S

JUN 19 2003 (25) STATION 4

ENGINEERING DATA TRANSMITTAL

1. EDT 637305

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: AX 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-13996	N/A	0	Sample AOR Calculation	N/A	1	1	1
				using ANSYS Slice				
				Parametric Model for Tank				
				SST-AX				

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	/	Design Agent	L.J. Julyk	L.J. Julyk	6/17/03	R1-14					
		Cog. Eng.									
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)

DISTRIBUTION SHEET

To	From	
Distribution	Design Engineering	Page 1 of 1
Project Title/Work Order		Date 6/17/03
Sample AOR Calculation using ANSYS Slice Parametric Model for Tank SST-AX (RPP-13996 Rev. 0)		EDT No. 637305
		ECN No.

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
M.A. Fish	R1-14				x
T.C. Oten	S5-07				x
E.R. Hamm	R1-31				x
M.R. Koch	S7-83				x
C. Defigh-Price	R2-58				x
L.J. Julyk	R1-14	x			
T.C. Mackey	R1-14	x			
A.H. Friberg	R1-14				x
Central Files	A3-88	s			
DOE Reading Room	H2-53	x			

A-6000-135 (10/97)

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

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: 637305 UC: N/A
Cost Center: 7G120 Charge Code: 102607
B&R Code: N/A Total Pages: 87

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

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

TRADEMARK DISCLAIMER. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

Printed in the United States of America. To obtain copies of this document, contact: Document Control Services, P.O. Box 950, Mailstop H6-08, Richland WA 99352, Phone (509) 372-2420; Fax (509) 376-4989.

6/19/03
Release Approval Date

JUN 19 2003
DATE:
HANFORD RELEASE
STA: 4
ID: 25 9
Release Stamp

Approved For Public Release

RPP-13996
Revision 0

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

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

Approved for Public Release; Further Dissemination Unlimited

RPP-13996
Revision 0

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

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

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC06-99RL14047

Approved for Public Release; Further Dissemination Unlimited

LEGAL DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced from the best available copy. Available in paper copy and microfiche.

Available electronically at
http://www.doe.gov/bridge. Available for a processing fee to the U.S. Department of Energy and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865-576-8401
fax: 865-576-5728
email: reports@adonis.osti.gov(423) 576-8401

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Phone: 800-553-6847
fax: 703-605-6900
email: orders@ ntis.fedworld.gov
online ordering:
http://www.ntis.gov/ordering.htm

Printed in the United States of America

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

Document Reviewed: RPP-13996, Rev. 0, Sample AOR Calculation using ANSYS Slice Parametric Model for Tank SST-AX

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) L. J. Julyk 6/17/03
Date

CHECKLIST FOR INDEPENDENT REVIEW

Document Reviewed: RPP-13996, Rev. 0, Sample AOR Calculation using ANSYS Slice Parametric Model for Tank SST-AX

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_ax.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_ax.mac and Sst_ax_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.

ANSYS is a registered trademark of SAS IP, Inc.

ANALYTICAL CALCULATIONS

		Page	1 of 80
Subject	**Sample AOR Calculation using ANSYS Slice Parametric Model for Tank SST-AX**		
Originator	Xianghong Li X. Li	Date	4/28/03
Checker	Jim Radochia	Date	4/28/03

TABLE OF CONTENTS

1.0 Objective/Purpose 5

2.0 Methods of Analysis 5

3.0 Input Data 5

4.0 Results 17

5.0 Conclusions 27

6.0 References 27

7.0 Attachments and Appendices 28

sst_sx_slice.mac 28

parm_sx.mac 56

sx_load_slice.mac 60

pst_sx_slice.mac 62

get_res_slice.mac 74

get_hpfrc.mac 76

axial_path.mac 77

shear_path.mac 77

hoop_path.mac 78

moment_path.mac 78

plpng.mac 79

path_sx.plt 79

smisc_plt.plt 80

FIGURES

Figure 1 - Geometry of SST-AX tank 11

Figure 2 – Soil layers 11

Figure 3 – Finite element mesh, showing elements colored by material ID 12

Figure 4 – Close-up of finite element mesh 12

Figure 5 – Close-up of finite element mesh 13

Figure 6 – Rebar region 13

Figure 7 – Close up of rebar region 14

Figure 8 – Close up of rebar region 14

Figure 9 – Rebar elements colored by real constants 15

Figure 10 – Rebar elements colored by element coordinate systems 15

Figure 11 – Rebar orientation at haunch core 16

Figure 12 – Rebar orientation at tank transition region 16

Figure 13 - Rebar orientation at wall/slab joint 17

Figure 14 – Total displacement contour of soil and tank 18

Figure 15 – Total displacement contour of tank 19

Figure 16 – Deformed shape of soil 19

Figure 17 – Deformed shape of tank 20

Figure 18 – Equivalent stress contours of tank and soil 20

Figure 19 – Equivalent stress contours of tank 21

Figure 20 – Hoop stress of tank 21

Figure 21 – Rebar stresses in first rebar direction....22

Figure 22 – Rebar stresses in second rebar direction....22

Figure 23 – Rebar stresses in third rebar direction....23

Figure 24 – Close up of rebar stresses in first rebar direction....23

Figure 25 – Close up of rebar stresses in second rebar direction....24

Figure 26 – Close up of rebar stresses in third rebar direction....24

Figure 27 – Unit section axial force....25

Figure 28 – Unit section shear force....25

Figure 29 – Unit section hoop force....26

Figure 30 – Unit section moment....26

TABLES

Table 1 – Material Properties.....6

Table 2 - Calculation of Steel Reinforcement Ratios for Slab.....7

Table 3 – Calculation of Steel Reinforcement Ratios for Wall.....8

Table 4 – Calculation of Steel Reinforcement Ratios for Dome and Haunch.....9

Table 5 – Calculation of Steel Reinforcement Ratios for Haunch Core.....9

Talbe 6 – Element Coordinate Systems 10

Talbe 7 – Input File List 10

1.0 OBJECTIVE/PURPOSE

The purpose of this calculation is to develop a parametric model for the single shell tank (SST) AX, and provide a sample analysis of the SST-AX tank based on analysis of record (AOR) loads. The SST-AX 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-AX tanks at the Hanford site.

2.0 METHODS OF ANALYSIS

1. A 3-degree slice 3D model of the SST-AX 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-13998 [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 and b) plastic soil material. Also, the reinforcement bars embedded in the concrete tank were included for analysis.

2. The parametric model of the SST-AX 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-AX tank is provided in drawing H-2-44562 [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 13.84 feet [Ref 3], with a unit weight of 125 pcf, Poisson ratio of 0.27. The soil is divided into three layers, shown in Figure 2. Each layer has different elastic moduli. 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 the soil, with a friction angle of 35.4 degrees for all three layers.

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). Volume ratios are calculated using an Excel spreadsheet. Tables 2 to 5 list these spreadsheets. In the dome and slab, the volume ratio of the radial rebars increase linearly with decreasing radius. Given this variety of rebar volume ratios, an average radius was used for the calculation of real constants for the radial rebars in the dome and slab. There are 3 element coordinate systems used to orient the rebar, and they are listed in Table 6. 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-AX tank include a uniform pressure load of 40 lbf/ft² on the soil surface and a concentrated load of 200 kips over a circular region with a radius of 10 ft. The concentrated load is applied to the soil surface as a pressure load in this calculation. A vacuum load of -6 in. water gage was 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 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 7.

Table 2. Calculation of Steel Reinforcement Ratios for Slab

SST-AX - Steel Reinforcement Ratios for Slab - Ref H-2-44562 100

Description	Elevation (in)	Radius (in)	Top / Meridional Size	Top / Meridional Spacing	Top / Meridional Area Ratio	Top / Meridional Volume Ratio	Top/ Circumferential Size	Top/ Circumferential Spacing	Top/ Circumferential Area Ratio	Top/ Circumferential Volume Ratio	Real Constant
Slab Center		0.0									
			5	12.0	0.0256	0.0256	5	12	0.0256	0.0256	100
Start of Dowel		330.5									
			5	12.0	0.0256	0.0256	5	12	0.0256	0.0256	100
Start of Transition		354.5									
			8	6.2	0.1262	0.1262	6	12	0.0368	0.0368	102
End of Dowel		378.5									
			8	7.7	0.1027	0.1027	6	12	0.0368	0.0368	103
Slab Outside Radius		522.5									

SST-AX - Steel Reinforcement Ratios for Slab - Ref H-2-44562 100

Description	Elevation (in)	Radius (in)	Bottom / Meridional Size	Bottom / Meridional Spacing (in)	Bottom / Meridional Area Ratio	Bottom / Meridional Volume Ratio	Bottom / Circumferential Size	Bottom / Circumferential Spacing (in)	Bottom / Circumferential Area Ratio	Bottom / Circumferential Volume Ratio	Real Constant
Slab Center		0.0									
			6	12.0	0.0368	0.0368	6	12	0.0368	0.0368	101
Start of Dowel		330.5									
			6	12.0	0.0368	0.0368	6	12	0.0368	0.0368	101
Start of Transition		354.5									
			8	6.2	0.1262	0.1262	6	12	0.0368	0.0368	105
End of Dowel		378.5									
			8	6.6	0.1184	0.1184	6	12	0.0368	0.0368	106
End of Transition		402.5									
			8	7.9	0.1000	0.1000	6	12	0.0368	0.0368	107
Slab Outside Radius		522.5									

SST-AX - Steel Reinforcement Ratios for Slab - Ref H-2-44562 100

Description	Elevation (in)	Radius (in)	vertical region #1 (Exterior) /Vertical Size	vertical region #1 (Exterior) /Vertical Spacing (in)	vertical region #1 (Exterior) /Vertical Area Ratio	vertical region #1 (Exterior) /Vertical Volume Ratio	vertical region #1 (Exterior) /Circumferential Size	vertical region #1 (Exterior) /Circumferential Spacing (in)	vertical region #1 (Exterior) /Circumferential Area Ratio	vertical region #1 (Exterior) /Circumferential Volume Ratio	Real Constant
Slab Outside Radius		522.5									
			0	0.0	0.0000	0.0000	6	15	0.0295	0.0295	104
Slab Outside Radius		522.5									

