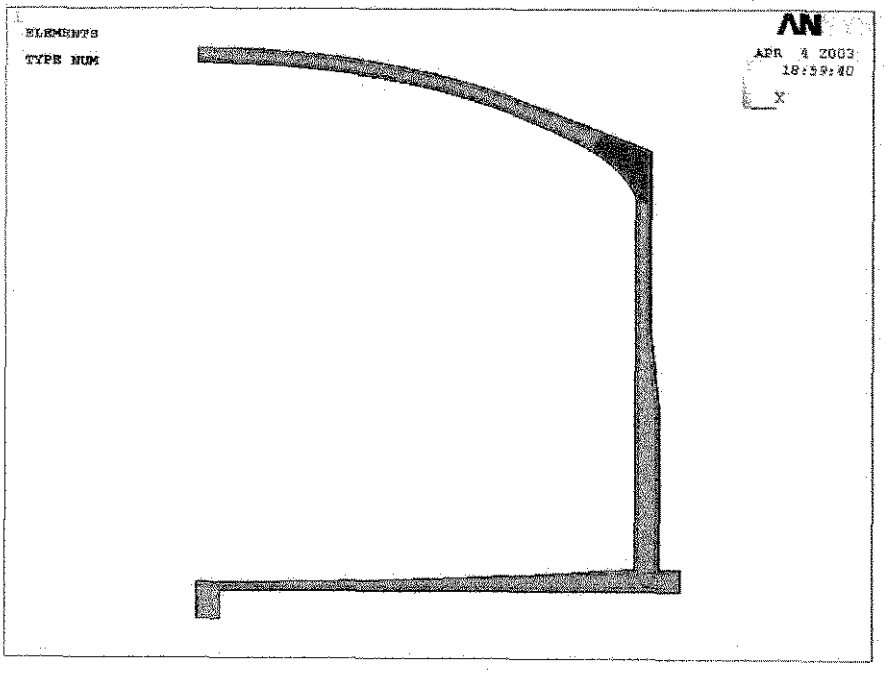

Figure 6. Rebar region (blue colored area)

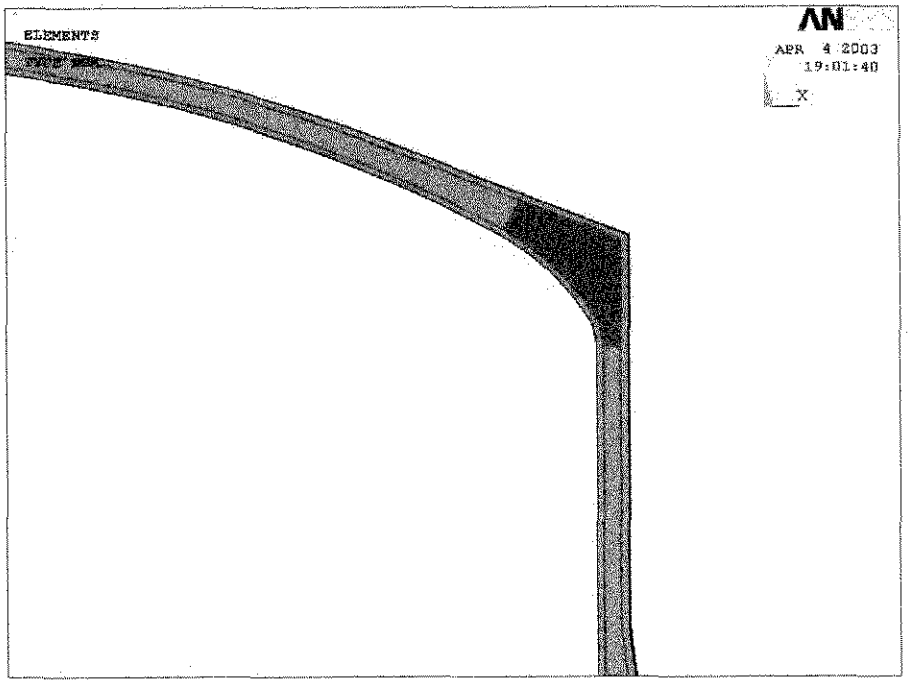

Figure 7. Close up of rebar region

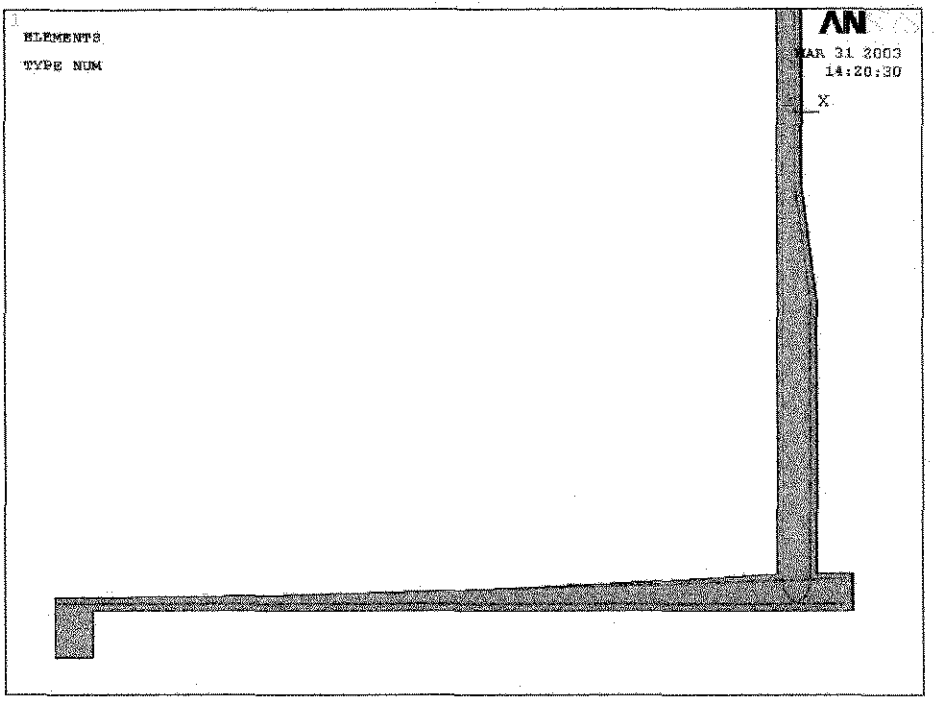

Figure 8. Close up of rebar region

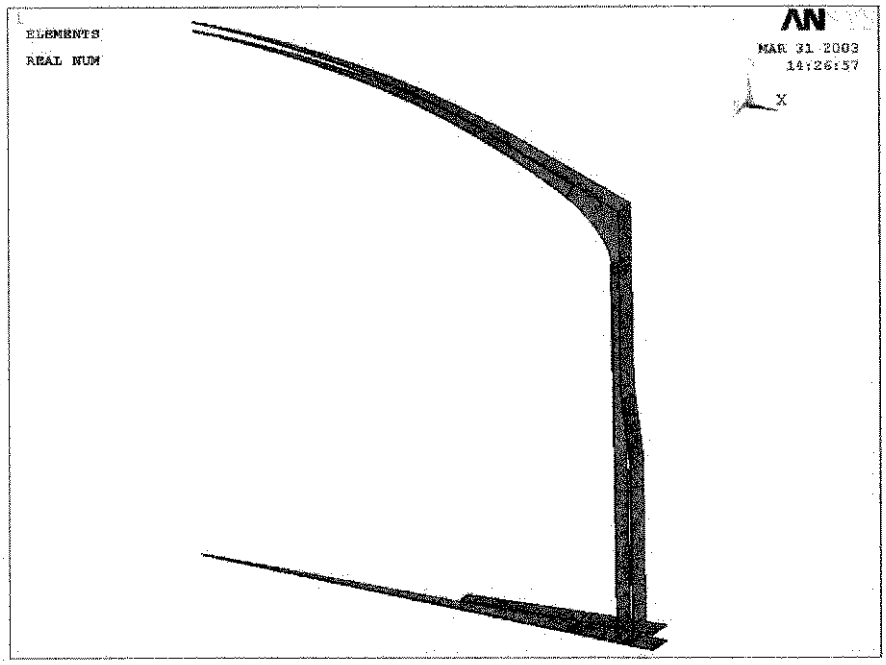

Figure 9. Rebar elements colored by real constants

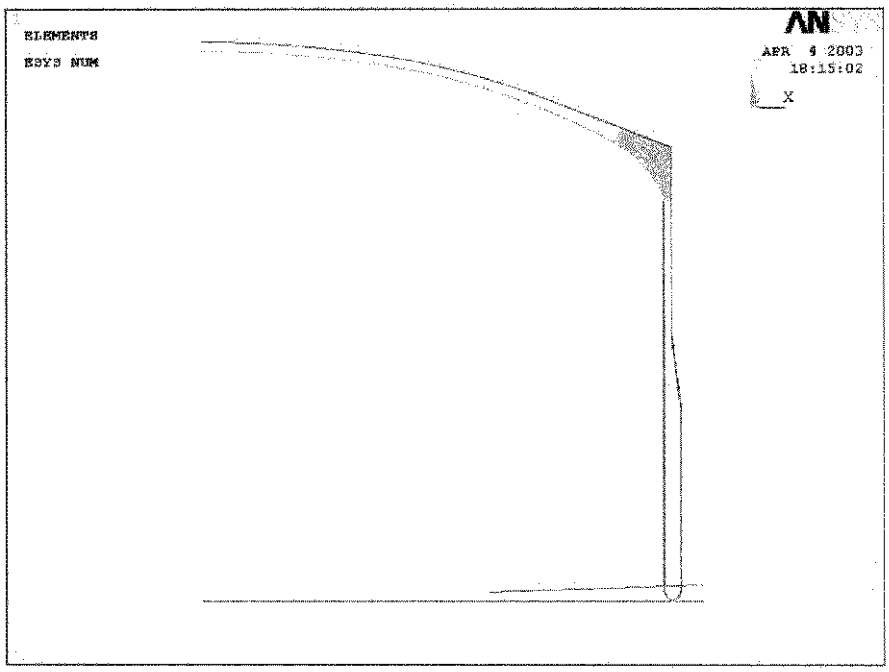

Figure 10. Rebar elements colored by element coordinate systems

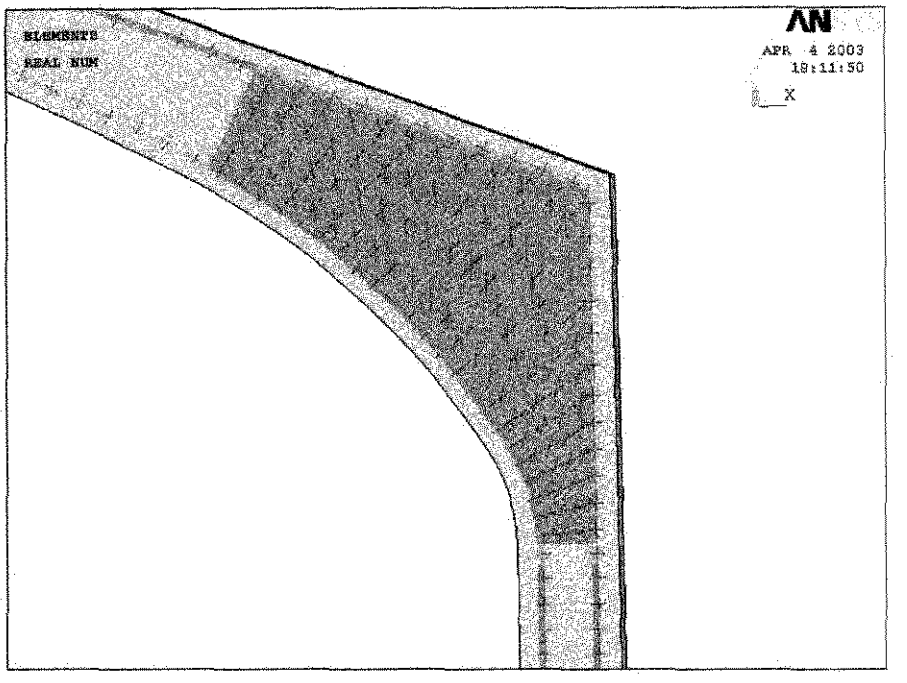

Figure 11. Rebar orientation at haunch core

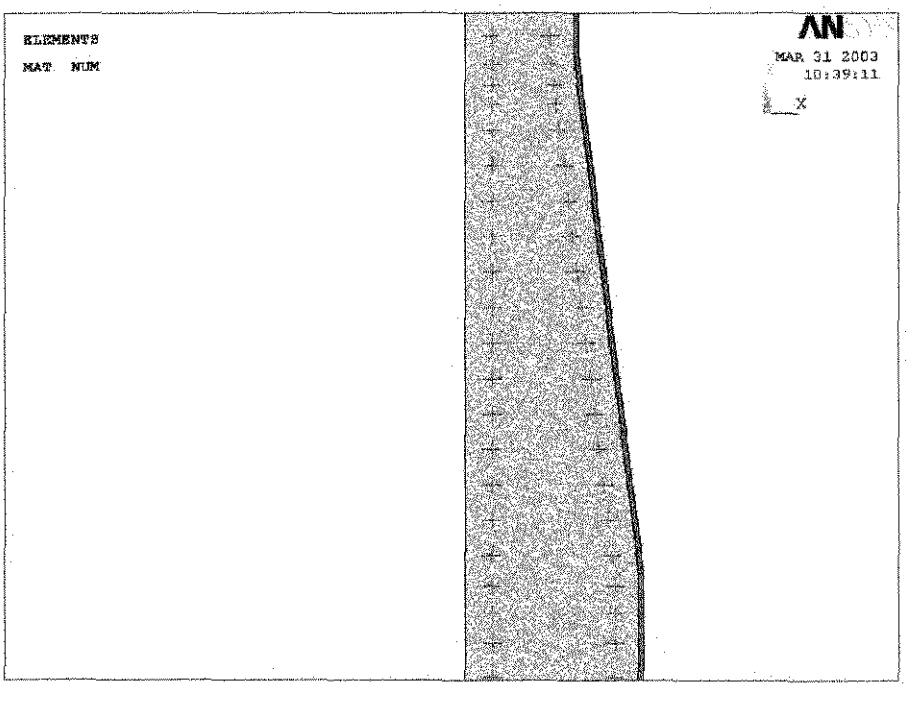

Figure 12. Rebar orientation at tank transition region

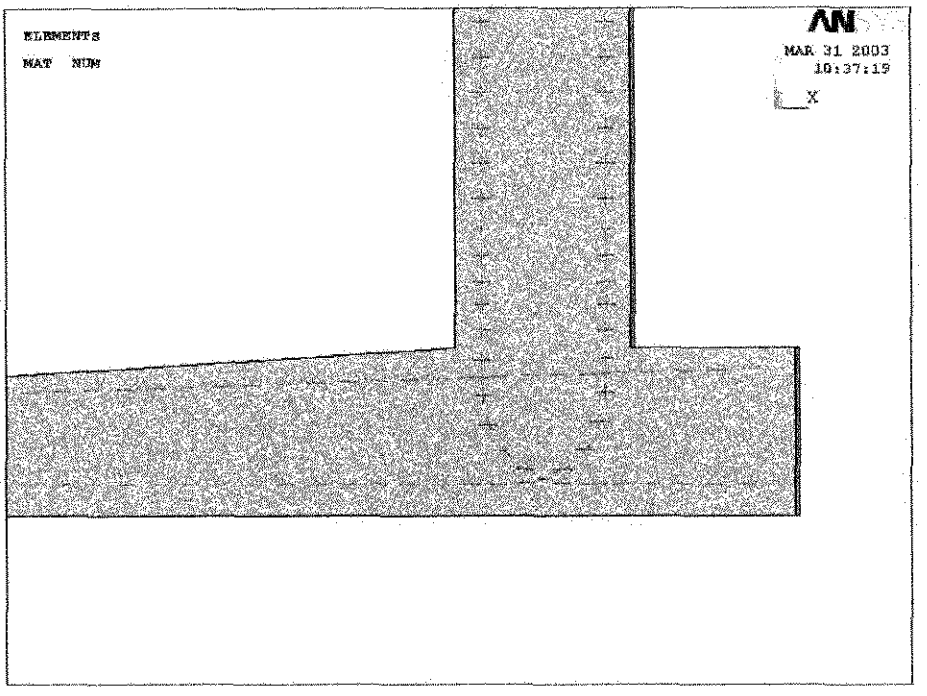

Figure 13. Rebar orientation at wall/slab joint

4.0 RESULTS

The solution can be obtained by running the master input macro **sst_sx_slice.mac** (see attachment), which loads the macro defining the parameters, creates the tank/soil geometry and finite element mesh, applies loads, and defines the material properties and real constants.