SST-AX - Steel Reinforcement Ratios for Slab - Ref H-2-44562 100

Description	Elevation (in)	Radius (in)	vertical region #2 /Vertical Size	vertical region #2 /Vertical Spacing (in)	vertical region #2 /Vertical Area Ratio	vertical region #2 /Vertical Volume Ratio	vertical region #2/Circumferential Size	vertical region #2/Circumferential Spacing (in)	vertical region #2/Circumferential Area Ratio	vertical region #2/Circumferential Volume Ratio	Real Constant
		472.5									
		472.5	0	0.0	0.0000	0.0000	0	0	0.0000	0.0000	108

SST-AX - Steel Reinforcement Ratios for Slab - Ref H-2-44562 100

Description	Elevation (in)	Radius (in)	vertical region #3 (Interior) /Vertical Size	vertical region #3 (Interior) /Vertical Spacing (in)	vertical region #3 (Interior) /Vertical Area Ratio	vertical region #3 (Interior) /Vertical Volume Ratio	vertical region #3 (Interior) /Circumferential Size	vertical region #3 (Interior) /Circumferential Spacing (in)	vertical region #3 (Interior) /Circumferential Area Ratio	vertical region #3 (Interior) /Circumferential Volume Ratio	Real Constant
		453.0									
		453.0	0	0.0	0.0000	0.0000	0	0	0.0000	0.0000	109

Table 3. Calculation of Steel Reinforcement Ratios for Wall

SST-AX - Steel Reinforcement Ratios for Wall - Ref H-2-44562 200

Description	Elevation (in)	Radius (in)	Interior(layer 1) / Vertical Size	Spacing (in)	Area Ratio	Volume Ratio	Interior layer 1 / Circumferential Size	Spacing (in)	Area Ratio	Volume Ratio	Real Constant
Dome Tangent Line	375.0										
			7	17.0	0.0354	0.0354	8	5	0.1571	0.1571	201
	168.0										
			7	8.5	0.0707	0.0707	8	5	0.1571	0.1571	202
	36.0										
			8	4.5	0.1745	0.1745	8	5	0.1571	0.1571	203
Top of Slab	0.0										

SST-AX - Steel Reinforcement Ratios for Wall - Ref H-2-44562 200

Description	Elevation (in)	Radius (in)	Layer 2 / Vertical Size	Spacing (in)	Area Ratio	Volume Ratio	Layer 2 / Circumferential Size	Spacing (in)	Area Ratio	Volume Ratio	Real Constant
Dome Tangent Line	375.0										
	300.0										
			0	0	0.0000	0.0000	8	10	0.0785	0.0785	204
	270.0										
			0	0	0.0000	0.0000	8	5	0.1571	0.1571	205
Top of Slab	0.0										

SST-AX - Steel Reinforcement Ratios for Wall - Ref H-2-44562 200

Description	Elevation (in)	Radius (in)	Layer 3 / Vertical Size	Spacing (in)	Area Ratio	Volume Ratio	Layer 3 / Circumferential Size	Spacing (in)	Area Ratio	Volume Ratio	Real Constant
Dome Tangent Line	375.0										
	240.0										
			0	0	0.0000	0.0000	8	10	0.0785	0.0785	204
	200.0										
			0	0	0.0000	0.0000	8	5	0.1571	0.1571	205
Top of Slab	0.0										

SST-AX - Steel Reinforcement Ratios for Wall - Ref H-2-44562 200

Description	Elevation (in)	Radius (in)	Exterior(layer 4) / Vertical Size	Spacing (in)	Area Ratio	Volume Ratio	Exterior (layer 4) / Circumferential Size	Spacing (in)	Area Ratio	Volume Ratio	Real Constant
Dome Tangent Line	375.0										
			8	18.0	0.0436	0.0436	8	5	0.1571	0.1571	206
End of Transition	300.0										
			8	18.0	0.0436	0.0436	8	5	0.1571	0.1571	206
Start of Transition	230.0										
			8	18.0	0.0436	0.0436	8	5	0.1571	0.1571	206
	168.0										
			8	9.0	0.0873	0.0873	8	5	0.1571	0.1571	207
Top of Slab	0.0										

Table 4. Calculation of Steel Reinforcement Ratios for Dome and Haunch

SST-AX - Steel Reinforcement Ratios for Dome and Haunch - Ref H-2-44565 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	4.9	0.0893	0.0893	6	12.0	0.0368	0.0368	300
		24.0									
			6	8.7	0.0510	0.0510	6	12.0	0.0368	0.0368	301
		60.0									
			6	9.3	0.0476	0.0476	6	12.0	0.0368	0.0368	302
		120.0									
			6	9.3	0.0476	0.0476	6	12.0	0.0368	0.0368	303
		240.0									
			6	7.4	0.0595	0.0595	6	12.0	0.0368	0.0368	304
		336.0									
			6	8.9	0.0496	0.0496	6	12.0	0.0368	0.0368	305
End of circular bars		354.8									
			6	9.4	0.0468	0.0468	0	0	0.0000	0.0000	306
		378.0									
			6	5.4	0.0813	0.0813	0	0	0.0000	0.0000	307
Outer Radius of Tank	66.4	465.5									
			6	6.0	0.0736	0.0736	0	0.0	0.0000	0.0000	308
Dome/Haunch Joint	0.0	465.5									

SST-AX - Steel Reinforcement Ratios for Dome and Haunch - Ref H-2-44565 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	4.9	0.0893	0.0893	6	12.0	0.0368	0.0368	300
		24.0									
			6	8.7	0.0510	0.0510	6	12.0	0.0368	0.0368	301
		60.0									
			6	9.3	0.0476	0.0476	6	12.0	0.0368	0.0368	302
		120.0									
			6	9.3	0.0476	0.0476	6	12.0	0.0368	0.0368	303
		240.0									
			6	7.4	0.0595	0.0595	6	12.0	0.0368	0.0368	304
		336.0									
			6	9.2	0.0480	0.0480	6	12.0	0.0368	0.0368	305
End of circular bars		354.8									
			6	9.4	0.0468	0.0468	0	0	0.0000	0.0000	306
		378.0									
			6	10.9	0.0406	0.0406	0	0	0.0000	0.0000	309
Outer Radius of Tank	0.0	465.5									

Table 5. Calculation of Steel Reinforcement Ratios for Haunch Core

SST-AX - Steel Reinforcement Ratios for Haunch Interior - Ref H-2-44562 500

Description	Circumferential Size	Quantity	Bar area (in^2)	Area (in^2)	Volume Ratio	Diagonal Ties Size	Quantity	Bar area	Area (in^2)	Volume Ratio	Vertical Ties Size	Quantity	Bar area	Area (in^2)	Volume Ratio	real constant
Mid Haunch Interior																
	11	42	65.58	2030.0	0.0323	5	7	2.15	1182.5	0.0018	5	7	2.15	1080.0	0.0023	500
Up Haunch Interior																
	9	17	16.99	1189.0	0.0143	0	0	0.00	0.00	0.00	0	0	0.00	0.00	0.00	501
Bottom Haunch Interior																
	11	11	17.18	457.7	0.0375	0	0	0.00	0	0	5	1	0.31	228	0.0013	502

Table 6. 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, upper and lower haunch core

Table 7. Input File List

Input File Name	*Function*	Calling For
sst_ax_slice.mac	Main input creating parametric slice model for SST-AX tank and getting solutions	parm_ax.mac slice_load_ax.mac
parm_ax.mac	Set all parametric variables used to create the parametric model	NONE
slice_load_ax.mac	Apply boundary conditions and AOR loads	NONE
pst_ax_slice.mac	Calculate section forces/moments and generate path plots, output path data to path_ax.dat file	get_res_slice.mac get_hpfrc.mac plpng.mac path_ax.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_ax.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
smisc_plt.plt	View setting for rebar stress plots	NONE

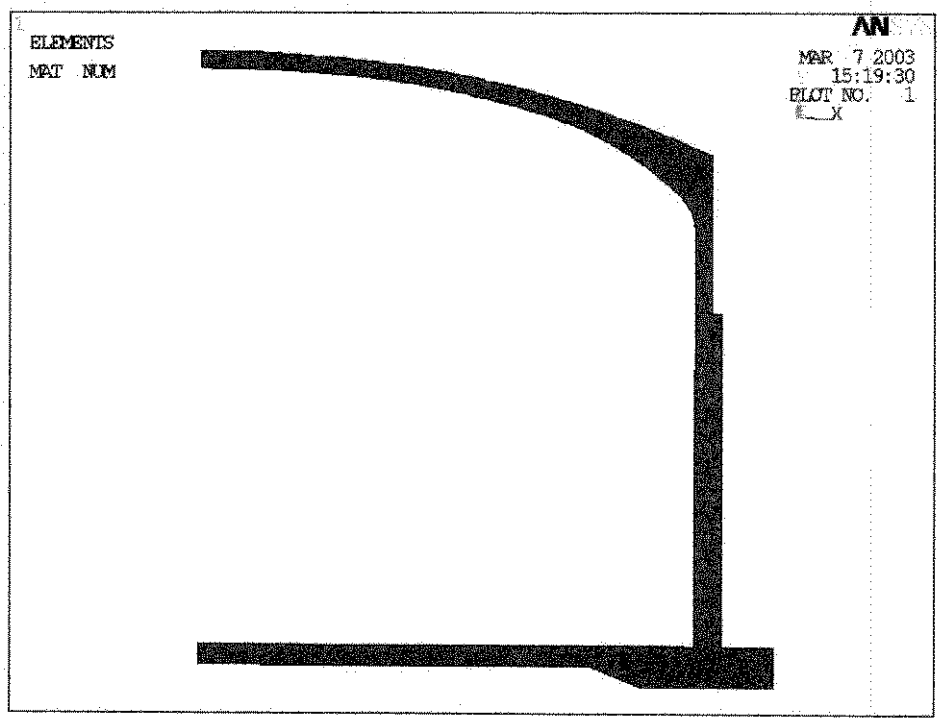

Figure 1. Geometry of SST-AX Tank

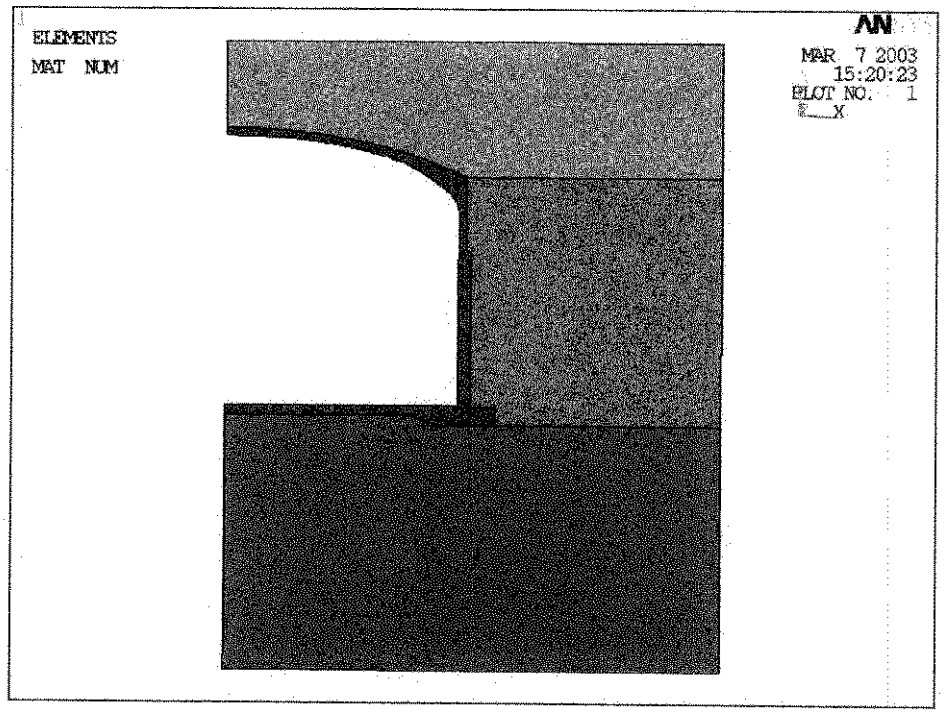

Figure 2. Soil Layers

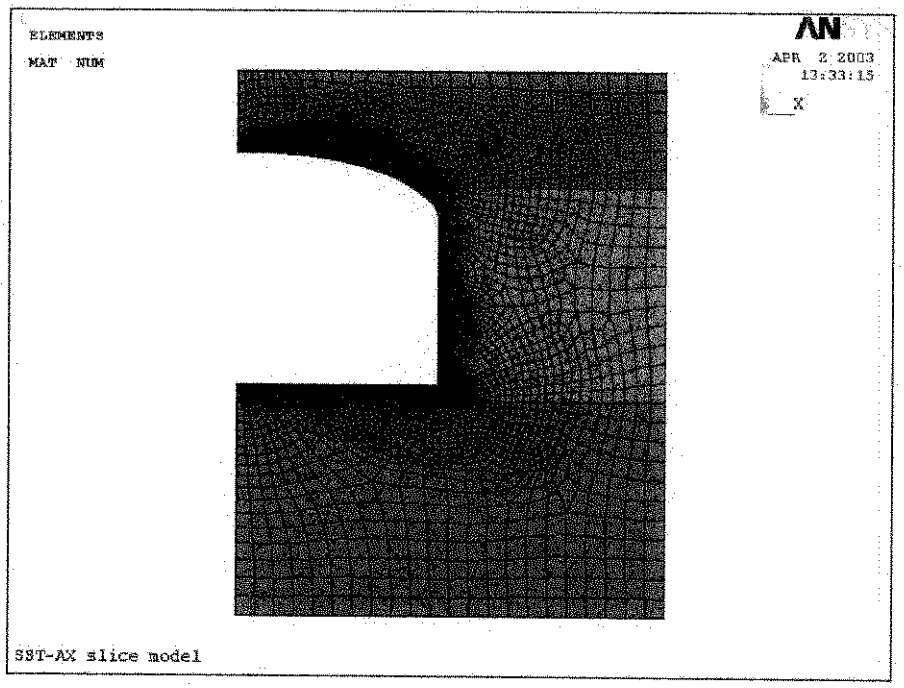

Figure 3. Finite element mesh, showing elements colored by material ID.

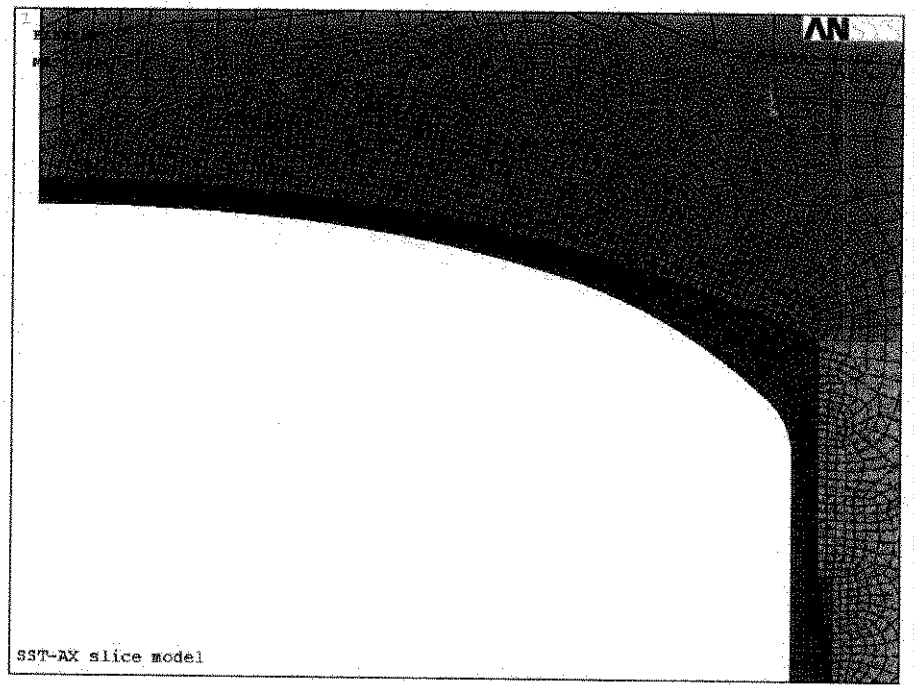

Figure 4. Close-up of finite element mesh.

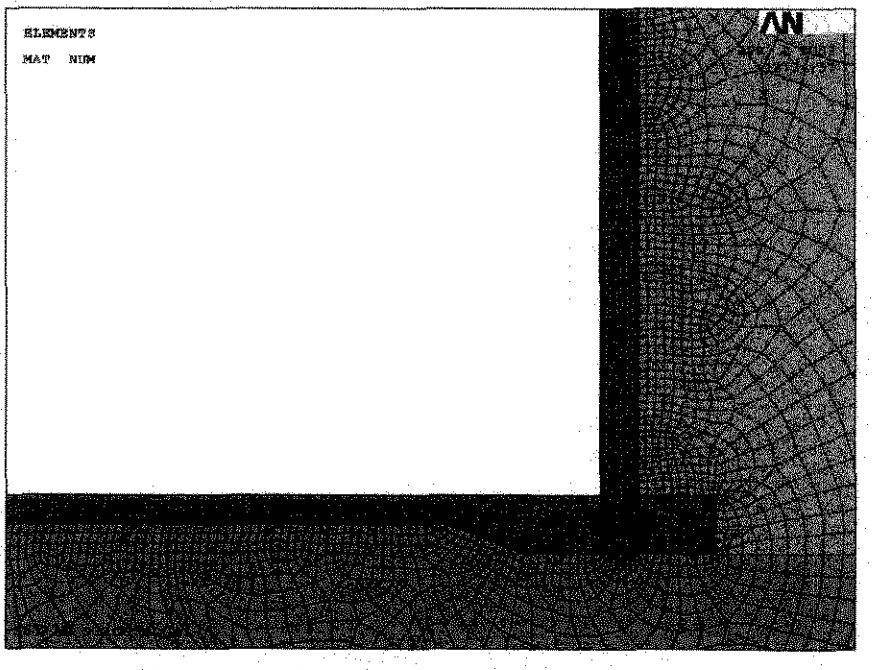

Figure 5. Close-up of finite element mesh.

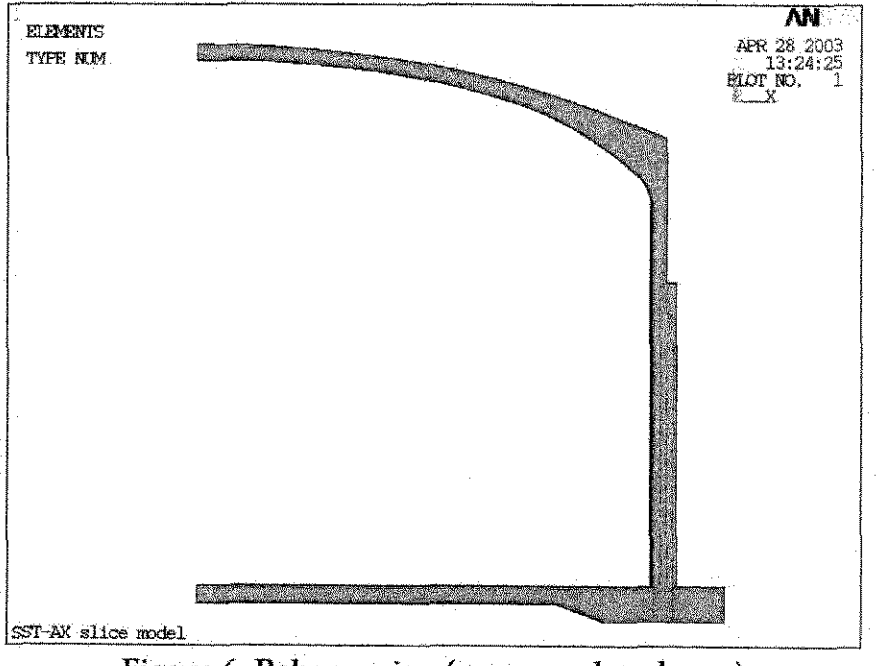

Figure 6. Rebar region (orange colored area)