Figures 14 and 15 summarize the displacement response due to AOR loads identified in Section 3. The peak displacement of the soil mass is 2.08 inches, and this occurs at grade far away from the tank. The peak tank displacement is 1.33 inches, at the dome apex. Figures 16 and 17 show exaggerated views of the tank/soil displacement.

The von Mises equivalent stress contours are presented in Figures 18 and 19. The peak equivalent stress in the tank is approximately 2.3 ksi, and this occurs at the joint of the tank wall and slab. The hoop stress of the tank is shown in Figure 20. The maximum hoop stress is about 471 psi at the haunch region, and the minimum hoop stress is -797 psi at the wall/slab joint. The rebar stresses in the element x, y, and z axes are plotted in Figures 21 to 26.

Force and moment resultants are calculated in **pst_sx_slice.mac**. In order for **pst_sx_slice.mac** to generate correct results, the tank has to be map meshed. The mapped mesh results in a set of nodes aligned in a straight line, creating a cross section for section force and moment evaluation. Once the cross section nodes and elements attached to one side of the nodes are selected, the macro **get_res_slice.mac** then calculates the nodal forces, determines the location of the neutral axis, and evaluates the moment about the neutral axis. The force and moment per unit length are calculated according to the radius of the neutral axis. The section hoop force is calculated in macro **get_hpfrc.mac**. The nodal hoop stresses are retrieved and averaged over the thickness. The hoop force over the meridional length is then obtained from the averaged nodal hoop stress and wall thickness. Figures 27 to 30 show the axial force, shear force, hoop force, and moment, respectively. The wall/slab joint sees the most severe loading, with maximum axial force of about 85 kip/ft, maximum shear force of 47 kip/ft, and maximum moment of 1786 kip-in/ft. Maximum hoop force of 97 kip/ft occurs at the haunch region.

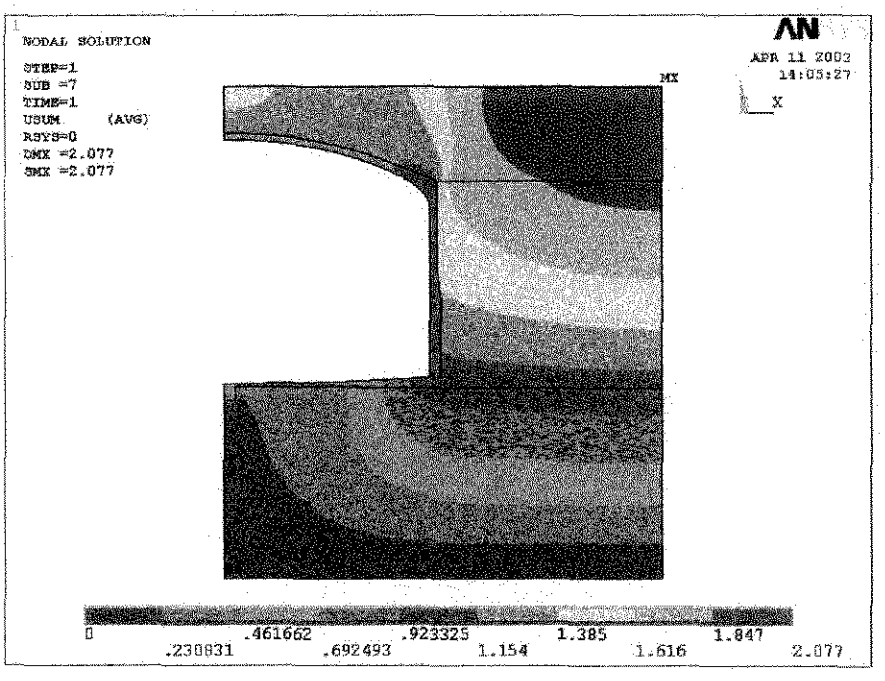

Figure 14. Total displacement contour of soil and tank

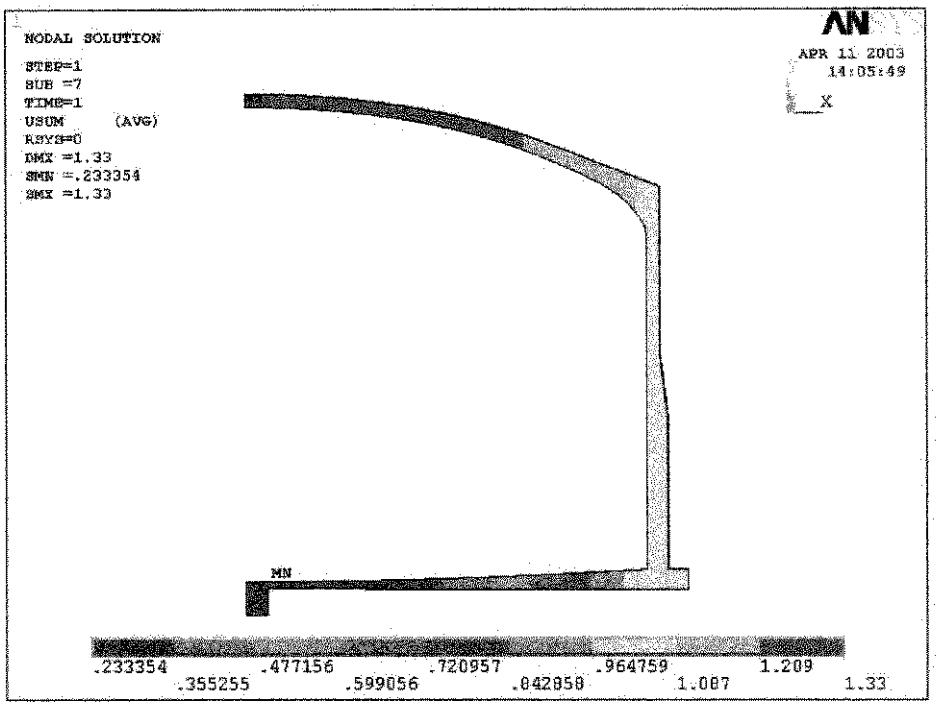

Figure 15. Total displacement contour of tank

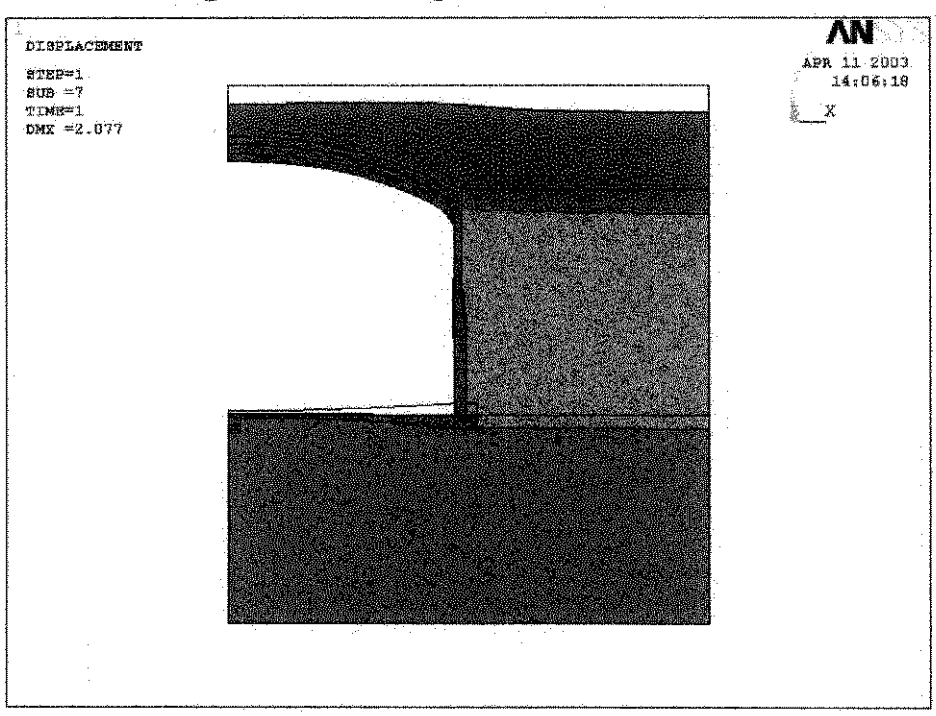

Figure 16. Deformed shape of soil

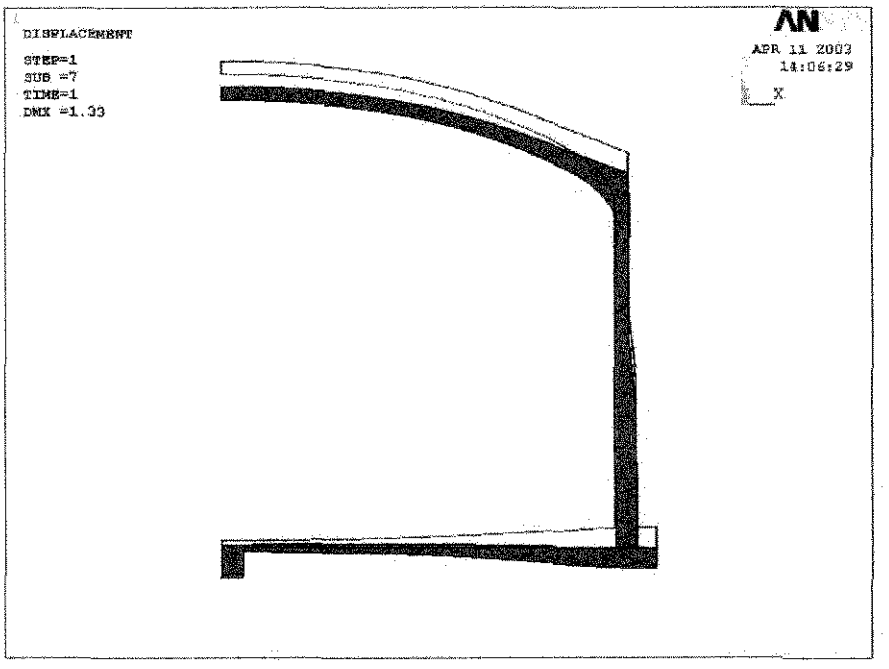

Figure 17. Deformed shape of tank

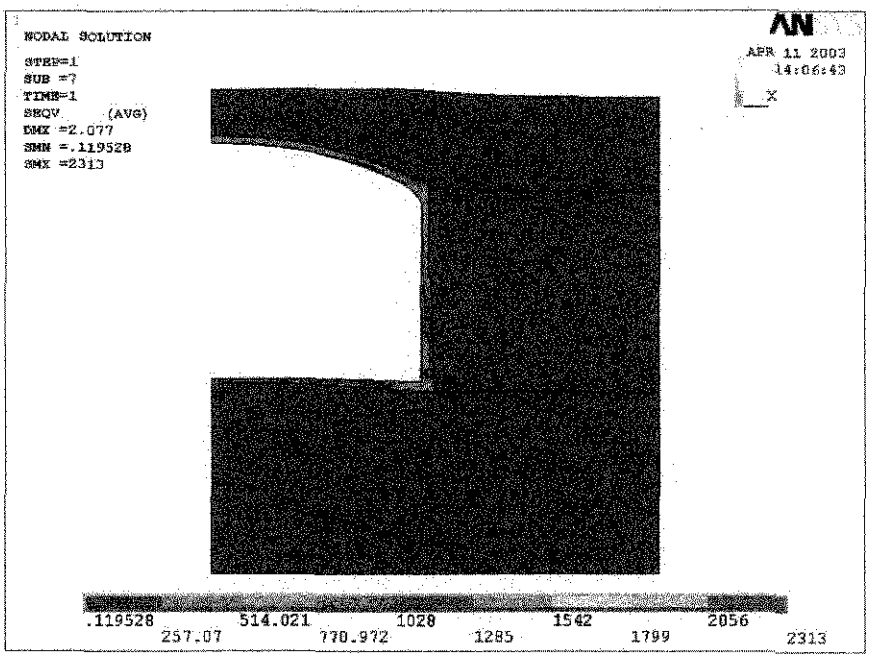

Figure 18. Equivalent stress contours of tank and soil (psi).