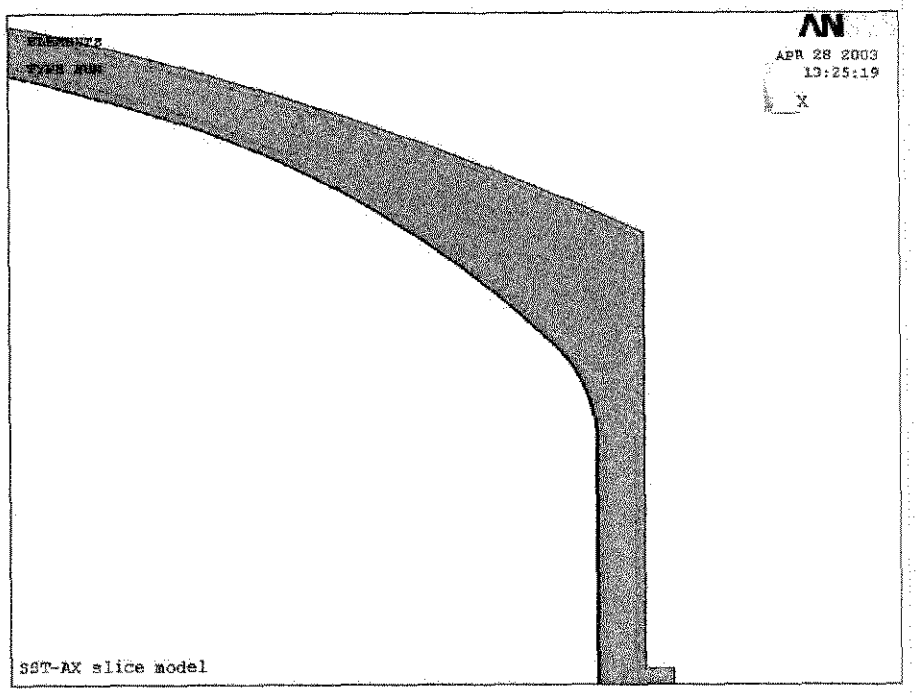

Figure 7. Close up of rebar region

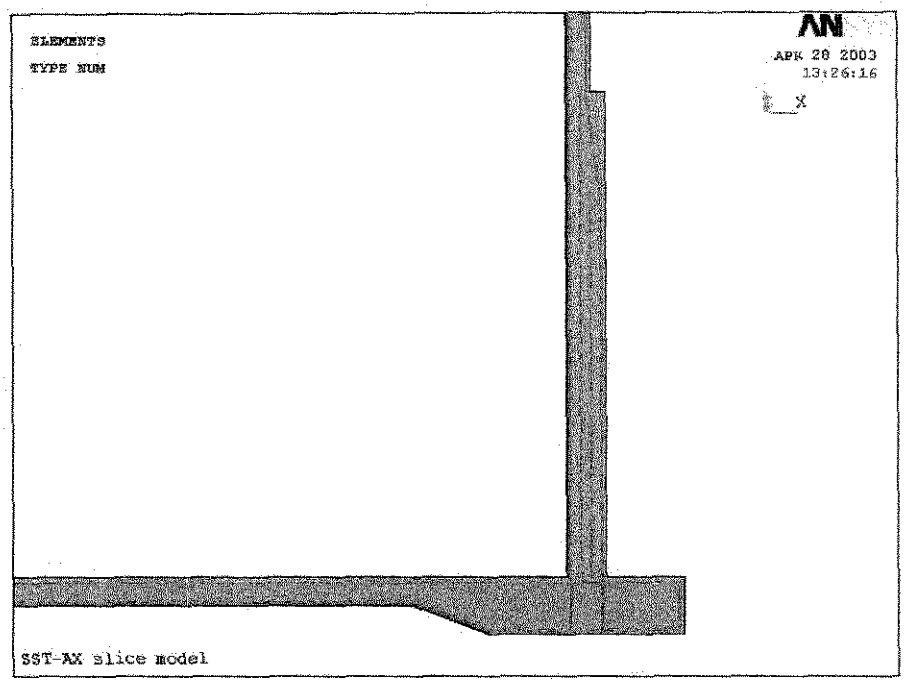

Figure 8. Close up of rebar region

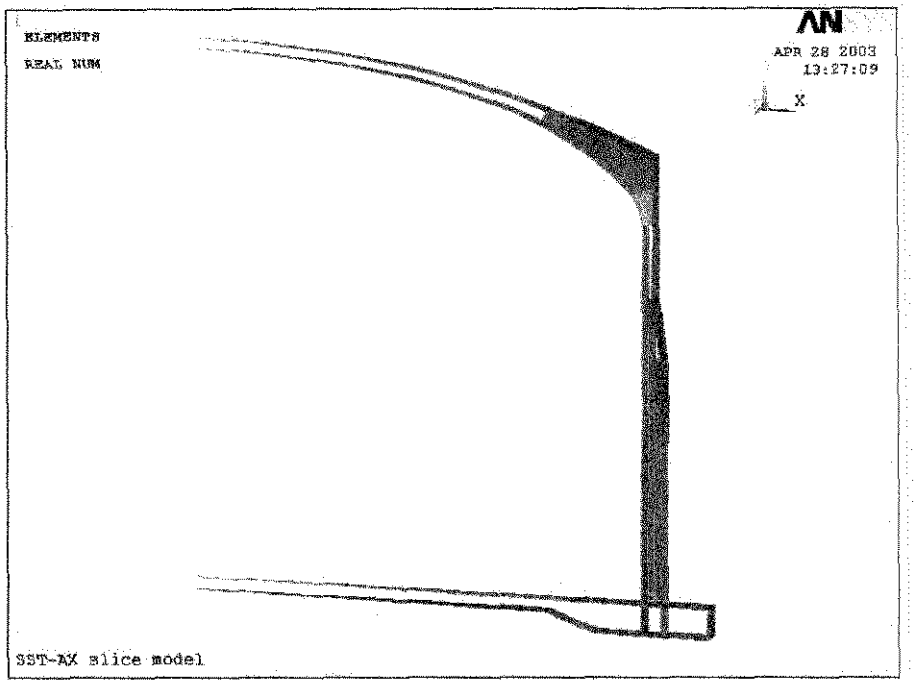

Figure 9. Rebar elements colored by real constants

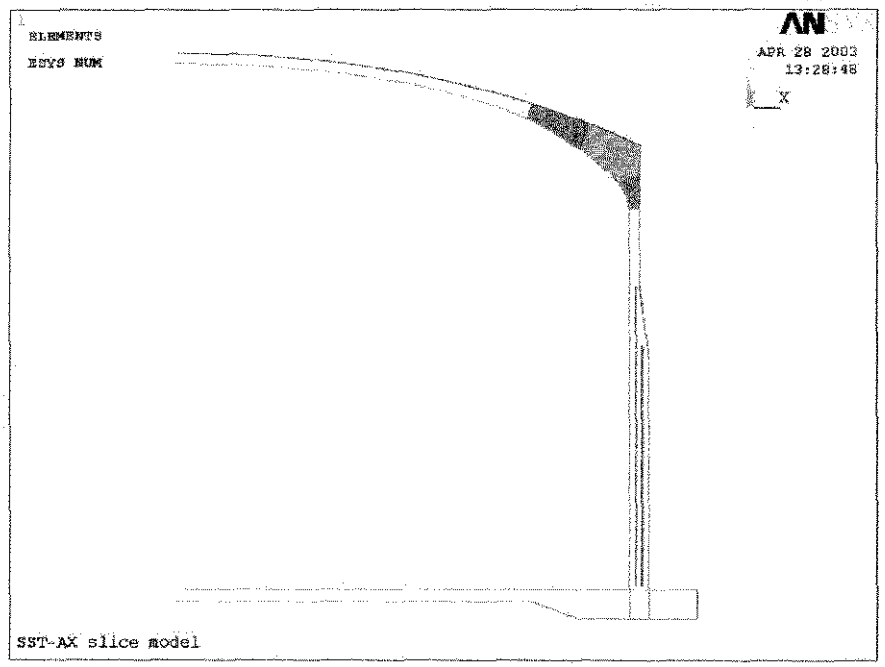

Figure 10. Rebar elements colored by element coordinate system

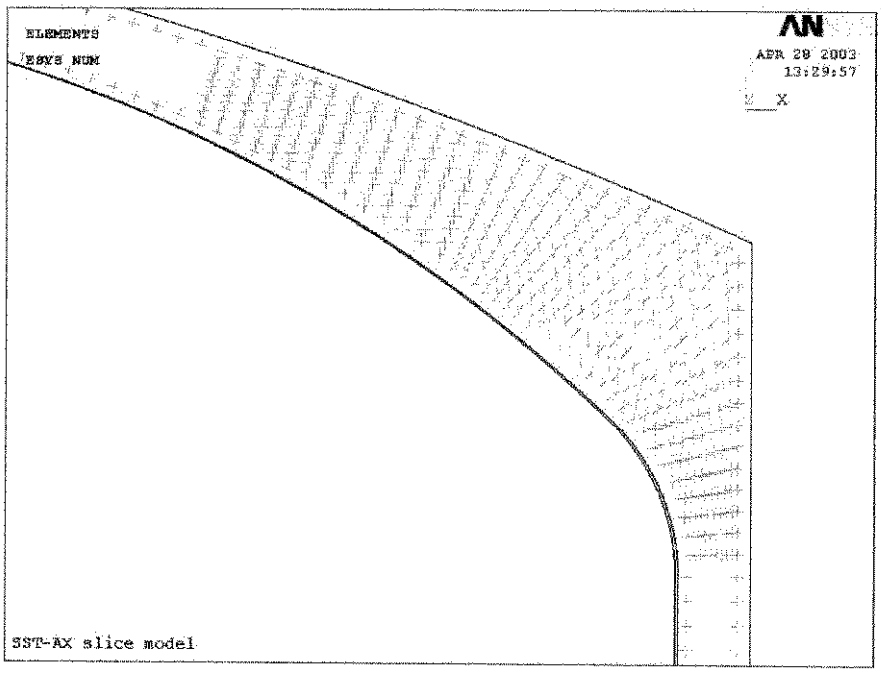

Figure 11. Rebar orientation at haunch core

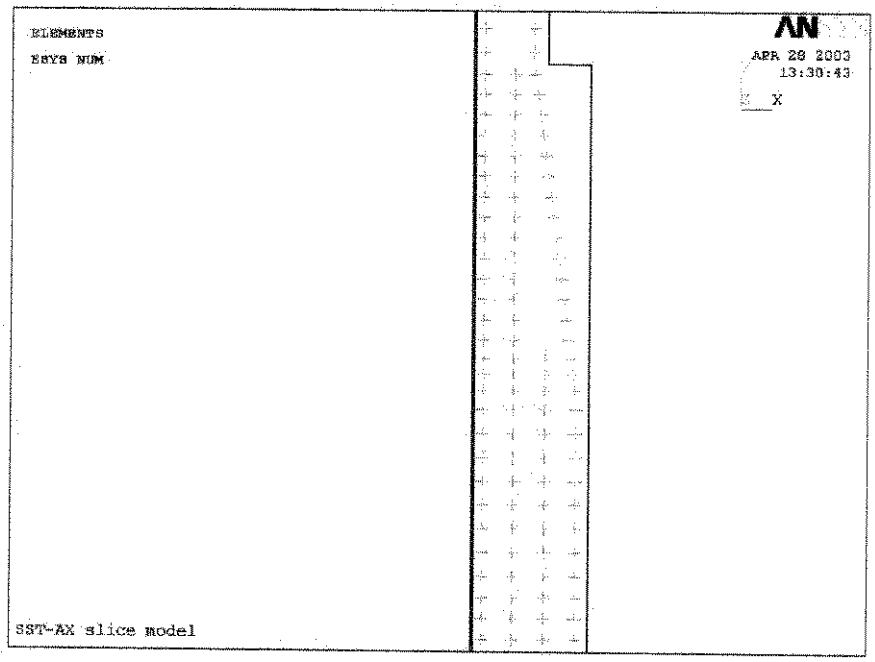

Figure 12. Rebar orientation at inclined region

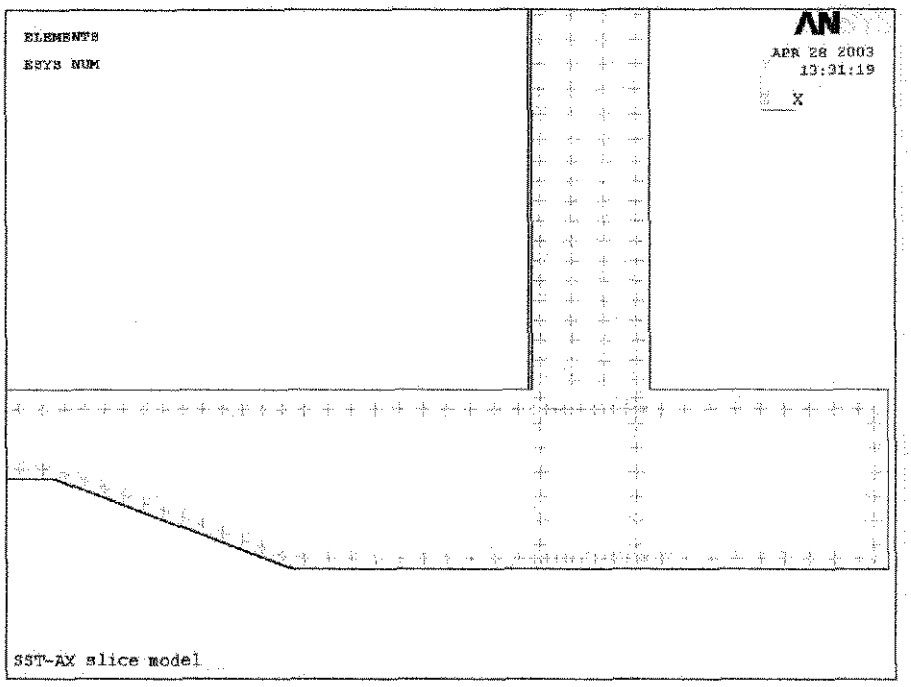

Figure 13. Rebar orientation at wall/slab joint

4.0 RESULTS

The solution can be obtained by running the master input macro **sst_ax_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 2.57 inches, and this occurs at grade far away from the tank. The peak tank displacement is 1.82 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 2.7 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 564 psi at the haunch region, and the minimum hoop stress is -1101 psi at the wall/slab joint. The rebar stresses in first, second, and third rebar directions are plotted in Figures 21 to 26.

Force and moment resultants are calculated in **pst_ax_slice.mac**. In order for **pst_ax_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 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 131 kip/ft, maximum shear force of 66 kip/ft, and maximum moment of 3506 kip-in/ft. Maximum hoop force of 145 kip/ft occurred at the haunch region.

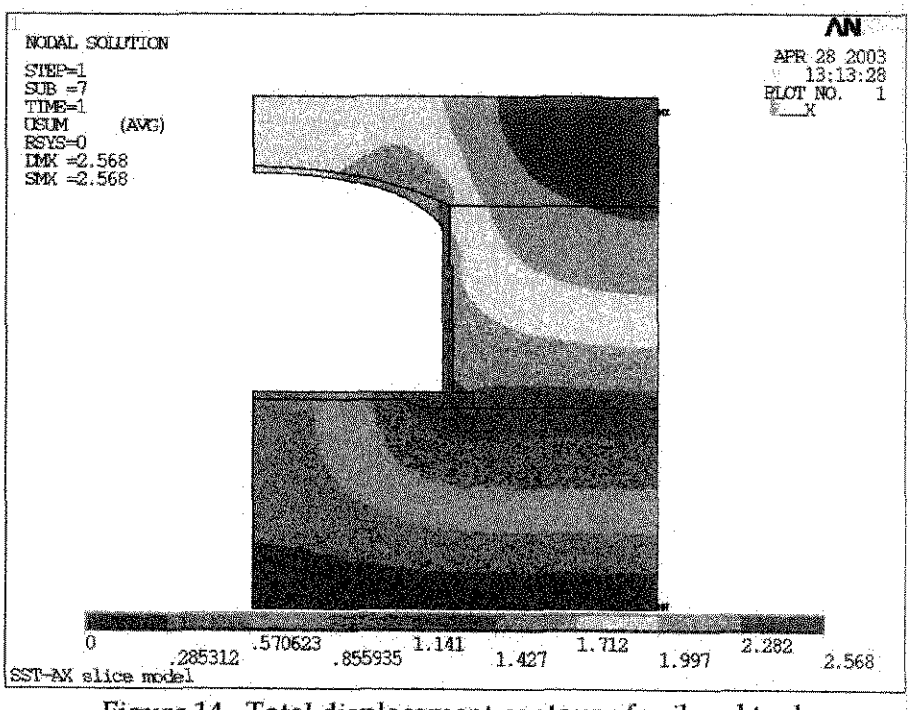

Figure 14. Total displacement contour of soil and tank

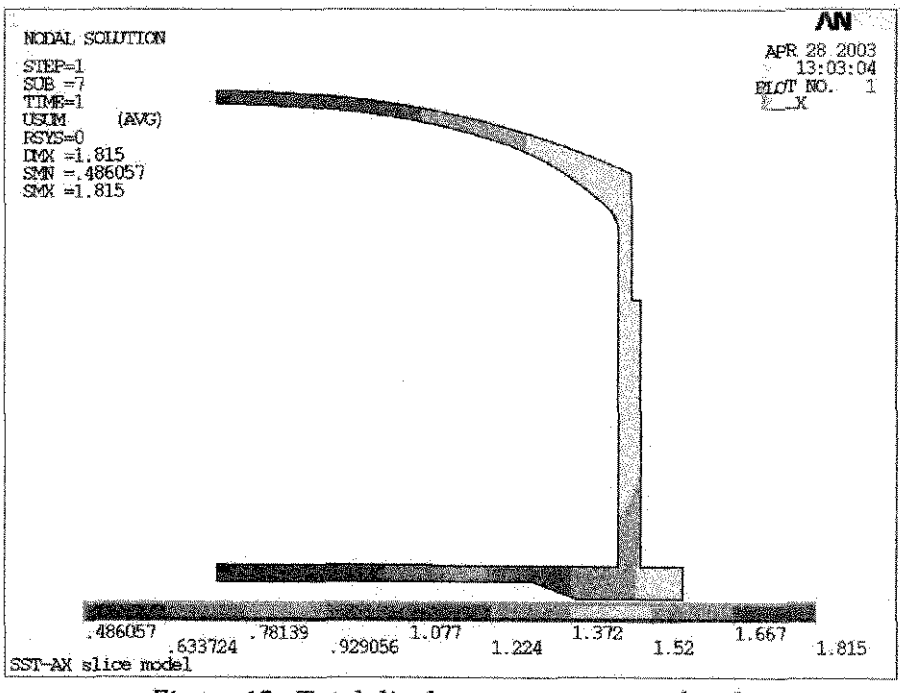

Figure 15. Total displacement contour of tank

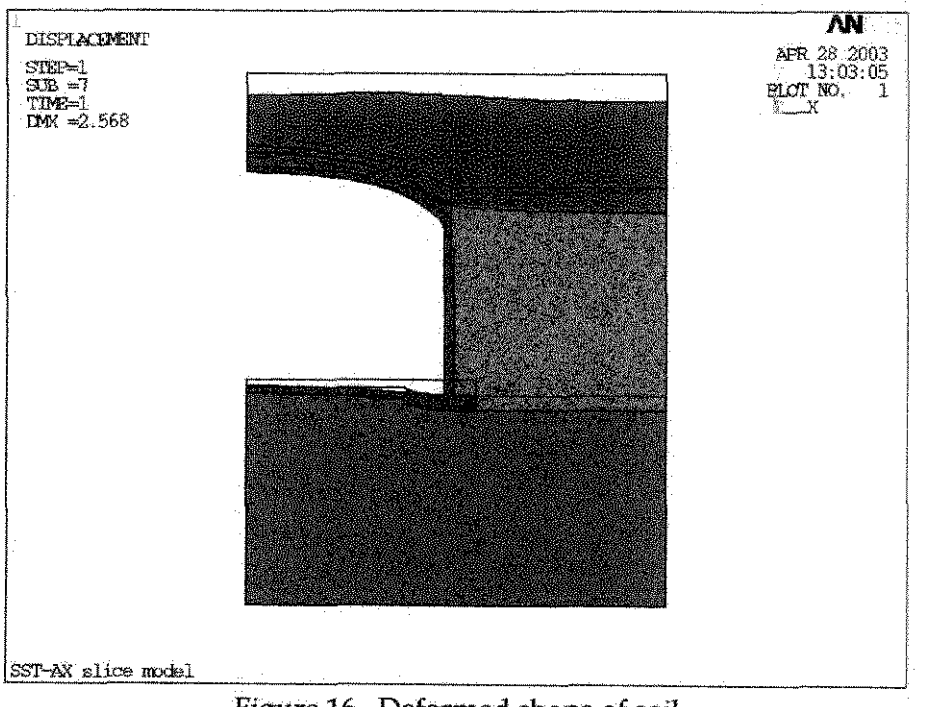

Figure 16. Deformed shape of soil

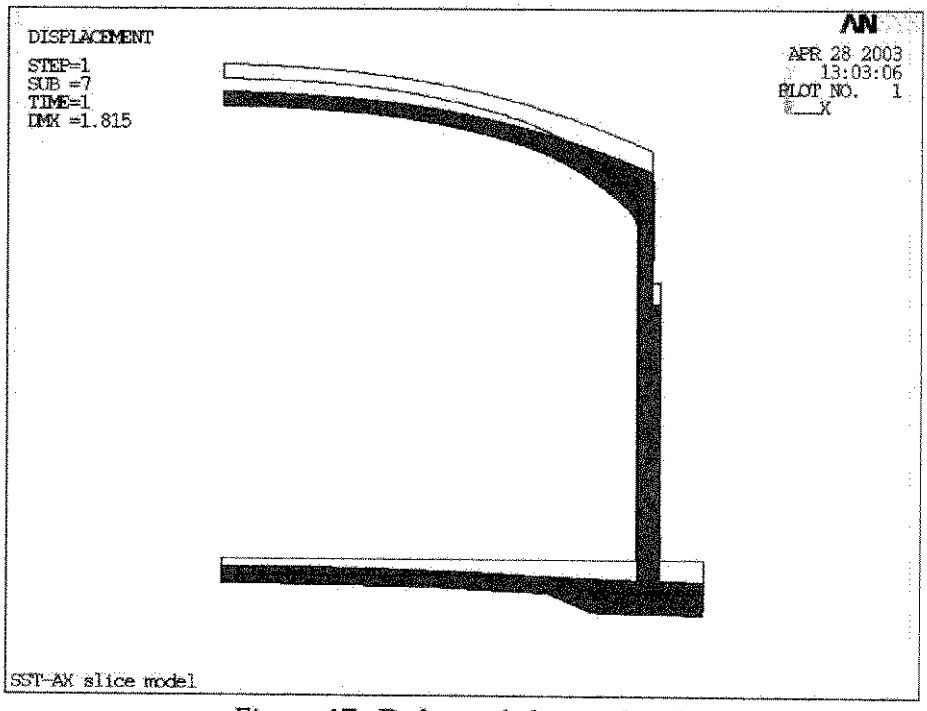