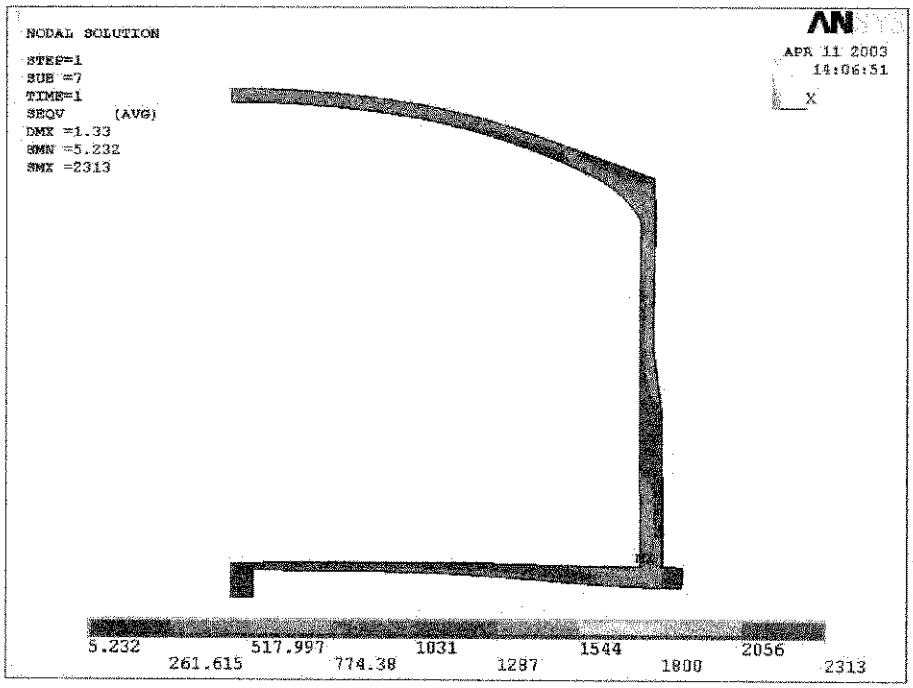

Figure 19. Equivalent stress contours of tank (psi).

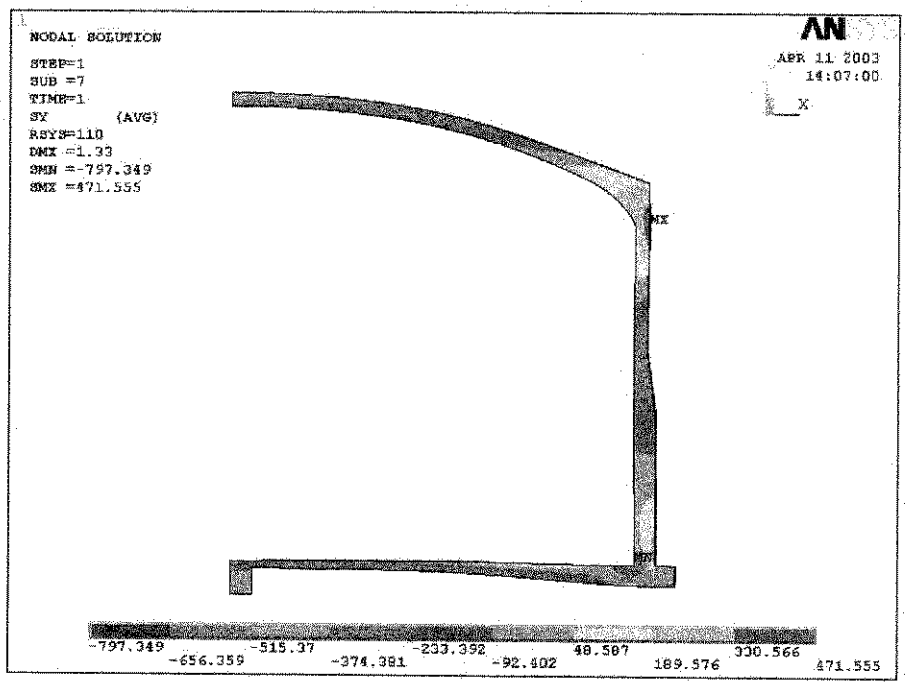

Figure 20. Hoop stress of tank (psi)