Figure 17. Deformed shape of tank

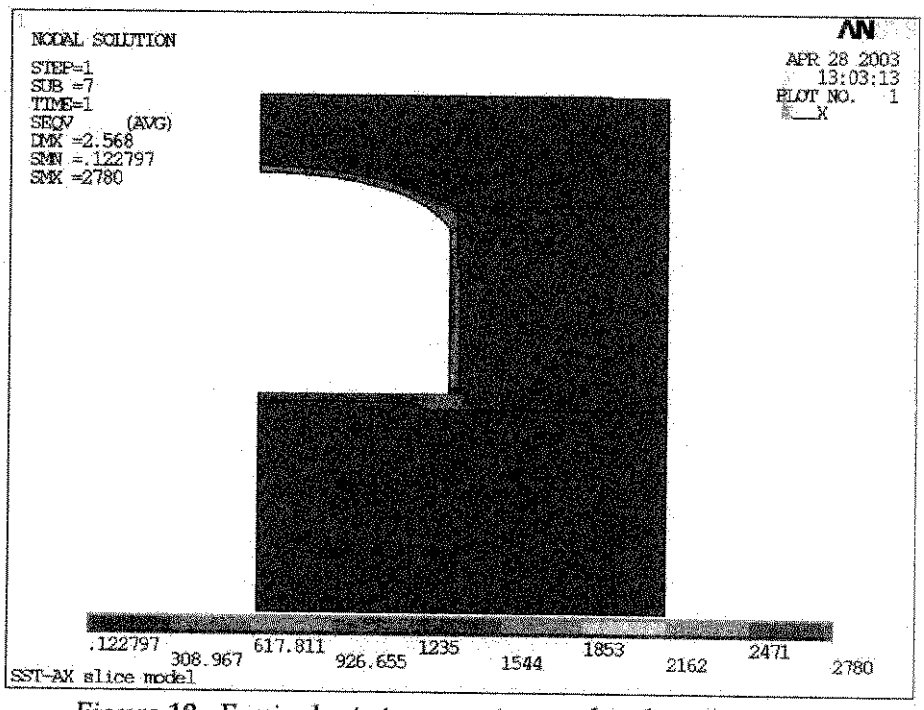

Figure 18. Equivalent stress contours of tank and soil (psi).

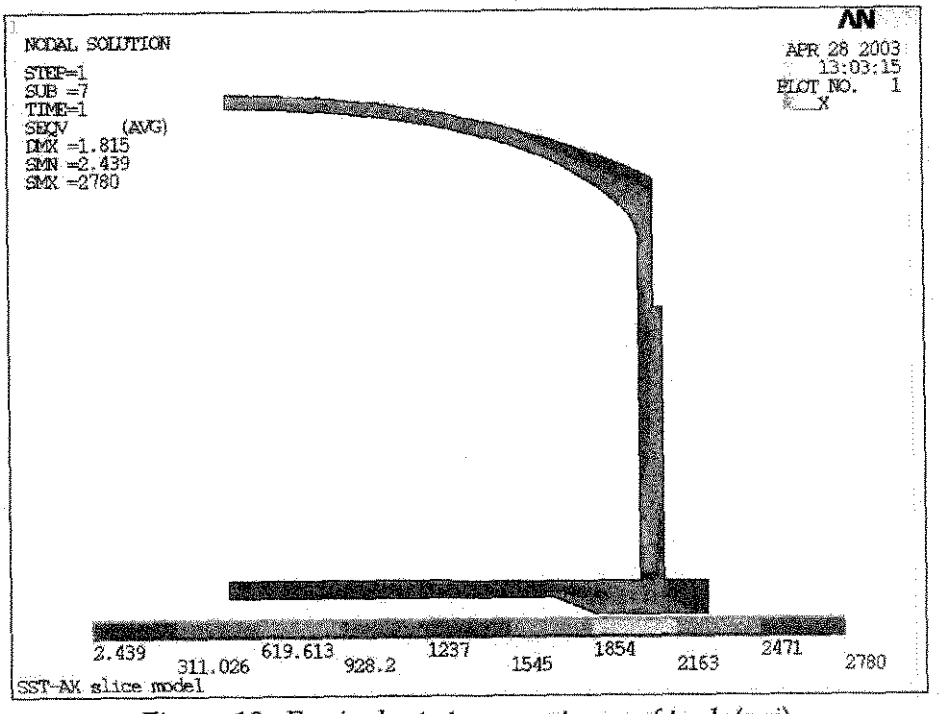

Figure 19. Equivalent stress contours of tank (psi).

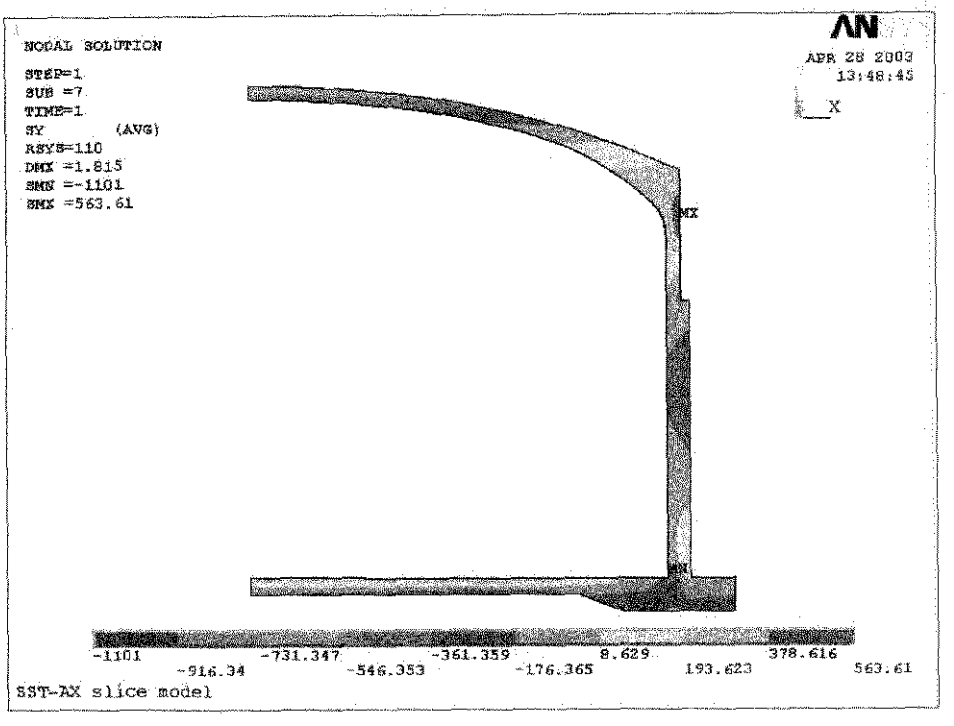

Figure 20. Hoop stress of tank (psi)