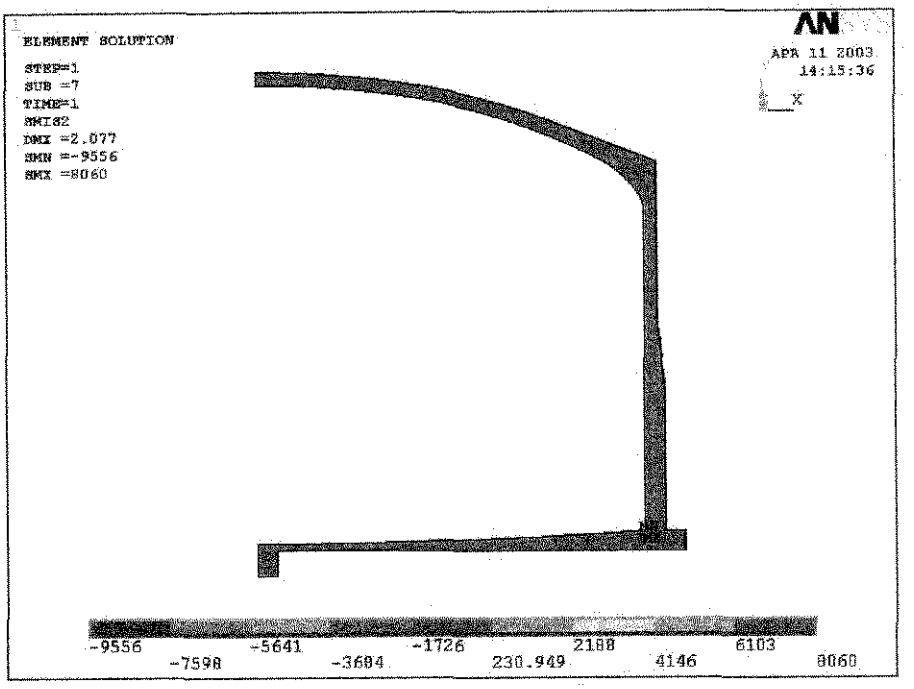

Figure 21. Rebar stresses in first rebar direction

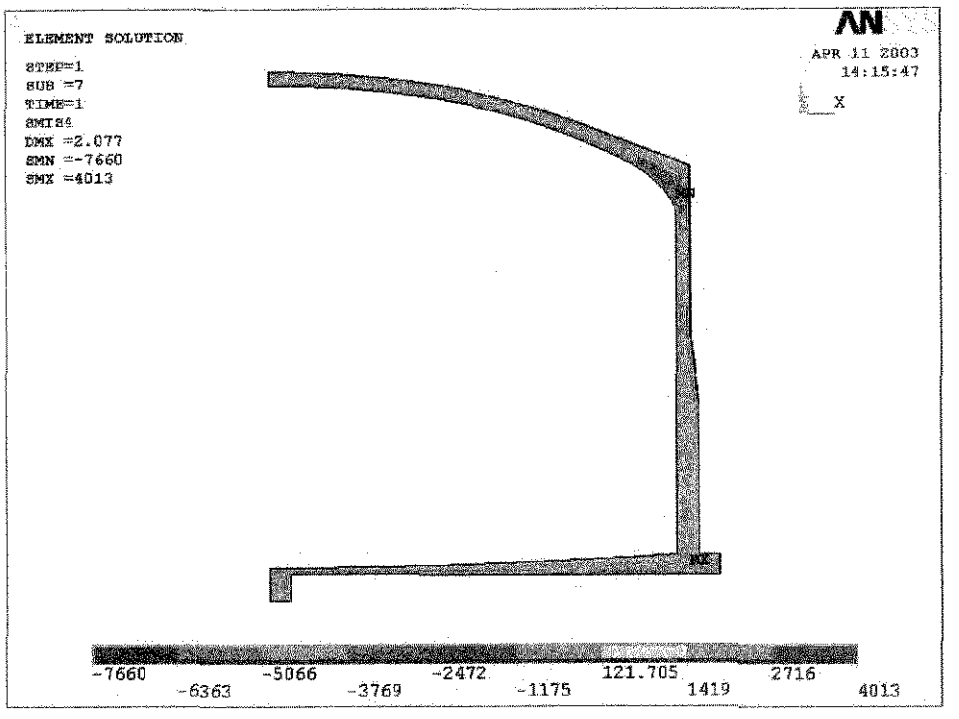

Figure 22. Rebar stresses in second rebar direction

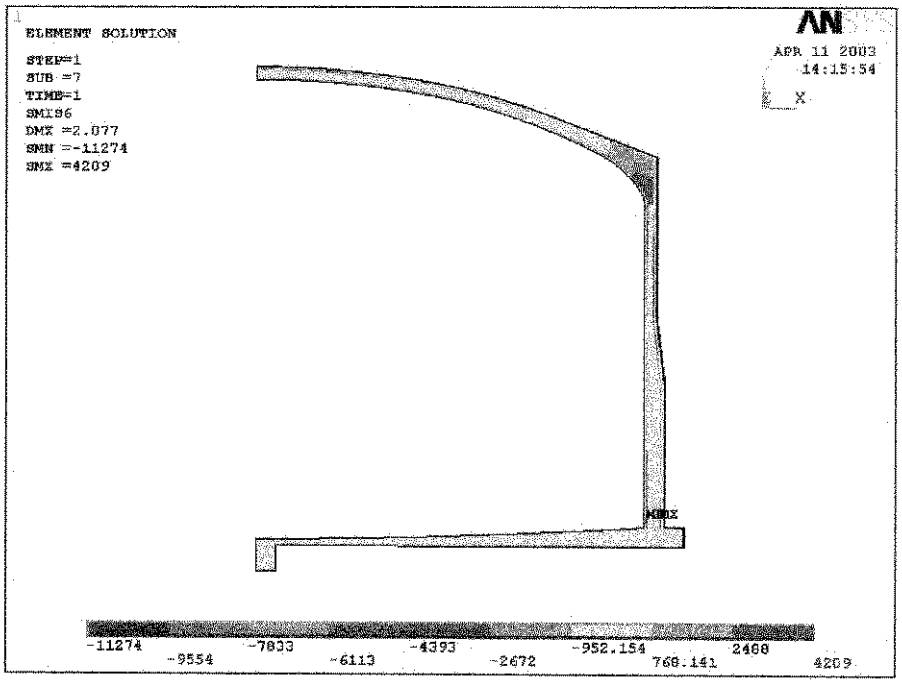

Figure 23. Rebar stresses in third rebar direction

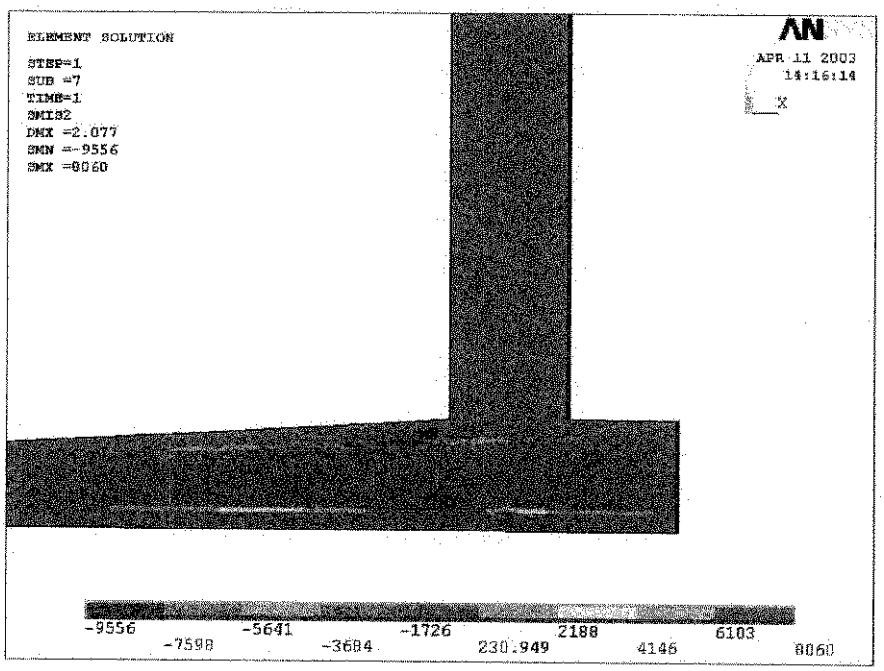

Figure 24. Close up of rebar stresses in first rebar direction

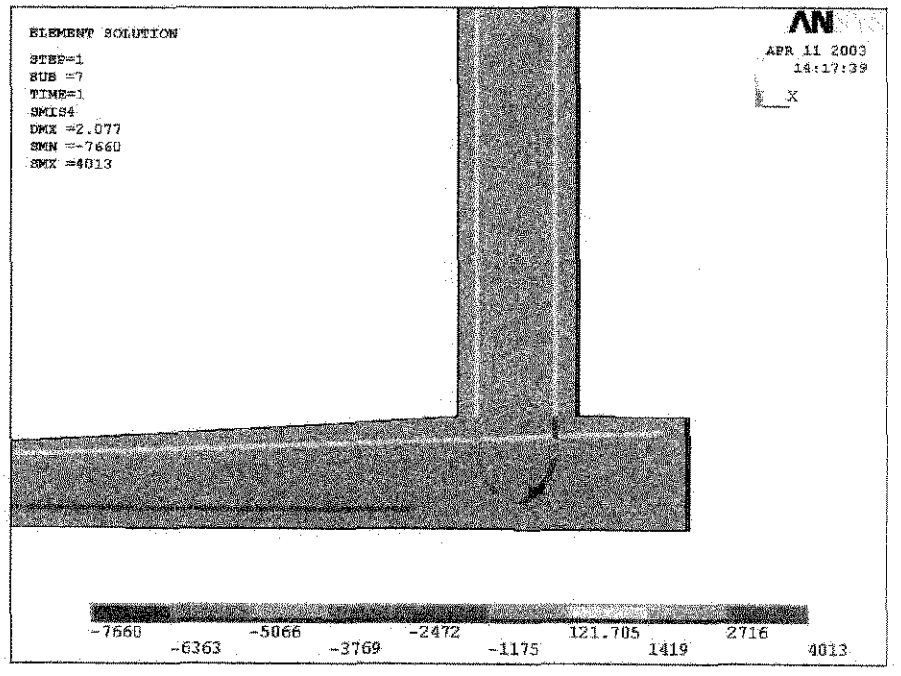

Figure 25. Close up of rebar stresses in second rebar direction

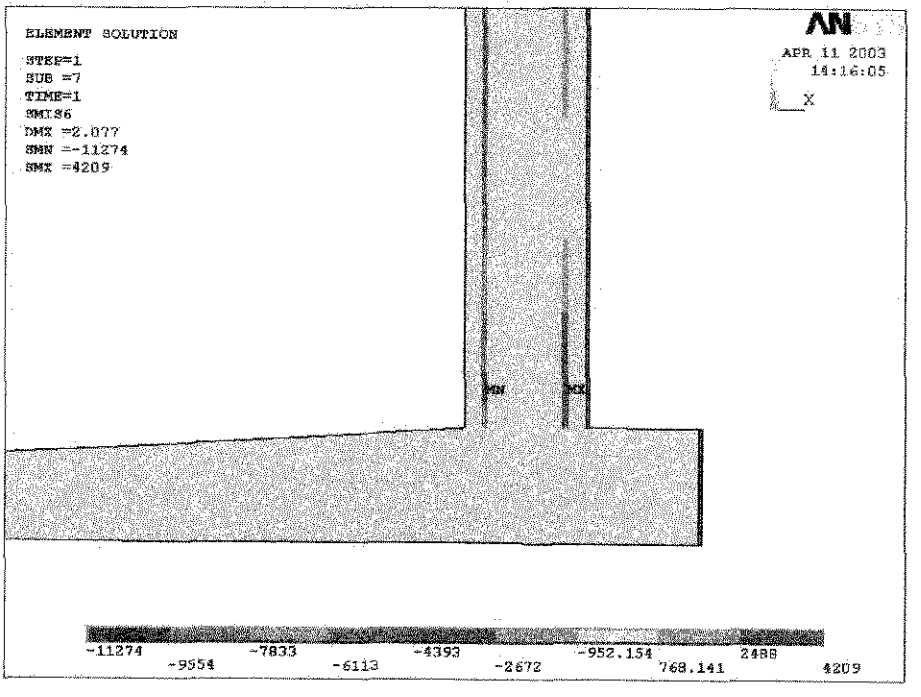

Figure 26. Close up of rebar stress in third rebar direction

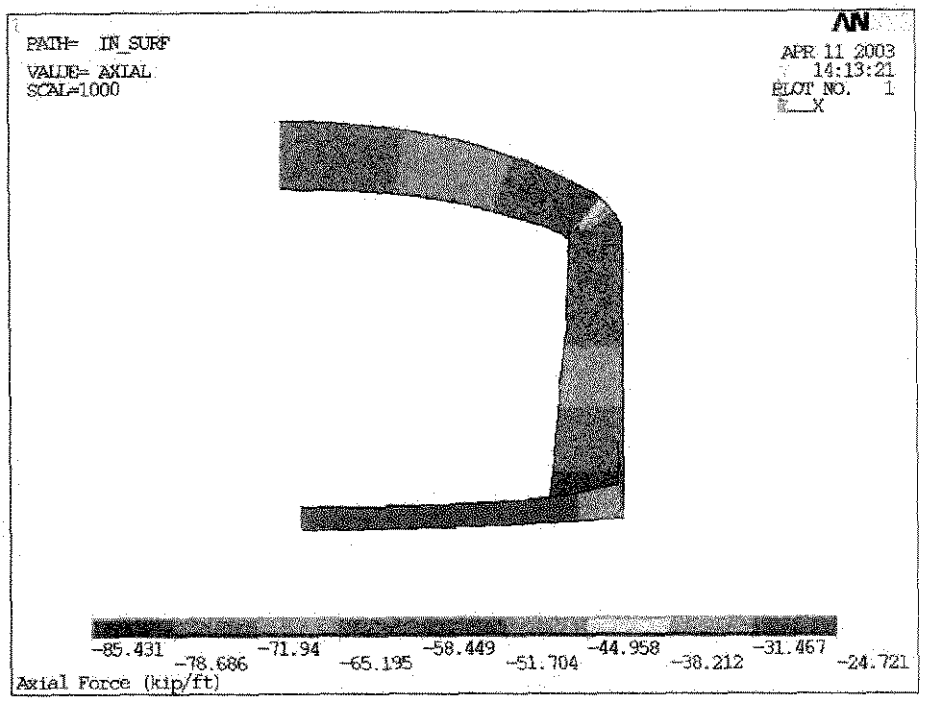

Figure 27. Unit section axial force (kip/ft)

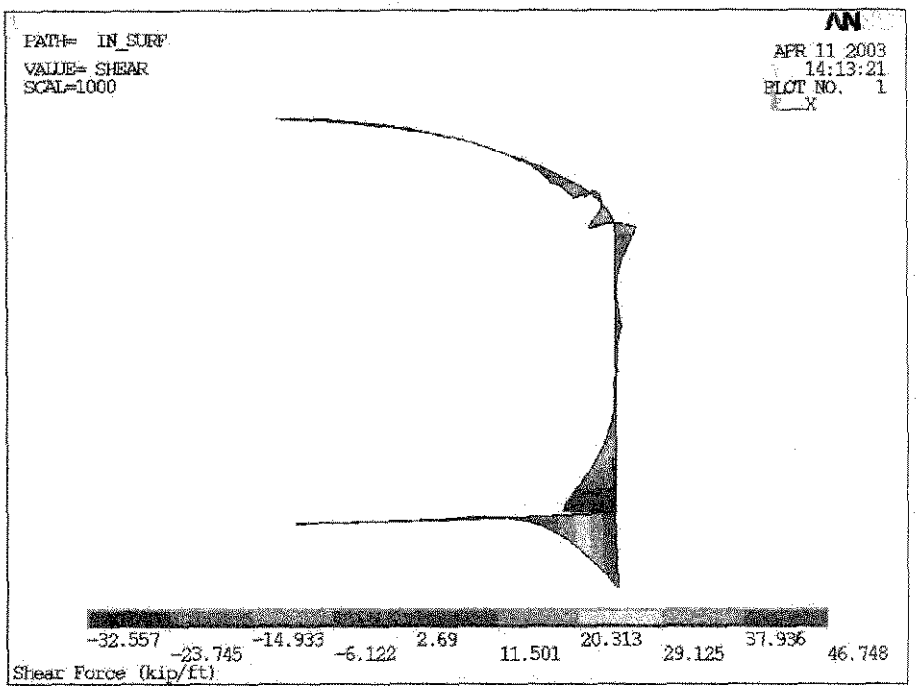

Figure 28. Unit section shear force (kip/ft)

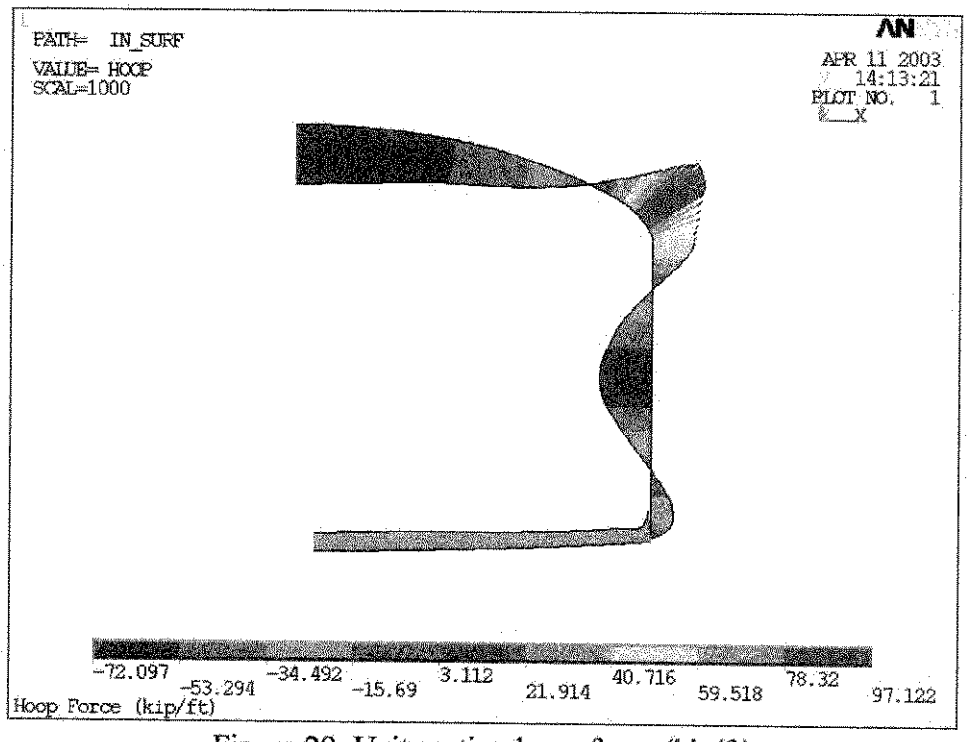

Figure 29. Unit section hoop force (kip/ft)

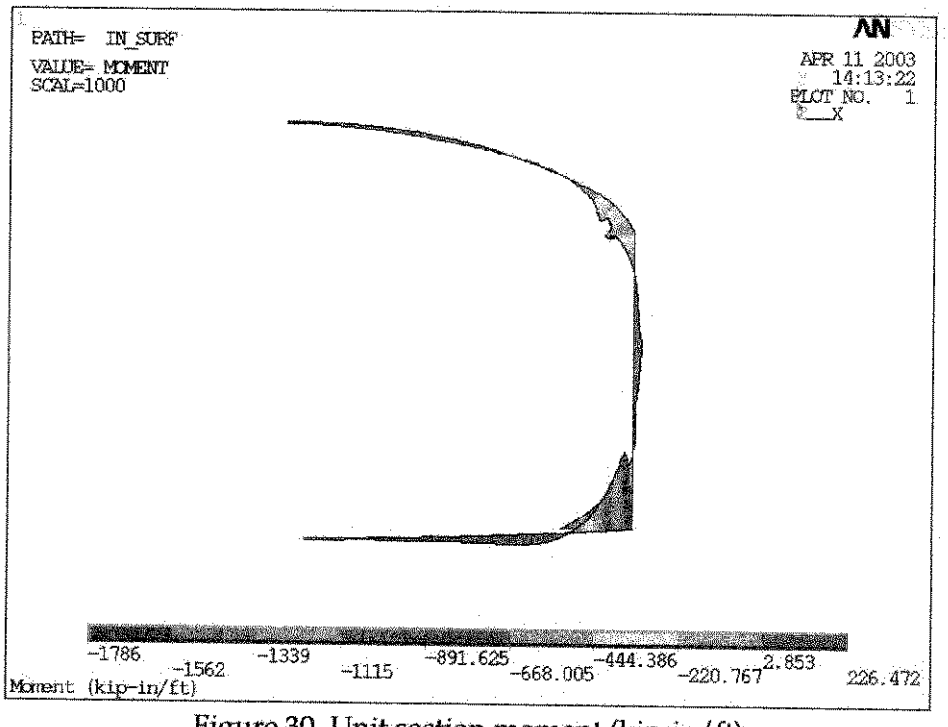

Figure 30. Unit section moment (kip-in/ft)

5.0 CONCLUSIONS

The 3D parametric slice model is capable of giving a more accurate estimation, compared with the 2D linear model, of tank behavior under AOR loads because of the inclusion of contact and soil plasticity. A sample calculation demonstrates the use of the parametric model for tank SST-SX, and provides examples of the types of inputs that can be defined and the types of outputs that can be obtained. The parametric model can be used effectively to evaluate the tank response to a broad range of loading conditions and material properties.

6.0 REFERENCES

[Ref_1] ANSYS 7.0 General-Purpose Finite Element Analysis Program, ANSYS Inc.

[Ref_2] M&D Professional Services, "Dome Load Evaluation for Hanford 241-C Farm 100-Series Tanks", Document Number RPP-14249, January 14, 2003.

[Ref_3] Statement of Work, Requisition #92879, "Development of ANSYS Finite Element Models for SST and DST Tanks," Revision 0, October 14, 2002.

[Ref_4] Drawing H-2-39511, September 2, 1953

[Ref_5] JLR The Engineering Solutions Company, "Sample AOR Calculation Using ANSYS Axisymmetric Parametric Model for Tank SST-SX", RPP-13991, March 11, 2003