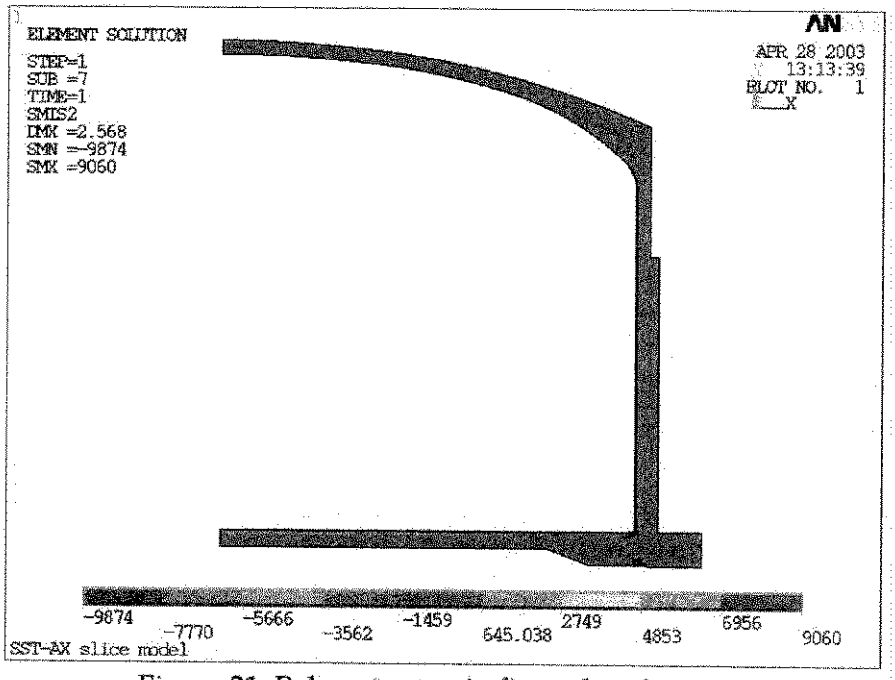

Figure 21. Rebar stresses in first rebar direction

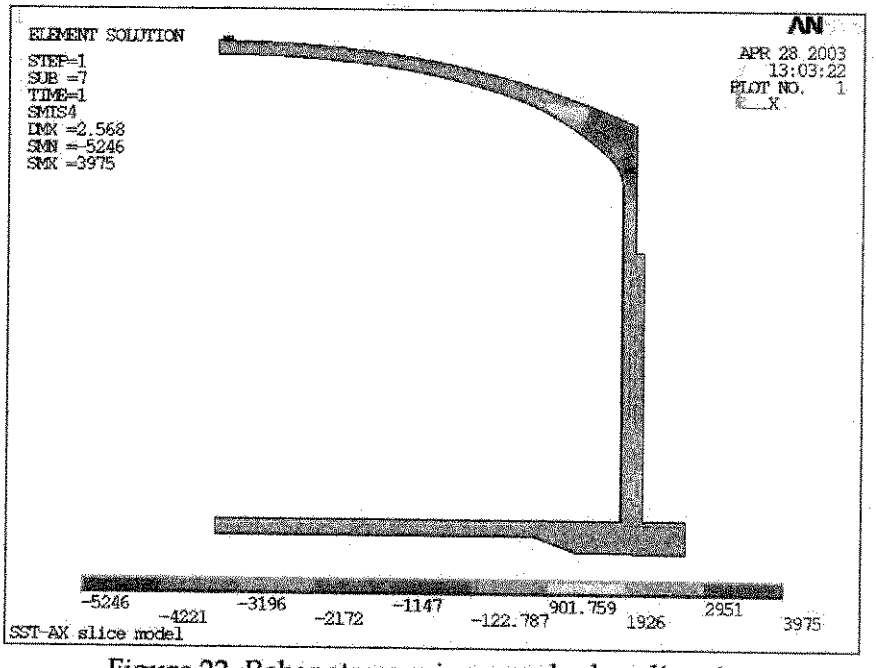

Figure 22. Rebar stresses in second rebar direction

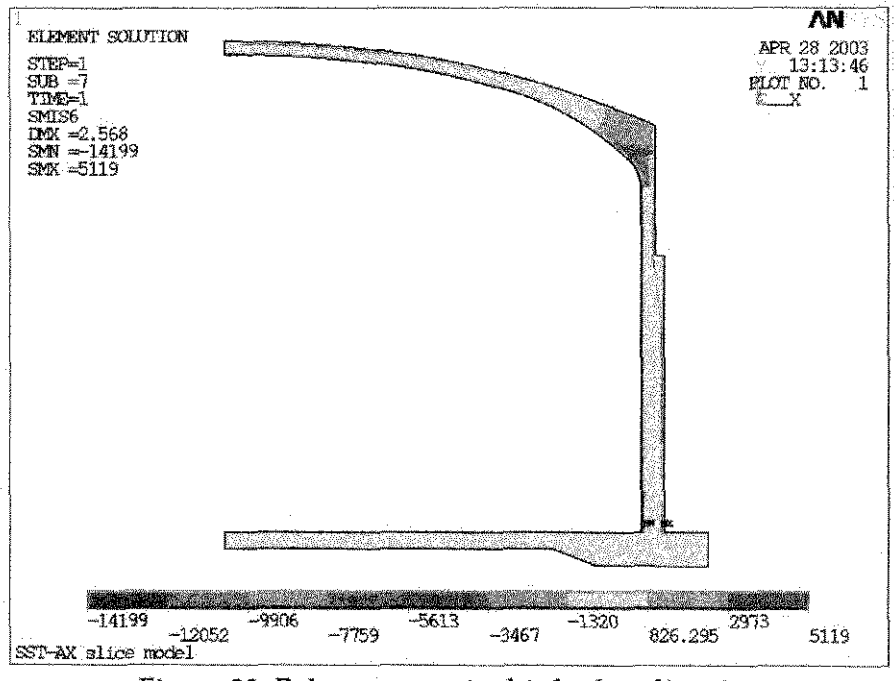

Figure 23. Rebar stresses in third rebar direction

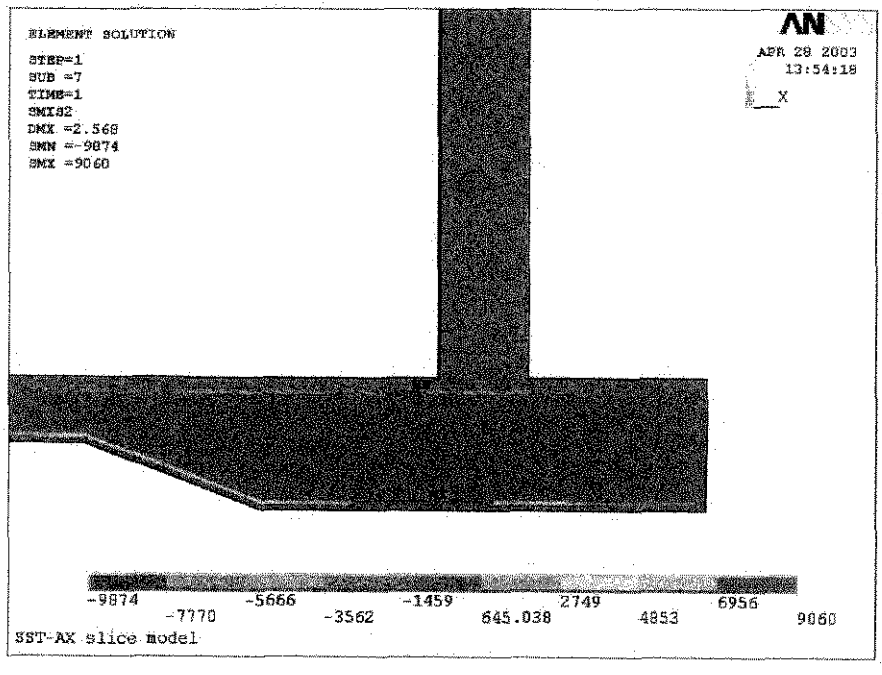

Figure 24. Close up of rebar stresses in first rebar direction

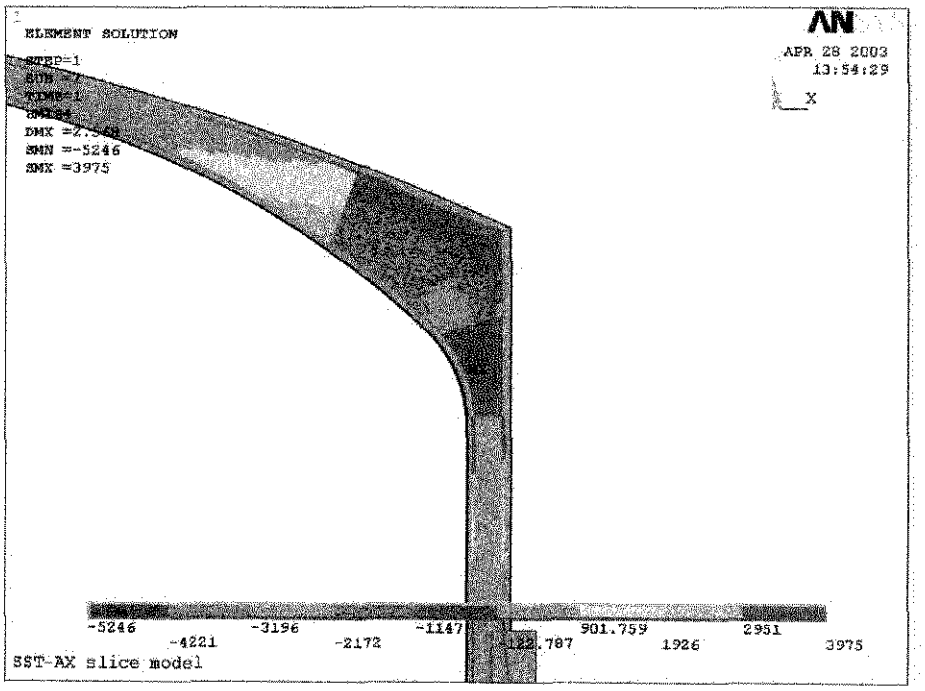

Figure 25. Close up of rebar stresses second rebar direction

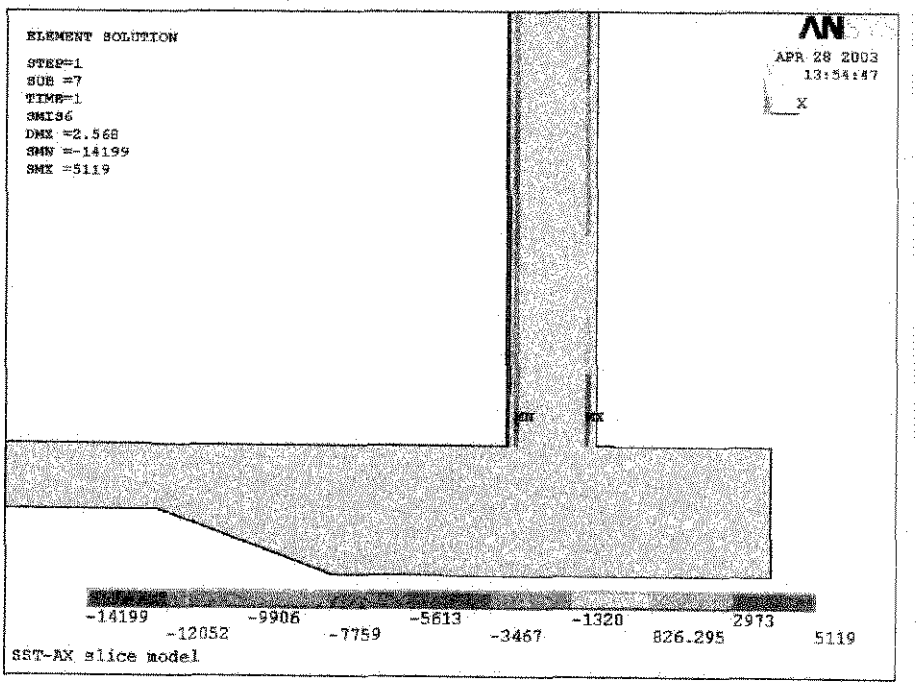

Figure 26. Close up of rebar stress third rebar direction