7.0 ATTACHMENTS AND APPENDICES

sst_sx_slice.mac

```
!--Create cross section of SST SX tank
finish
/clear
/prep7

/INPUT,'parm_sx','mac'

!--Create dome
/TRIAD,RTOP
k,1,
wpcsys,-1,0
wpoff,,dm_r1,
csys,4
k
*get,k_max,kp,,num,max
*get,x_loc,kp,k_max,loc,x
*get,y_loc,kp,k_max,loc,y
k,,,dm_r2-dm_r1
k,,x_loc-dm_dr1,y_loc-dm_oh1
k,,x_loc-dm_dr3-dm_dr1,y_loc-dm_oh2
k,,x_loc-tk_or1,y_loc-hnch_h1

*get,x_loc,kp,3,loc,x
*get,y_loc,kp,3,loc,y
k,,x_loc-dm_dr2,y_loc-dm_ih1
*get,x_loc,kp,7,loc,x
*get,y_loc,kp,7,loc,y
k,,x_loc-dm_dr4,y_loc-dm_ih2
*get,x_loc,kp,8,loc,x
*get,y_loc,kp,8,loc,y
k,,x_loc-hnch_dr3,y_loc-hnch_h3
*get,x_loc,kp,9,loc,x
*get,y_loc,kp,9,loc,y
k,,x_loc-hnch_dr4,y_loc-hnch_h4

*get,x_loc,kp,6,loc,x
*get,y_loc,kp,6,loc,y
k,,x_loc,y_loc-hnch_h2

*get,x_loc,kp,11,loc,x
*get,y_loc,kp,11,loc,y
k,,x_loc,y_loc-tk_h1

*get,x_loc,kp,12,loc,x
*get,y_loc,kp,12,loc,y
k,,x_loc-(tk_t2-tk_t1),y_loc-tk_h2
```

```
*get,x_loc,kp,13,loc,x
*get,y_loc,kp,13,loc,y
k,,x_loc,y_loc-tk_h3

*get,x_loc,kp,14,loc,x
*get,y_loc,kp,14,loc,y
k,,x_loc-slb_dr,y_loc

*get,x_loc,kp,15,loc,x
*get,y_loc,kp,15,loc,y
k,,x_loc,y_loc-slb_t1

*get,x_loc,kp,3,loc,x
*get,y_loc,kp,16,loc,y
k,,x_loc-slb_dr2,y_loc

*get,x_loc,kp,17,loc,x
*get,y_loc,kp,17,loc,y
k,,x_loc,y_loc-slb_dt1

*get,x_loc,kp,3,loc,x
*get,y_loc,kp,18,loc,y
k,,x_loc,y_loc

*get,x_loc,kp,3,loc,x
*get,y_loc,kp,19,loc,y
k,,x_loc,y_loc+slb_dt1+slb_dt2+slb_dt3

*get,x_loc,kp,10,loc,x
*get,y_loc,kp,10,loc,y
k,,x_loc,y_loc-tk_h4+slb_dh2

lstr,2,3
larc,2,4,1,dm_r1
larc,4,5,1,dm_r3
larc,3,7,1,dm_r2
larc,7,8,1,dm_r4
lstr,5,6
larc,8,9,1,hnch_r1
larc,9,10,1,hnch_r2
lstr,6,11
lstr,11,12
lstr,12,13
lstr,13,14
lstr,14,15
lstr,15,16
lstr,16,17
lstr,17,18
lstr,18,19
lstr,19,20
```

```
larc,20,21,3,liner_r1
lstr,10,21
al,all

*get,x_loc,kp,21,loc,x
*get,y_loc,kp,21,loc,y
k,,x_loc-slb_dr3,y_loc

*get,x_loc,kp,22,loc,x
*get,y_loc,kp,21,loc,y
k,,x_loc-slb_dr4,y_loc-slb_dh

*get,x_loc,kp,20,loc,x
*get,y_loc,kp,20,loc,y
k,,x_loc,y_loc-slb_dt3

lstr,21,22
larc,23,24,3,slb_r1
lstr,23,14
lsel,s,,,22,23
asel,s,,,1
asbl,all,all

lsel,none
lstr,21,23
*get,l_num,line,,num,min
asel,s,,,3
lsel,s,,,l_num
asbl,all,all

allsel
lsel,none
lstr,10,11
*get,l_num,line,,num,min
asel,s,,,4
lsel,s,,,l_num
asbl,all,all

allsel
lwplan,-1,7
asbw,5

wpcsys,-1,0
kwpave,2
wpoff,,depth
csys,4
rectng,0,-soil_r,0,-soil_h,
allsel
aovlp,all
adele,7,,,1
```

```
allsel
wpcsys,-1,0
wprot,,90
cswpla,11,0
cswpla,12,1

kwpave,2
wprot,,90
wprot,,,90
off_set1=5*12
off_set2=3*12
wpoff,,,-tk_or1-off_set1
asbw,8
kwpave,19
wprot,,90
wpoff,,,-off_set2
asbw,5
asbw,7

csys,0
arsym,x,all,,,,1,0
asel,s,loc,x,0,-99999
adele,all,,,1
allsel
numcmp,all
wpcsys,-1,0
wprot,,,90
kwpave,35
wpoff,,,cload_1
lsbw,41

!--cut soil for different soil properties
kwpave,20
wprot,,90
asbw,8
asbw,9
kwpave,11
asbw,10
asbw,12
wprot,,-90

!------- Cut tank for mesh
allsel
asel,u,,,7,11
asel,u,,,5
asel,u,,,13,14
allsel,below,area
kwpave,10
wprot,,90
asbw,2
kwpave,13
```

```
wprot,,-90
asbw,15
kwpave,7
asbw,16
kwpave,10
asbw,17
wprot,,90
kwpave,15
asbw,3
kwpave,16
asbw,19
adele,1,,,1
lcomb,4,5
cm,a_tank,area

!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!    Cut dome for rbar regions
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]

rbar_dep=2  !clearance for rbar @dome
rbar_t=1.
rbar_dep2=3.375 !clearance for interior rebar @ wall
rbar_dep3=3.625 !clearance for exterior rebar @ wall
rbar_dep4=3.5     !clearance for bottomr rebar @ slab
rbar_dep5=11.75 !distance from top slab rbar to slab bottom(int. end)
rbar_dep6=19.25   !distance from top slab rbar to slab bottom(ext. end)

csys,4
lwpla,-1,27
wpoff,,,rbar_dep
k
wpoff,,,rbar_t
k
lwpla,-1,27,1
wpoff,,,-rbar_dep
k
wpoff,,,-rbar_t
k

kwpla,-1,28,30
wpoff,rbar_dep
k
wpoff,rbar_t
k
kwpla,-1,30,28
wpoff,rbar_dep
k
wpoff,rbar_t
k
```

```
lwpla,-1,31,1
lsbw,29
wpoff,rbar_dep
k
wpoff,rbar_t
k
kwpave,53
wpoff,-rbar_dep
k
wpoff,-rbar_t
k

lwpla,-1,22
wpoff,,,rbar_dep
k
wpoff,,,rbar_t
k
kwpave,21
wpoff,,,-rbar_dep
k
wpoff,,,-rbar_t
k

lstr,4,5
lstr,47,48
larc,4,51,8,dm_r1-rbar_dep
larc,5,52,8,dm_r1-rbar_dep-rbar_t
larc,51,54,8,dm_r3-rbar_dep
larc,52,55,8,dm_r3-rbar_dep-rbar_t
lstr,54,60
lstr,55,61
lstr,60,61

lstr,47,48
larc,48,50,8,dm_r2+rbar_dep+rbar_t
larc,47,49,8,dm_r2+rbar_dep
larc,50,57,8,dm_r4+rbar_dep+rbar_t
larc,49,56,8,dm_r4+rbar_dep
larc,57,59,8,dm_r4+rbar_dep+rbar_t
larc,56,58,8,dm_r4+rbar_dep

lwpla,-1,18,1
wpoff,-rbar_dep
k
wpoff,-rbar_t
k
larc,59,63,8,hnch_r1+rbar_dep+rbar_t
larc,58,62,8,hnch_r1+rbar_dep
```

```
lwpla,-1,17
wpoff,,,rbar_dep2
k
wpoff,,,rbar_t
k
lwpla,-1,17,1
wpoff,,,-rbar_dep3
k
wpoff,,,-rbar_t
k
larc,63,65,8,hnch_r2+rbar_dep+rbar_t
larc,62,64,8,hnch_r2+rbar_dep

lextnd,67,60,60
lextnd,68,61,60
ldele,67,,,1
ldele,68,,,1

lsbw,81
ldele,68,,,1
kwpave,66
lsbw,80
ldele,81,,,1

lsbw,13
kwpave,67
lsbw,81
kwpave,65
lsbw,13
kwpave,64
lsbw,81

lstr,66,69
lstr,67,70
lstr,66,68
lstr,67,71
lstr,65,72
lstr,64,73

lwpla,-1,60
wpoff,,,rbar_dep3
lsbw,12
lsbw,60
wpoff,,,rbar_t
lsbw,90
lsbw,92

kwpave,45
wpoff,,,-rbar_dep2
lsbw,60
lsbw,90
```

```
wpoff,,,-rbar_t
lsbw,95
lsbw,96

lstr,72,81
lstr,73,79
lstr,68,75
lstr,71,77

lstr,75,74
lstr,76,77
lstr,80,81
lstr,78,79

lwpla,-1,53,1
wpoff,,,-rbar_dep4
asbw,2
asbw,15
asbw,16
asbw,18
wpoff,,,-rbar_t
asbw,19
asbw,21
asbw,22
asbw,23

kwpave,41
wpoff,282,,-rbar_dep5
k
kwpave,11
wpoff,-4.5,,-rbar_dep6
k
lstr,92,93
wpoff,,,-rbar_t
k
kwpave,92
wpoff,,,-rbar_t
k
lstr,94,95
lstr,92,95
lstr,93,94
al,115,125,126,127
al,97,98,104,105
al,93,94,102,103
al,84,96,98,99
al,82,94,100,101

lstr,64,65
lstr,66,67
al,84,88,89,128
al,82,86,87,129
```

```
aovlp,all


lstr,69,70
lstr,58,59
lstr,53,29
lstr,28,30

cm,l_temp,line
cm,a_temp,area

al,17,81,85,129

lsel,s,,,29
lsel,a,,,70,79
lsel,a,,,128
al,all

cmsel,a,l_temp
cmsel,a,a_temp

lsel,s,,,5
lsel,a,,,17
lsel,a,,,61
lsel,a,,,64,68
al,all

cmsel,a,l_temp
cmsel,a,a_temp

asbl,6,120
asbl,20,116
aovlp,all

wprot,,,90
asbw,15
asbw,26
asbw,48

lcomb,76,78
lcomb,77,79
lcomb,18,19

ksll
nummrg,kp

kwpave,78
asbw,2
asbw,19
asbw,43
asbw,46
```

```
asbw,49

kwpave,80
asbw,50
asbw,68
asbw,69
asbw,70
asbw,71

kwpave,76
asbw,69
asbw,72
asbw,73
asbw,74
asbw,76

kwpave,74
asbw,69
asbw,71
asbw,72
asbw,73
asbw,81

kwpave,94
asbw,1
asbw,24
asbw,47

wprot,,,90
asbw,90
kwpave,93
asbw,91

ksll
nummrg,kp

!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!        Cut division for different rbar length along
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]

!----dome radial direction
cut_r1=5*12
cut_r2=6.25*12
cut_r3=10*12
cut_r4=20*12
cut_r5=31*12+6
cut_dr6=54
wpcsys,-1,0
wprot,,,90
```

```
kwpave,26
wpoff,,,cut_r1
lsbw,32
wpoff,,,cut_r2-cut_r1
lsbw,216
wpoff,,,cut_r3-cut_r2
lsbw,32
wpoff,,,cut_r4-cut_r3
lsbw,31
wpoff,,,cut_r5-cut_r4
lsbw,30
lwpla,-1,21
wpoff,,,cut_dr6
lsbw,21

lwpla,-1,213,1
asbw,25
asbw,52
asbw,53
asbw,56
asbw,57

lwpla,-1,217,1
asbw,25
asbw,93
asbw,95
asbw,96
asbw,97

lwpla,-1,218,1
asbw,25
asbw,57
asbw,96
asbw,100
asbw,101

lwpla,-1,219,1
asbw,23
asbw,55
asbw,58
asbw,59
asbw,60

lwpla,-1,220,1
asbw,20
asbw,54
asbw,61
asbw,62
asbw,63
```

```
lwpla,-1,261
kwpave,132
asbw,51
asbw,64
asbw,65
asbw,66
asbw,67


!----Rebar regions in tank wall
!----interior surface
cut_vi1=3
cut_vi2=4
cut_vi3=11
cut_vi4=5
cut_vi5=4*12+8
cut_vi6=5*12
cut_vi7=19*12+1.5

lwpla,-1,63
wpoff,,,cut_vi1
asbw,all
wpoff,,,cut_vi2
asbw,all
wpoff,,,cut_vi3
asbw,all
wpoff,,,cut_vi4
asbw,all
wpoff,,,cut_vi5
asbw,all
wpoff,,,cut_vi6
asbw,all
wpoff,,,cut_vi7
asbw,all

!---cut exterior wall rebar areas
cut_vo1=3
cut_vo2=4
cut_vo3=11
cut_vo4=9
cut_vo5=4*12
cut_vo6=7
cut_vo7=4*12+6
cut_vo8=5.25
cut_vo9=19*12+1.5

lwpla,-1,297
wpoff,,,cut_vo1
wpoff,,,cut_vo2
wpoff,,,cut_vo3
wpoff,,,cut_vo4
```

```
asbw,all
wpoff,,,cut_vo5
asbw,all
wpoff,,,cut_vo6
asbw,all
wpoff,,,cut_vo7
asbw,all
wpoff,,,cut_vo8
asbw,all
wpoff,,,cut_vo9
asbw,all

!---rebar in top footing/slab
cut_tp_r1=23*12+6
cut_tp_r2=29*12+6

lwpla,-1,52,1
wpoff,,,-cut_tp_r2
asbw,6
asbw,17
asbw,18
asbw,21
asbw,44

!--- bottom footing rbars
cut_bt_r1=29*12+6+1.5*12
cut_bt_r2=cut_bt_r1+1.5*12
cut_bt_dr3=6*12

lwpla,-1,52,1
wpoff,,,-cut_bt_r1
asbw,6
asbw,17
asbw,18
asbw,21
asbw,36

lwpla,-1,52,1
wpoff,,,-cut_bt_r2
asbw,6
asbw,17
asbw,18
asbw,21
asbw,44

kwpave,121
wpoff,,,cut_bt_dr3
asbw,6
asbw,18
asbw,21
asbw,36
```

```
asbw,200

!---Misc. cut
wpcsys,-1,0
kwpave,18
wpoff,,-42.25
wprot,,90
lsbw,277

lwpla,-1,468,1
asbw,119
asbw,121
asbw,122
asbw,3
asbw,120

lwpla,-1,361
wpoff,,,15/2
asbw,30
asbw,31
asbw,158
asbw,159
asbw,161

kwpave,13
wpoff,,,-18
asbw,213
asbw,214
asbw,215
asbw,216
asbw,217

cm,a_tank,area
!-cut curved rebar at wall/slab joint
asel,s,,,50
asel,a,,,68
asel,a,,,79
asel,a,,,84,85
aadd,all
asel,a,,,80
aadd,all

asel,s,,,2
asel,a,,,19
asel,a,,,48,50
asel,a,,,71,72
asel,a,,,76,78,2
asel,a,,,82
aadd,all

cmsel,a,a_tank
```

```
lsla
lsel,s,,,19
lsel,a,,,173
lsel,a,,,189
lsel,a,,,193,196,3
lcomb,all
lsla
wpcsys,-1,0
wprot,,,90
kwpave,100
asbw,68
kwpave,109
asbw,19
kwpave,111
asbw,49
kwpave,118
asbw,50
wprot,,90
kwpave,88
asbw,19
kwpave,83
asbw,48
asbw,49
asbw,50
cm,a_tank,area

LFILLT,177,176,12, ,
lcomb,176,193
LFILLT,178,194,12, ,
lcomb,179,173
lfillt,201,183,12+rbar_t
lcomb,188,173
lfillt,190,503,12+rbar_t

asel,s,,,71
asel,a,,,76,78,2
lsel,s,,,178
lsel,a,,,190
lsel,a,,,194,195
lsel,a,,,503,504
asbl,all,all
cmsel,a,a_tank
cm,a_tank,area

asel,s,,,50
asel,a,,,72
asel,a,,,79,80
asel,a,,,82
asel,a,,,84,85
asel,a,,,217
lsel,s,,,175,177
```

```
lsel,a,,,183
lsel,a,,,201
lsel,a,,,501
asbl,all,all

aadd,227,228
aadd,223,231
aadd,82,226
cmsel,a,a_tank
cm,a_tank,area

aadd,233,71
aadd,232,76
aadd,49,78
asbw,68
asbw,2
kwpave,88
asbw,78
asbw,85
asbw,82
asbw,230
aadd,223,226
aadd,84,217
aadd,224,227
aadd,223,225
cm,a_tank,area

lsel,s,,,183
lsel,a,,,523
lsel,a,,,531
lcomb,all
lsla
lcomb,177,529
lcomb,178,526
lsel,s,,,190
lsel,a,,,513
lsel,a,,,525
lcomb,all
lsla
lcomb,515,521
lcomb,197,520
lcomb,517,532
lcomb,196,524
lcomb,194,503
lcomb,514,518
lsla

!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!--Set Elelment types
!
```

```
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]

r_liner=1
r,1,liner_t

!mat_liner=1
mat_conc=2  !structural concrete in tank
mat_tsoil=3 !for top soil
mat_msoil=4     !for mid soil
mat_bsoil=5 !for bottom soil
mat_rebar=6
mat_srebar=7

type_2d_liner=1
type_2d_conc=2
type_2d_soil=3
type_2d_rebar=4

type_3d_conc=type_2d_conc+10
type_3d_soil=type_2d_soil+10
type_3d_rebar=type_2d_rebar+10

!et,type_liner,shell61
et,type_2d_conc,plane42
et,type_2d_soil,plane42
et,type_2d_rebar,plane42

et,type_3d_conc,solid65
et,type_3d_soil,solid45
et,type_3d_rebar,solid65


!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!-----set material properties
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]

![1]               steel (for liner)
mp,ex,mat_liner,steel_ex
mp,dens,mat_liner,steel_dens
mp,prxy,mat_liner,steel_prxy
mp,alpx,mat_liner,steel_alpx
mp,kxx,mat_liner,steel_kx
mp,c,mat_liner,steel_c

![2]               structural concrete
mp,ex,mat_conc,conc_ex
mp,dens,mat_conc,conc_dens
mp,prxy,mat_conc,conc_prxy
mp,alpx,mat_conc,conc_alpx
```

```
mp,kxx,mat_conc,conc_kx
mp,c,mat_conc,conc_c

*if,crush_id,eq,1,then
   tb,concr,mat_conc
   tbdata,1,conc_open,conc_closed,conc_crack,conc_crush
*endif

*if,usr_crp_id,eq,1,then
   tb,creep,mat_conc,,,100
   tbdata,1,c1,c2,c3,c4,c5
   tbdata,6,c6,c7,c8,c9,c10,c11
*endif



![3]              top soil
mp,ex,mat_tsoil,tsoil_ex
mp,dens,mat_tsoil,tsoil_dens
mp,prxy,mat_tsoil,tsoil_prxy
tb,dp,mat_tsoil,,,0
tbdata,1,tsoil_cohesion,tsoil_friction,tsoil_dilat

![4]              mid soil
mp,ex,mat_msoil,msoil_ex
mp,dens,mat_msoil,msoil_dens
mp,prxy,mat_msoil,msoil_prxy
tb,dp,mat_msoil,,,0
tbdata,1,msoil_cohesion,msoil_friction,msoil_dilat

![5]              bottom soil
mp,ex,mat_bsoil,bsoil_ex
mp,dens,mat_bsoil,bsoil_dens
mp,prxy,mat_bsoil,bsoil_prxy
tb,dp,mat_bsoil,,,0
tbdata,1,bsoil_cohesion,bsoil_friction,bsoil_dilat

![6]              rebar
mp,ex,mat_rebar,rebar_ex
mp,dens,mat_rebar,rebar_dens
mp,prxy,mat_rebar,rebar_prxy

![7]              slab rebar
mp,ex,mat_srebar,srebar_ex
mp,dens,mat_srebar,srebar_dens
mp,prxy,mat_srebar,srebar_prxy


!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!---Assign attribute to areas, real constants will be defined later
```

```
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
cmsel,s,a_tank
aatt,2,700,type_2d_conc

!-- slab rebar
asel,s,,,15
asel,a,,,27
asel,a,,,41
asel,a,,,193
aatt,mat_conc,100,type_2d_rebar

asel,s,,,202
aatt,mat_conc,101,type_2d_rebar

asel,s,,,205
aatt,mat_conc,102,type_2d_rebar


asel,s,,,18
asel,a,,,85
aatt,mat_conc,103,type_2d_rebar

asel,s,,,71,72
asel,a,,,78,82,2
aatt,mat_conc,104,type_2d_rebar

asel,s,,,2
asel,a,,,88
aatt,mat_conc,105,type_2d_rebar

asel,s,,,192
aatt,mat_conc,106,type_2d_rebar

asel,s,,,17
asel,a,,,36
asel,a,,,43
asel,a,,,196
asel,a,,,207
aatt,mat_conc,107,type_2d_rebar

asel,s,,,77
aatt,mat_conc,108,type_2d_rebar

asel,s,,,69
asel,a,,,45
aatt,mat_conc,109,type_2d_rebar

asel,s,,,50
asel,a,,,70
asel,a,,,75
```

```
asel,a,,,79
asel,a,,,83,86,3
cuv_real_i=110
aatt,mat_conc,cuv_real_i,type_2d_rebar

!---interior Wall rebar
asel,s,,,136
aatt,mat_conc,200,type_2d_rebar

asel,s,,,141
aatt,mat_conc,201,type_2d_rebar

asel,s,,,146
aatt,mat_conc,202,type_2d_rebar

asel,s,,,163,171,4
aatt,mat_conc,203,type_2d_rebar

asel,s,,,126
asel,a,,,166
asel,a,,,176
asel,a,,,181
aatt,mat_conc,204,type_2d_rebar

asel,s,,,182,186,4
aatt,mat_conc,205,type_2d_rebar

asel,s,,,159
asel,a,,,216
aatt,mat_conc,206,type_2d_rebar

asel,s,,,222
aatt,mat_conc,207,type_2d_rebar

asel,s,,,187
asel,a,,,191
aatt,mat_conc,208,type_2d_rebar

!---exterior wall rebar
asel,s,,,134
aatt,mat_conc,200,type_2d_rebar

asel,s,,,139
aatt,mat_conc,201,type_2d_rebar

asel,s,,,42
asel,a,,,144
aatt,mat_conc,209,type_2d_rebar

asel,s,,,169
aatt,mat_conc,203,type_2d_rebar
```

```
asel,s,,,150
asel,a,,,174
aatt,mat_conc,210,type_2d_rebar

asel,s,,,124
asel,a,,,164
asel,a,,,174
aatt,mat_conc,204,type_2d_rebar

asel,s,,,179
asel,a,,,184
aatt,mat_conc,211,type_2d_rebar

asel,s,,,152
aatt,mat_conc,212,type_2d_rebar

asel,s,,,31
asel,a,,,214
aatt,mat_conc,206,type_2d_rebar

asel,s,,,220
asel,a,,,190
aatt,mat_conc,207,type_2d_rebar

asel,s,,,155
aatt,mat_conc,208,type_2d_rebar

asel,s,,,127,128
aatt,mat_conc,213,type_2d_rebar


!---External dome rebar
asel,s,,,91,99,8
aatt,mat_conc,300,type_2d_rebar

asel,s,,,103
aatt,mat_conc,301,type_2d_rebar

asel,s,,,97
asel,a,,,110
aatt,mat_conc,302,type_2d_rebar

asel,s,,,55
aatt,2,303,type_2d_rebar

asel,s,,,117
aatt,mat_conc,304,type_2d_rebar

asel,s,,,62
asel,a,,,118
```

```
aatt,mat_conc,305,type_2d_rebar

!---Interna dome rebar
asel,s,,,52
asel,a,,,93
aatt,mat_conc,300,type_2d_rebar

asel,s,,,106
aatt,mat_conc,301,type_2d_rebar

asel,s,,,96
asel,a,,,112
aatt,mat_conc,302,type_2d_rebar

asel,s,,,59
aatt,mat_conc,303,type_2d_rebar

asel,s,,,115
aatt,mat_conc,304,type_2d_rebar

asel,s,,,54
asel,a,,,65
aatt,mat_conc,306,type_2d_rebar

!----External haunch rebar
asel,s,,,63
aatt,mat_conc,400,type_2d_rebar

asel,s,,,122
asel,a,,,211
aatt,mat_conc,401,type_2d_rebar

!----Internal haunch rebar
asel,s,,,119
asel,a,,,209
aatt,mat_conc,402,type_2d_rebar

!----Haunch interior region
asel,s,,,121
asel,a,,,210
aatt,mat_conc,500,type_2d_rebar

allsel

!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!     2D Meshing
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]

!-- tank mesh
```

```
cmsel,s,a_tank
lsla
esize,tank_size
lccat,272,475
lccat,30,479
lccat,85,271
lsel,s,,,121
lsel,a,,,126
lsel,a,,,167
lccat,all
lsla
mshkey,1
asel,u,,,212
asel,u,,,76
asel,u,,,84
asel,u,,,217
lesize,133,,,4
lesize,134,,,4
lesize,177,,,4
lesize,178,,,4
lesize,183,,,4
lesize,190,,,4
amesh,all
asel,a,,,212
esize,6
amesh,212

asel,a,,,76
asel,a,,,84
asel,a,,,217
mshkey,0
esize,4
amesh,76
amesh,84
amesh,217

!--delete concat lines
CM,_Y,LINE
*SET,_Z1,LSINQR(0,13)
*IF,_z1,ne,0,then
LSEL,R,LCCA
*SET,_Z2,LSINQR(0,13)
LDELE,ALL
*SET,_Z3,_Z1-_Z2
*IF,_Z3,NE,0,THEN
CMSEL,S,_Y
CMDELE,_Y
*ENDIF
*ELSE
CMSEL,S,_Y
CMDELE,_Y
```

```
*ENDIF

!-- soil mesh
asel,s,,,7,11
asel,a,,,5
asel,a,,,13,14
cm,a_soil,area
lsla
esize,soil_esize
lesize,43,,,10
lesize,42,,,25,.25
lesize,25,,,25,.25
lesize,40,,,12,5

lesize,46,,,10,.25
lesize,50,,,35
lesize,38,,,7

lesize,47,,,10,.25
lesize,51,,,15
lesize,48,,,7


mopt,trans,1.25
mopt,expnd,1.25

lesize,37,,,8,.5
lesize,34,,,8,.5
lesize,33,,,8,.5
lesize,45,,,8,2
lesize,49,,,8,2
lesize,26,,,8,.3
lesize,35,,,8,.3
lesize,24,,,8,.3
lesize,23,,,25,4

type,type_2d_soil
mat,mat_tsoil
asel,s,,,8
mshkey,0
mopt,expnd,1.25
mopt,trans,1.25
amesh,all
asel,s,,,11
mshkey,1
amesh,all

mat,mat_msoil
asel,s,,,13,14
mshkey,0
amesh,all
```

```
mat,mat_bsoil
mopt,expnd,1.25
mopt,trans,1.25
asel,s,,,10
amesh,all

asel,s,,,5,9,2
mshkey,1
amesh,all

![[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
!
!     3D mesh by rotation, reassign general elem. attr.
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
allsel
type,type_3d_soil
extopt,attr,1,1,1
extopt,esize,1
vrotat,all,,,,,,35,22,slice_ang

cmsel,s,a_tank
vsla
eslv
emodif,all,type,type_3d_conc

asel,s,type,,type_2d_rebar
vsla
eslv
emodif,all,type,type_3d_rebar

cmsel,s,a_soil
vsla
allsel,below,volu
cm,junk,volu
vgen,2,all
cm,v_soil,volu
cmsel,s,junk
allsel,below,volu
aclear,all
vclear,all
vdele,all,,,1
allsel


!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!    Create local coordinate systems
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
```

```
!--- csys 100 spheroid: for internal dome/haunch rebar/interior haunch
!    the x and y radius are from error-and-try process
!
a=453
b=160
wpcsys,-1,0
kwpave,47
wpoff,,-b
cswpla,100,2,b/a,b/a

!--- csys 101 sperical: external dome/haunch
a=600
b=300
wpcsys,-1,0
kwpave,5
wpoff,,-b
cswpla,101,2,b/a,b/a

!--- csys 110 cylindrical: wall and slab rebars
wpcsys,-1,0
wprot,,-90
cswpla,110,1


!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!     Define real constants for rebars
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
mat_null=0

!slab
vrx=
vrz=
vry=
rc=
*dim,vrx,,20
*dim,vry,,20
*dim,vrz,,20
*dim,rc,,20
vrx(1)=.0256,.0714,.0671,.0622,.0589,.0565,.0855,.0675,.0589,.0565
vry(1)=.0256,.0256,.0256,.0256,.0256,.0256,.0256,.0256,.0256,.0256
rc(1)=100,101,102,103,104,105,106,107,108,109
*do,i,1,10
      r,rc(i),mat_srebar,vrx(i),0,0,mat_srebar,vry(i)
      rmore,90,0,mat_null,0,90,90
*enddo

!--define real constants for curved rebars
allsel
asel,s,,,75
```

```
asel,a,,,83
lsla
nsla,,1
esln
esel,r,real,,110
cm,ele_r110,elem
r,cuv_real_i,mat_null,0,0,0,mat_srebar,.0552
rmore,0,90,mat_srebar,.0,90,90

wpcsys,-1,0
kwpave,433,473
nsle
csys,4

esln
esel,r,real,,cuv_real_i
cmsel,u,ele_r110
nsle
nsel,r,loc,x,0,-99999
esln,,1
cm,ele_r111,elem
emodif,all,real,111
r,111,mat_null,0,0,0,mat_srebar,.0552
rmore,0,110,mat_srebar,.0,90,90

esln
esel,r,real,,110
cmsel,u,ele_r110
nsle
cm,ele_r112,elem
emodif,all,real,112
r,112,mat_null,0,0,0,mat_srebar,.0552
rmore,0,130,mat_srebar,.0,90,90

esln
esel,r,real,,110
cmsel,u,ele_r110
nsle
cm,ele_r113,elem
emodif,all,real,113
r,113,mat_null,0,0,0,mat_srebar,.0552
rmore,0,160,mat_srebar,.0,90,90

cmsel,s,ele_r110
nsle
nsel,r,loc,x,0,9999
esln,,1
nsle
esln
esel,r,real,,110
cmsel,u,ele_r110
```

```
nsle
cm,ele_r114,elem
emodif,all,real,114
r,114,mat_null,0,0,0,mat_srebar,.0552
rmore,0,70,mat_srebar,.0,90,90

esln
esel,r,real,,110
cmsel,u,ele_r110
nsle
cm,ele_r115,elem
emodif,all,real,115
r,115,mat_null,0,0,0,mat_srebar,.0552
rmore,0,50,mat_srebar,.0,90,90

esln
esel,r,real,,110
cmsel,u,ele_r110
nsle
cm,ele_r116,elem
emodif,all,real,116
r,116,mat_null,0,0,0,mat_srebar,.0552
rmore,0,20,mat_srebar,.0,90,90

!wall
vrz(1)=.0276,.0276,.0276,.0276,.0276,.0276,.0552,.0552,.0552,.0276,
vrz(11)=.0276,.0276,.0276,.0276
vry(1)=.1963,.0714,.1571,.0982,.1309,.1745,.1745,.1745,.0552,.0873
vry(11)=.1122,.1496,.1745,.132
rc(1)=200,201,202,203,204,205,206,207,208,209,210,211,212,213
*do,i,1,14
      r,rc(i),mat_null,0,0,0,mat_rebar,vry(i)
      rmore,90,0,mat_rebar,vrz(i),90,90
*enddo

!redefine the inclined rebars
r,rc(12),mat_null,0,0,0,mat_rebar,vry(12)
rmore,90,0,mat_rebar,vrz(12),0,97.1

r,rc(13),mat_null,0,0,0,mat_rebar,vry(13)
rmore,90,0,mat_rebar,vrz(13),0,97.1


!dome
vry(1)=.0736,.0433,.0469,.0577,.0467,.0426,.0426
vrz(1)=.0736,.0368,.0368,.0368,.0654,.1735,.1735
rc(1)=300,301,302,303,304,305,306
*do,i,1,7
      r,rc(i),mat_null,0,0,0,mat_rebar,vry(i)
      rmore,90,0,mat_rebar,vrz(i),90,90
*enddo
```

```
!haunch
vry(1)=.0773,.3203,.0386
vrz(1)=.2192,.0276,.1438
rc(1)=400,401,402
*do,i,1,3
      r,rc(i),mat_null,0,0,0,mat_rebar,vry(i)
      rmore,90,0,mat_rebar,vrz(i),90,90
*enddo

!haunch core
r,500,mat_rebar,.0011,0,0,mat_rebar,0.002
rmore,45,0,mat_rebar,.0349,90,90

!real constants for curved rebars at wall/slab joint
r,600,mat_rebar,,
allsel


!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!     Assign esys to rebar elem.
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]

!--- dome rebar
asel,s,,,52
asel,a,,,93
asel,a,,,96
asel,a,,,106
asel,a,,,54
asel,a,,,59
asel,a,,,112
asel,a,,,115
asel,a,,,209,210
asel,a,,,65
asel,a,,,119,121,2
vsla
eslv
emodif,all,esys,100

asel,s,,,91
asel,a,,,97
asel,a,,,99
asel,a,,,103
asel,a,,,55
asel,a,,,110
asel,a,,,117

asel,a,,,62,63
```

```
asel,a,,,118

vsla
eslv

emodif,all,esys,101


asel,s,,,122
asel,a,,,211
vsla
eslv
emodif,all,esys,110

!---wall rebar
asel,s,real,,200,299
vsla
eslv
emodif,all,esys,110


!---slab rebar
asel,s,real,,100,199
vsla
eslv
emodif,all,esys,110


!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!     Assign real constants to 3D elements
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
*do,i,100,105
    asel,s,real,,i
    vsla
    eslv
    emodif,all,real,i
*enddo

*do,i,200,220
    asel,s,real,,i
    vsla
    eslv
    emodif,all,real,i
*enddo

*do,i,300,320
    asel,s,real,,i
    vsla
    eslv
```

```
    emodif,all,real,i
*enddo

*do,i,400,410
    asel,s,real,,i
    vsla
    eslv
    emodif,all,real,i
*enddo

asel,s,real,,500
vsla
eslv
emodif,all,real,500

allsel


!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!     Define contact between soil and tank
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
et,21,170
et,22,173
r,21,,,10,.1
mp,mu,21,.3

asel,s,,,223
asel,a,,,234
asel,a,,,237
asel,a,,,239
asel,a,,,249
asel,a,,,260,269
asel,a,,,277,294
asel,a,,,297,324
cm,tk_cnt_area,area
lsla
nsla,,1
esln
type,22
real,21
mat,21
esurf

asel,s,,,953,962
asel,a,,,972,986
asel,a,,,998,1024
cm,soil_cnt_area,area
lsla
nsla,,1
```

```
esln
type,21
esurf

allsel
aclear,all

/pnum,real,1
/num,1

csys,110
nrotat,all
eplot

slice_load_sx
finish
/filname,sst_sx_slice
/config,nproc,4
/solu
neqit,50
time,1
nlgeom,on
cnvtol,f,,.001,2
nsubst,10,100,5
allsel
save
solve
```

parm_sx.mac

```
!--Define parameters for SST-SX tank
!--dimensions are in INCH and DEG

dm_r1=1155  !inch, radius of outer inboard dome surface
dm_r2=1140  !inch, radius of inner inboard dome surface
dm_r3=804   !inch, radius of outer outboard dome surface
dm_r4=720   !inch, radius of inner outboard dome surface
dm_theta1=9.084722  !deg, angle of outer inboard dome surface
dm_theta2=9.084722  !deg, angle of inner inboard dome surface
dm_theta3=12.05972  !deg, angle of outer outboard dome surface
dm_theta4=18.581944 !deg, angle of inner outboard dome surface
dm_oh1=14.5  !vrtcal dist. from dome top to end of out radius 1
dm_oh2=58.5  !vrtcal dist. from dome top to end of out radius 2
dm_ih1=14.3125 !vrtcal dist. from dome top to end of inner radius 1
dm_ih2=73.3125 !vrtcal dist. between end of inner radius 1 and 2
dm_dr1=182.375
dm_dr2=180
dm_dr3=163.0625 !horizontal span of outer radius 2
dm_dr4=220.625  !horizontal span of inner radius 2


hnch_r1=120 !inch, big haunch radius
hnch_r2=26.5      !inch, small haunch radius
hnch_theta1=30.09583    !deg, angle of big haunch radius
hnch_theta2=32.2375     !deg, angle of big haunch radius
hnch_h1=104.9375  !vrtcl. dist between dome top and haunch corner
hnch_h2=54.0625   !vrtcl. dist between haunch corner and haunch bot.
hnch_h3=42.25     !vrtcl. span of big haunch radius
hnch_dr3=45.8125  !horizontal span of big haunch radius
hnch_h4=14.125    !vrtcl. span of small haunch radius
hnch_dr4=4.0625

tk_or1=465.5  !radius of out tank surface (top)
tk_t1=15   !top tank thickness
tk_t2=24   !bot. tank thickness
tk_h1=133 !vtcl dist between haunch bot. to start of tank slope
tk_h2=72  !vtcl dist of tank slope
tk_h3=170.625  !vtcl dist between end of slope to bot. of tank
tk_h4=387.875

slb_t1=23  !outer slab thickness
slb_dt1=30
slb_dt2=8
slb_dt3=2.75
slb_dr=22.5 !radius difference between out tank and slab
slb_dr2=24
slb_r1=569.82*12 !radius of top slab surface
slb_dr3=1
slb_dr4=-1  !=1 in drawing, simplied to 0
```

```
slb_dh=2.625
slb_dh2=14.875

liner_r1=569.59*12  !radius of bottom steel liner

depth=8.52*12
soil_r=80*12
soil_h=90*12

!---Parameters for materials
crush_id=0  !=0, no crush capability, =1, with crush capability
usr_crp_id=0 !=0, no user creep; =1, with user creep

!-----Liner steel
steel_ex=27.7e6   !elastic modulus [psi]
steel_prxy=0.3    !Poisson ratio
steel_alpx=6.38   !thermal expansion coefficient [microstrain/degree F]
steel_gamma=490   !unit weight [lbf/ft^3]
steel_kx=1        !thermal conductivity [BTU/hr/ft/degreeF]
steel_c=1         !specific heat [BTU/R-lbf/(in/sec^2)]
steel_alpx=steel_alpx*1e-6          !in/in/F
steel_dens=steel_gamma/1728/386     !lb-sec^2/in^4
steel_kx=steel_kx/3600/12           !BTU/sec-in-degreeF
steel_yield=36000 !yield strength [psi]

!---- Structural Concrete
conc_ex=3.1e6     !elastic modulus [psi]
conc_prxy=0.2     !Poisson ratio
conc_alpx=6.38    !thermal expansion coefficient [microstrain/degree F]
conc_gamma=150    !unit weight [lbf/ft^3]
conc_kx=1         !thermal conductivity [BTU/hr/ft/degreeF]
conc_c=1          !specific heat [BTU/R-lbf/(in/sec^2)]
conc_alpx=conc_alpx*1e-6            !in/in/F
conc_dens=conc_gamma/1728/386 !lb-sec^2/in^4
conc_kx=conc_kx/3600/12       !BTU/sec-in-degreeF
conc_open=0.1           !shear transfer coefficient for open crack
conc_closed=0.98  !shear transfer coefficient for closed crack
conc_crush=3000   !uniaxial crushing stress [psi]
conc_crack=0.1*conc_crush     !tensile cracking stress [psi]

c1=.1936    !creep coefficients per Tab 11 of RPP-13990
c2=.28
c3=.375
c4=.348
c5=.069
c6=226.09
c7=-0.00429
c8=147.52
c9=-.367
c10=-309.26
c11=-.044
```

```
!--bottom soil
bsoil_ex=20e3      !elastic modulus [psi]
bsoil_prxy=0.27    !Poisson ratio
bsoil_alpx=0             !thermal expansion coefficient [me/F]
bsoil_gamma=125    !unit weight [lbf/ft^3]
bsoil_kx=1         !thermal conductivity [BTU/hr/ft/F]
bsoil_c=1          !specific heat [BTU/R/(lbf-sec^2/in)]
bsoil_cohesion=0   !drucker-prager constant (assume small number) [psi]
bsoil_friction=35.4!internal friction angle [deg]
bsoil_dilat=35.4   !dilatancy angle [deg]
bsoil_alpx=bsoil_alpx*1e-6    !in/in/F
bsoil_dens=bsoil_gamma/1728/386      !lb-sec^2/in^4
bsoil_kx=bsoil_kx/3600/12            !BTU/sec-in-degreeF

!--mid soil
msoil_ex=13e3
msoil_prxy=0.27
msoil_dens=125/1728/386
msoil_cohesion=0   !drucker-prager constant (assume small number) [psi]
msoil_friction=35.4
msoil_dilat=35.4   !dilatancy angle [deg]

!-top soil
tsoil_ex=7e3
tsoil_prxy=0.27
tsoil_dens=125/1728/386
tsoil_cohesion=0   !drucker-prager constant (assume small number) [psi]
tsoil_friction=35.4
tsoil_dilat=35.4   !dilatancy angle [deg]

!----rebar steel
rebar_ex=27.7e6          !elastic modulus [psi]
rebar_prxy=0.3           !Poisson ratio
rebar_alpx=6.38*1e-6     !thermal expansion coefficient
[microstrain/degree F]
rebar_gamma=490    !unit weight [lbf/ft^3]
rebar_kx=1         !thermal conductivity [BTU/hr/ft/degreeF]
rebar_c=1          !specific heat [BTU/R-lbf/(in/sec^2)]
rebar_yield=60000 !yield strength [psi]
rebar_tan=0        !rebar tangent modulus [psi]
rebar_dens=rebar_gamma/1728/386  !lb-sec^2/in^4
rebar_kx=rebar_kx/3600/12  !BTU/sec-in-F


!---Slab rbar steel
srebar_ex=27.7e6   !elastic modulus [psi]
srebar_prxy=0.3          !Poisson ratio
srebar_alpx=6.38*1e-6    !thermal expansion coefficient
[microstrain/degree F]
srebar_gamma=490   !unit weight [lbf/ft^3]
```

```
srebar_kx=1        !thermal conductivity [BTU/hr/ft/degreeF]
srebar_c=1         !specific heat [BTU/R-lbf/(in/sec^2)]
srebar_yield=40000       !yield strength [psi]
srebar_tan=0             !rebar tangent modulus [psi]
srebar_dens=srebar_gamma/1728/386  !lb-sec^2/in^4
srebar_kx=srebar_kx/3600/12  !BTU/sec-in-F


!---Element size control
liner_size=5
tank_size=5
soil_esize=7
slice_ang=3 !deg


!---liner thickness
liner_t=3/8

!--Load
p_uniform=40/144
ff=200000
cload_l=10*12

vac_pres=-0.217  !-6" w.g. vacuum
```

slice_load_sx.mac

```
finish
/prep7
!--set BCs
csys,110
asel,s,loc,y,-.1,.1
lsla
nsla,,1
d,all,uy,0

asel,s,loc,y,-slice_ang-.1,-slice_ang+.1
lsla
nsla,,1
d,all,uy,0

allsel
asel,s,,,942,947,5
lsla
nsla,,1
d,all,uz,0

asel,s,loc,x,soil_r-.1,soil_r+.1
lsla
nsla,,1
d,all,ux,0

nsel,s,loc,x,-.1,.1
d,all,ux,0


asel,s,,,951,952
asel,a,,,991
lsla
nsla,,1
sf,all,pres,p_uniform

p_cload=ff/(3.14159*cload_l**2)
asel,s,,,952
lsla
nsla,,1
sf,all,pres,p_cload+p_uniform
allsel

acel,,386

!Apply -6" w.g. to dome
esel,s,mat,,mat_conc
vsle
aslv
asel,r,ext
```

```
asel,u,loc,y,-.1,.1
asel,u,loc,y,-slice_ang-.1,-slice_ang+.1
cmsel,u,tk_cnt_area
lsla
nsla,,1
sf,all,pres,vac_pres

allsel
```

pst_sx_slice.mac

```
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!     post processing macro to obtain the section
!     force forces and moments
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
finish
/clear
/filname,sst_sx_slice
/prep7
resume
allsel
*afun,deg

/post1
set,last

csys,110
esel,s,mat,,2
vsle
aslv
asel,r,loc,y,-slice_ang-.1,-slice_ang+.1
cm,a_tank2,area

!--------------------SECTION FORCE/MOMENT

*dim,path_nd,,1000      !path node definition
*dim,path_fa,,1000      !axial force
*dim,path_ft,,1000      !transverse force
*dim,path_mz,,1000      !moment
*dim,path_fh,,1000

csys,110
pstart=0  !starting point of consequent path points

!=========================dome region
lsel,s,,,31,32
lsel,a,,,213
lsel,a,,,216,221
nsll,,1
cm,nd_out,node

lsel,s,,,61
lsel,a,,,148
lsel,a,,,227
lsel,a,,,234
lsel,a,,,247
lsel,a,,,251
lsel,a,,,254
```

```
lsel,a,,,261
lsel,a,,,264
nsll,,1
cm,nd_in,node

!--unselect end nodes
cmsel,s,nd_out
*get,x_min,node,,mnloc,x
nsel,u,loc,x,x_min-.1,x_min+.1
cm,nd_out,node

cmsel,s,nd_in
*get,x_min,node,,mnloc,x
nsel,u,loc,x,x_min-.1,x_min+.1
cm,nd_in,node


!--reorder nodes according x-coord.
cmsel,s,nd_out
*get,out_num,node,,count
*dim,nodeout,,out_num
*do,i,1,out_num
    cmsel,s,nd_out
    *get,x_min,node,,mnloc,x
    nsel,r,loc,x,x_min-.1,x_min+.1
    *get,ndnum,node,,num,min
    nodeout(i)=ndnum
    cmsel,s,nd_out
    nsel,u,,,ndnum
    cm,nd_out,node
*enddo

cmsel,s,nd_in
*get,in_num,node,,count
*dim,nodein,,in_num
*do,i,1,in_num
    cmsel,s,nd_in
    *get,x_min,node,,mnloc,x
    nsel,r,loc,x,x_min-.1,x_min+.1
    *get,ndnum,node,,num,min
    nodein(i)=ndnum
    cmsel,s,nd_in
    nsel,u,,,ndnum
    cm,nd_in,node
*enddo

cmsel,s,a_tank
wpcsys,-1,0
kwpave,160
csys,4
asel,r,loc,y,0,99999
```

```
asel,u,,,63
cm,dome_area,area
lsla
nsla,,1
cm,dome_nd,node

wpcsys,-1,0
csys,0
!--for line equation for each pair of in/out nodes
*do,ii,1,in_num
    nsel,s,,,nodeout(ii)
    nsel,a,,,nodein(ii)
    path_nd(pstart+ii)=nodein(ii)
    csys,0
    *get,x_out,node,nodeout(ii),loc,x
    *get,y_out,node,nodeout(ii),loc,y
    *get,x_in,node,nodein(ii),loc,x
    *get,y_in,node,nodein(ii),loc,y

    *if,ii,ne,in_num,then
          *get,xplus_in,node,nodein(ii+1),loc,x
          *get,yplus_in,node,nodein(ii+1),loc,y
          ds=sqrt((xplus_in-x_in)**2+(yplus_in-y_in)**2)
    *endif

    nwpla,-1,nodeout(ii),nodein(ii)
    csys,4
    cmsel,s,dome_nd
    nsel,r,loc,y,-2,2
    cm,ntemp,node
    esln
    esel,r,mat,,2
    nsle
    nsel,r,loc,y,-1,99999
    esln,,1
    cm,etemp,elem
    cmsel,s,ntemp
    cmsel,s,etemp
    csys,0
    get_res_slice

    cmsel,s,ntemp
    ttt=sqrt((x_out-x_in)**2+(y_out-y_in)**2)
    get_hpfrc

    path_fa(pstart+ii)=unit_fsumy
    path_ft(pstart+ii)=unit_fsumx
    path_mz(pstart+ii)=unit_mz
    path_fh(pstart+ii)=hp_f
```

```
*enddo


pstart=pstart+in_num

!===============haunch and wall
lsel,s,,,20
lsel,a,,,30
lsel,a,,,81
lsel,a,,,105
lsel,a,,,297,298
lsel,a,,,305
lsel,a,,,309
lsel,a,,,316
lsel,a,,,327
lsel,a,,,341
lsel,a,,,343
lsel,a,,,367
lsel,a,,,382
lsel,a,,,393
lsel,a,,,402
lsel,a,,,408
lsel,a,,,423
lsel,a,,,479
lsel,a,,,490
lsel,a,,,493
nsll,,1
cm,nd_out,node

lsel,s,,,4
lsel,a,,,15
lsel,a,,,103
lsel,a,,,281
lsel,a,,,296
lsel,a,,,303
lsel,a,,,314
lsel,a,,,325
lsel,a,,,336
lsel,a,,,339
lsel,a,,,345
lsel,a,,,391
lsel,a,,,404
lsel,a,,,415
lsel,a,,,419
lsel,a,,,426
lsel,a,,,468,469
lsel,a,,,482
lsel,a,,,496
nsll,,1
cm,nd_in,node
```

```
cmsel,s,a_tank
cmsel,u,dome_area
wpcsys,-1,0
kwpave,7
csys,4
asel,r,loc,y,0,9999
cm,hnch_area,area
lsla
nsla,,1
cm,hnch_nd,node

csys,0
!--unselect end nodes
cmsel,s,nd_out
*get,y_max,node,,mxloc,y
nsel,u,loc,y,y_max-.1,y_max+.1
cm,nd_out,node

cmsel,s,nd_in
*get,y_max,node,,mxloc,y
nsel,u,loc,y,y_max-.1,y_max+.1
cm,nd_in,node

!--reorder nodes according y-coord.
cmsel,s,nd_out
*get,out_num,node,,count
*dim,nodeout,,out_num
*do,i,1,out_num
cmsel,s,nd_out
*get,y_max,node,,mxloc,y
nsel,r,loc,y,y_max-.1,y_max+.1
*get,ndnum,node,,num,min
nodeout(i)=ndnum
cmsel,s,nd_out
nsel,u,,,ndnum
cm,nd_out,node
*enddo

cmsel,s,nd_in
*get,in_num,node,,count
*dim,nodein,,in_num
*do,i,1,in_num
    cmsel,s,nd_in
    *get,y_max,node,,mxloc,y
    nsel,r,loc,y,y_max-.1,y_max+.1
    *get,ndnum,node,,num,min
    nodein(i)=ndnum
    cmsel,s,nd_in
    nsel,u,,,ndnum
    cm,nd_in,node
*enddo
```

```
!--for line equation for each pair of in/out nodes
*do,ii,1,in_num
    nsel,s,,,nodeout(ii)
    nsel,a,,,nodein(ii)
    path_nd(pstart+ii)=nodein(ii)
    csys,0
    *get,x_out,node,nodeout(ii),loc,x
    *get,y_out,node,nodeout(ii),loc,y
    *get,x_in,node,nodein(ii),loc,x
    *get,y_in,node,nodein(ii),loc,y

    *if,ii,ne,in_num,then
          *get,xplus_in,node,nodein(ii+1),loc,x
          *get,yplus_in,node,nodein(ii+1),loc,y
          ds=sqrt((xplus_in-x_in)**2+(yplus_in-y_in)**2)
    *endif

    nwpla,-1,nodeout(ii),nodein(ii)
    csys,4
    cmsel,s,hnch_nd
    nsel,r,loc,y,-1,1
    cm,ntemp,node
    esln
    esel,r,mat,,2
    nsle
    nsel,r,loc,y,-1,99999
    esln,,1
    cm,etemp,elem
    cmsel,s,ntemp
    cmsel,s,etemp
    csys,0
    get_res_slice

    cmsel,s,ntemp
    ttt=sqrt((x_out-x_in)**2+(y_out-y_in)**2)
    get_hpfrc

    path_fa(pstart+ii)=unit_fsumy
    path_ft(pstart+ii)=unit_fsumx
    path_mz(pstart+ii)=unit_mz
    path_fh(pstart+ii)=hp_f

*enddo

pstart=pstart+in_num

!==========================slab region
lsel,s,,,22
lsel,a,,,68
```

```
lsel,a,,,357
lsel,a,,,446
lsel,a,,,457
lsel,a,,,463
nsll,,1
cm,nd_out,node

lsel,s,,,168
lsel,a,,,432
lsel,a,,,435
lsel,a,,,443
lsel,a,,,452
lsel,a,,,460
nsll,,1
cm,nd_in,node

csys,110
!--unselect end nodes
cmsel,s,nd_out
*get,x_max,node,,mxloc,x
nsel,u,loc,x,x_max-.1,x_max+.1
cm,nd_out,node

cmsel,s,nd_in
*get,x_max,node,,mxloc,x
nsel,u,loc,x,x_max-.1,x_max+.1
cm,nd_in,node

!--reorder nodes according x-coord.
cmsel,s,nd_out
*get,out_num,node,,count
*dim,nodeout,,out_num
*do,i,1,out_num
    cmsel,s,nd_out
    *get,x_max,node,,mxloc,x
    nsel,r,loc,x,x_max-.1,x_max+.1
    *get,ndnum,node,,num,min
    nodeout(i)=ndnum
    cmsel,s,nd_out
    nsel,u,,,ndnum
    cm,nd_out,node
*enddo

cmsel,s,nd_in
*get,in_num,node,,count
*dim,nodein,,in_num
*do,i,1,in_num
    cmsel,s,nd_in
    *get,x_max,node,,mxloc,x
    nsel,r,loc,x,x_max-.1,x_max+.1
    *get,ndnum,node,,num,min
```

```
    nodein(i)=ndnum
    cmsel,s,nd_in
    nsel,u,,,ndnum
    cm,nd_in,node
*enddo

cmsel,s,a_tank
cmsel,u,dome_area
cmsel,u,hnch_area
cm,slab_area,area
lsla
nsla,,1
cm,slab_nd,node

!--for line equation for each pair of in/out nodes
*do,ii,1, in_num-1
    nsel,s,,,nodeout(ii)
    nsel,a,,,nodein(ii)
    path_nd(pstart+ii)=nodein(ii)
    csys,0
    *get,x_out,node,nodeout(ii),loc,x
    *get,y_out,node,nodeout(ii),loc,y
    *get,x_in,node,nodein(ii),loc,x
    *get,y_in,node,nodein(ii),loc,y

    *if,ii,ne,in_num,then
          *get,xplus_in,node,nodein(ii+1),loc,x
          *get,yplus_in,node,nodein(ii+1),loc,y
          ds=sqrt((xplus_in-x_in)**2+(yplus_in-y_in)**2)
    *endif

    nwpla,-1,nodeout(ii),nodein(ii)
    csys,4
    cmsel,s,slab_nd
    nsel,r,loc,y,-1,1
    cm,ntemp,node
    esln
    esel,r,mat,,2
    nsle
    nsel,r,loc,y,-1,99999
    esln,,1
    cm,etemp,elem
    cmsel,s,ntemp
    cmsel,s,etemp
    csys,0
    get_res_slice

    cmsel,s,ntemp
    ttt=sqrt((x_out-x_in)**2+(y_out-y_in)**2)
    get_hpfrc
```

```
    path_fa(pstart+ii)=unit_fsumy
    path_ft(pstart+ii)=unit_fsumx
    path_mz(pstart+ii)=unit_mz
    path_fh(pstart+ii)=hp_f

*enddo

pstart=pstart+in_num-1

rsys,0

/gresume,path_sx,plt
axial_path
plpng

shear_path
plpng

hoop_path
plpng

moment_path
plpng

!----Output path data to file
/sys,del path_sx.dat
*dim,pl,,pstart
ss=0
*do,i,1,pstart
     *get,path_x,path,,point,i,x
     *get,path_y,path,,point,i,y
     *if,i,gt,1,then
         ss=ss+sqrt((path_x-path_x0)**2+(path_y-path_y0)**2)

     *endif
     pl(i)=ss
     path_x0=path_x
     path_y0=path_y
*enddo

i=1
/output,path_sx,dat,,
*vwrite,pl(i),path_fa(i),path_ft(i),path_fh(i),path_mz(i)
(5e12.4)
/output
```

get_res_slice.mac

```
cm,etemp,elem
cm,ntemp,node
*get,nelem,elem,,count
*get,nnode,node,,count

xx(1)=
yy(1)=
zz(1)=
ffx(1)=
ffy(1)=
ffz(1)=

*dim,xx,,nnode
*dim,yy,,nnode
*dim,zz,,nnode
*dim,ffx,,nnode
*dim,ffy,,nnode
*dim,ffz,,nnode

xmean=0
ymean=0
zmean=0

fsumx=0
fsumy=0
fsumz=0

cm,nn0,node
csys,0
*do,i,1,nnode
      *get,inode,node,,num,min
      nsel,s,,,inode
      xx(i)=nx(inode)
      yy(i)=ny(inode)
      zz(i)=nz(inode)
      cmsel,s,etemp
      fsum,0
      *get,ffx(i),fsum,fx
      *get,ffy(i),fsum,fy
      *get,ffz(i),fsum,fz
      xmean=xmean+xx(i)
      ymean=ymean+yy(i)
      zmean=zmean+zz(i)
      fsumx=fsumx+ffx(i)
      fsumy=fsumy+ffy(i)
      fsumz=fsumz+ffz(i)
      cmsel,s,nn0
      nsel,u,,,inode
      cm,nn0,node
```

```
*enddo

xmean=xmean/nnode
ymean=ymean/nnode
zmean=zmean/nnode

!get centroids
mmxx=0
mmyy=0
mmzz=0

cmsel,s,ntemp
cm,nn0,node
*do,i,1,nnode
      mmxx=mmxx+ffy(i)*(zz(i)-zmean)+ffz(i)*(yy(i)-ymean)
      mmyy=mmyy+ffx(i)*(zz(i)-zmean)+ffz(i)*(xx(i)-xmean)
      mmzz=mmzz+ffx(i)*(yy(i)-ymean)+ffy(i)*(xx(i)-xmean)
*enddo

fsumx=fsumx/1000     !kip
fsumy=fsumy/1000     !kip
mmzz=mmzz/1000       !kip-in

arc_length=3.14159*xmean*2
unit_fsumx=fsumx/arc_length*12 ! kip/ft
unit_fsumy=fsumy/arc_length*12 ! kip/ft
unit_mz=mmzz/arc_length*12     ! kip-in/ft
```

get_hpfrc.mac

```
!---This macro should be run after get_res.mac, xmean is calculated in
!   get_res.mac

cm,ntemp,node
*get,nnode,node,,count

csys,0

hp_f=0
sz_sum=0
nn=0
*do,i,1,nnode
      ndnxt=ndnext(nn)
      nsel,s,,,ndnxt
        esln
        esel,r,mat,,mat_conc
        cm,etemp,elem
        *get,s_z,node,ndnxt,s,z
        sz_sum=sz_sum+s_z
        cmsel,s,ntemp
        nn=ndnxt
*enddo

sz_sum=sz_sum/nnode

hp_f=sz_sum*ttt/1000*12  !kip/ft
```

axial_path.mac

```
!=======Define path
allsel
PADEL,ALL
path,in_surf,pstart,,1
*do,i,1,pstart
       ppath,i,path_nd(i)
       dnsol,path_nd(i),u,x,path_fa(i)
*enddo

allsel
PDEF,axial,u,x,AVG
/PBC,PATH, ,0


PLPAGM,axial,1000,Blank
/title,Axial Force (kip/ft)
/rep
```

shear_path.mac

```
!=======Define path
allsel
rsys,0
PADEL,ALL
path,in_surf,pstart,,1
*do,i,1,pstart
       ppath,i,path_nd(i)
       dnsol,path_nd(i),u,x,path_ft(i)
*enddo

allsel
PDEF,shear,u,x,AVG
/PBC,PATH, ,0


PLPAGM,shear,1000,Blank
/title,Shear Force (kip/ft)
/rep
```

hoop_path.mac

```
!=======Define path
allsel
PADEL,ALL
path,in_surf,pstart,,1
*do,i,1,pstart
       ppath,i,path_nd(i)
       dnsol,path_nd(i),u,x,path_fh(i)
*enddo

allsel
PDEF,hoop,u,x,AVG
/PBC,PATH, ,0


PLPAGM,hoop,1000,Blank
/title,Hoop Force (kip/ft)
/rep
```

moment_path.mac

```
!=======Define path
allsel
PADEL,ALL
path,in_surf,pstart,,1
*do,i,1,pstart
       ppath,i,path_nd(i)
       dnsol,path_nd(i),u,x,path_mz(i)
*enddo

allsel
PDEF,moment,u,x,AVG
/PBC,PATH, ,0


PLPAGM,moment,1000,Blank
/title,Moment (kip-in/ft)
/rep
```

plpng.mac

```
/SHOW,PNG
PNGR,COMP,1,-1
PNGR,ORIENT,HORIZ
PNGR,COLOR,2
PNGR,TMOD,1
/GFILE,600,
!*
/CMAP,_TEMPCMAP_,CMP,,SAVE
/RGB,INDEX,100,100,100,0
/RGB,INDEX,0,0,0,15
/REPLOT
/CMAP,_TEMPCMAP_,CMP
/DELETE,_TEMPCMAP_,CMP
/SHOW,CLOSE
/DEVICE,VECTOR,0
```

path_sx.plt

```
/NOPR
/RESET
/DEVICE,VECT,OFF
! General Graphics Settings
/NUM,  1
/PLOP,INFO, 3
/TRIAD,RTOP
/GTHIC,CURV,  2
/GROPT,CGRI,ON
/GROPT,CURL,  1
/PNUM,MAT , 1
/COL, NUM ,ORAN, 2
/TRLCY,ON
/TXTRE,ON
! Window Settings
/VIEW,1,  0.0000    ,  0.0000    ,  1.0000
/FOC, 1,  241.31    ,  836.95    ,  13.005
/DIST,1,  446.41
/TYPE,1, 6
/EDG, 1, 0,  45.000
/CONT,1,  9,AUTO
/GO
```