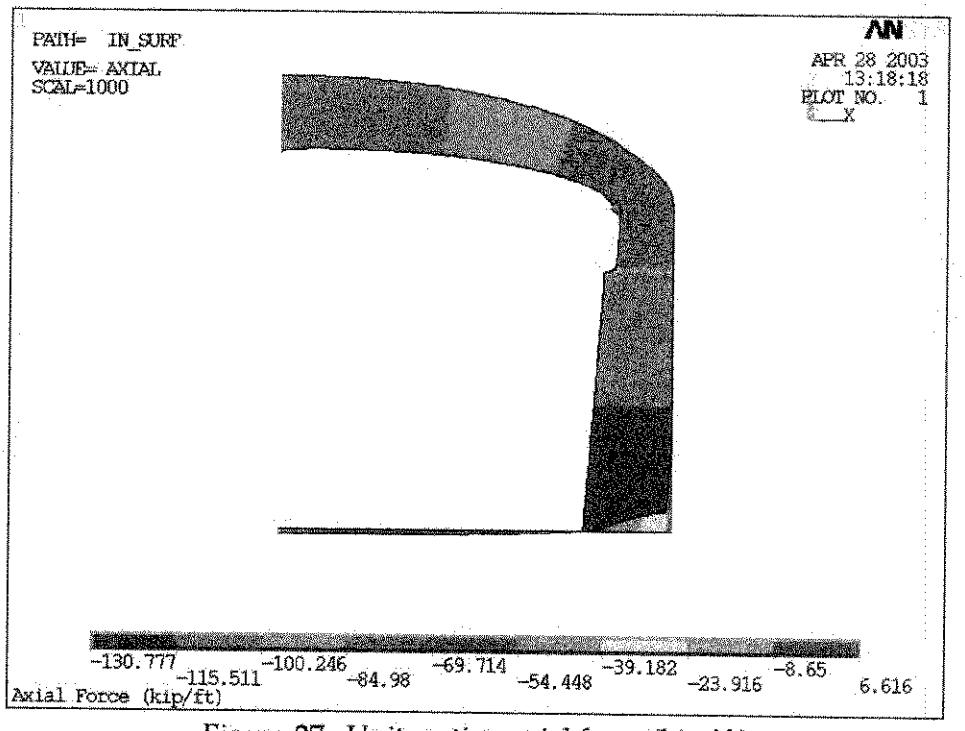

Figure 27. Unit section axial force (kip/ft)

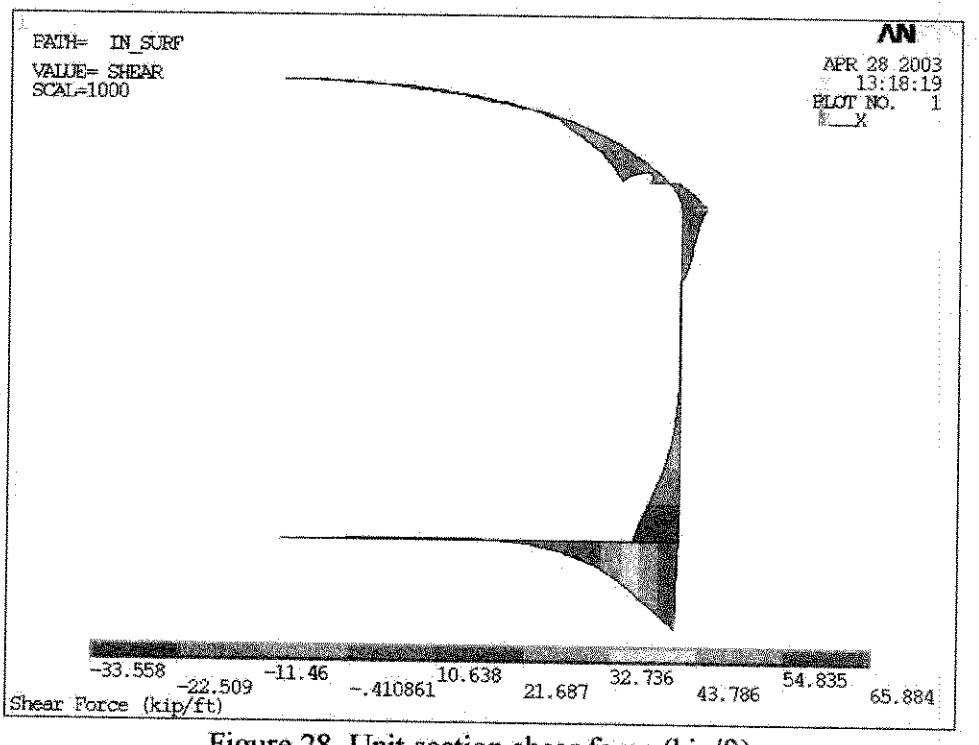

Figure 28. Unit section shear force (kip/ft)

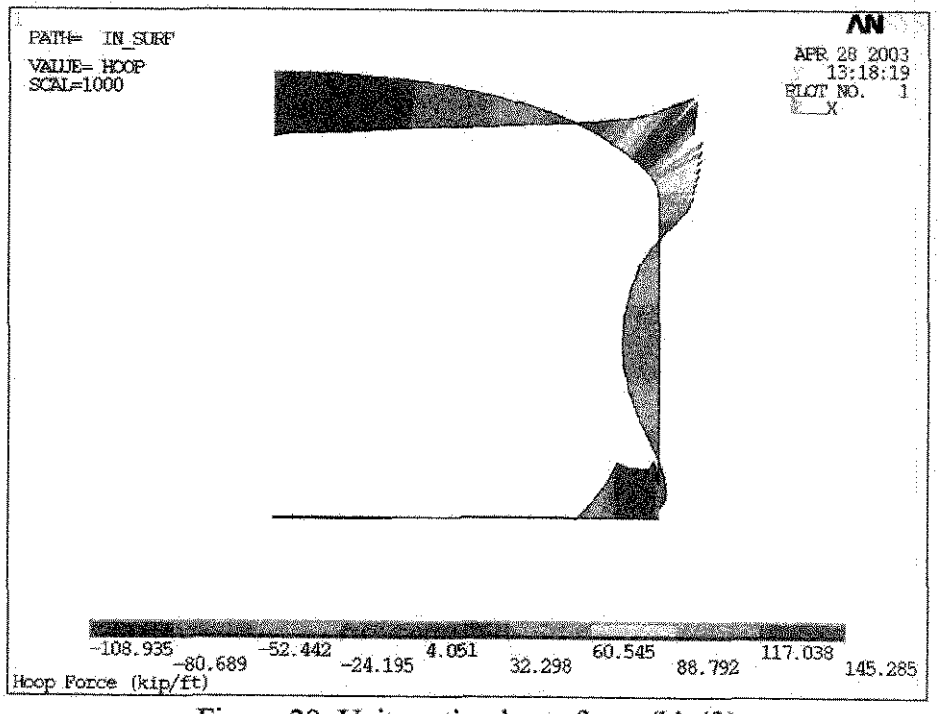

Figure 29. Unit section hoop force (kip/ft)

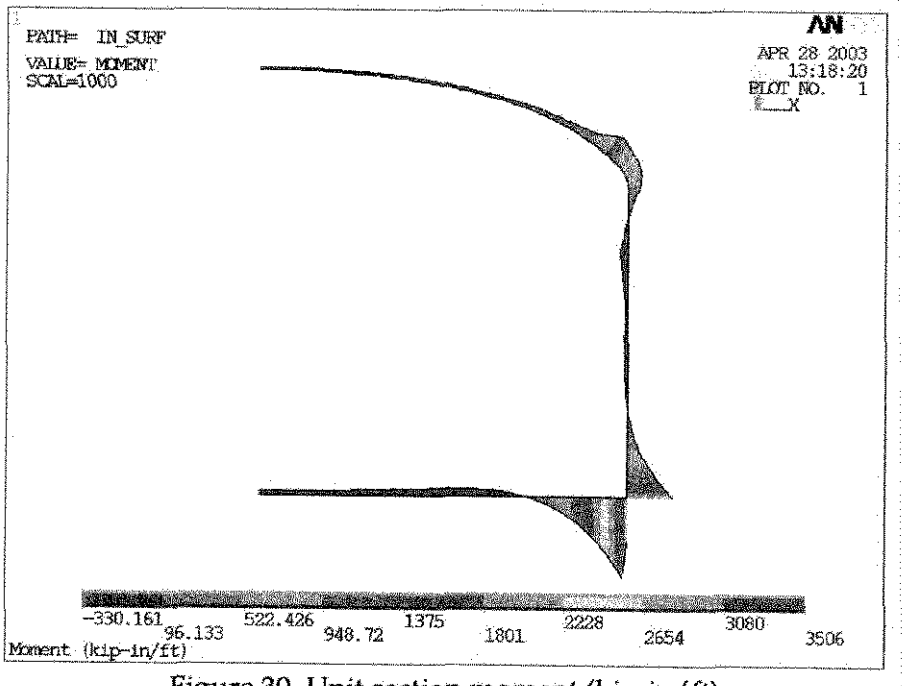

Figure 30. Unit section moment (kip-in/ft)

5.0 CONCLUSIONS

The 3D parametric slice model is capable of giving a more accurate estimation 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-AX, 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 1, February 24, 2003.

[Ref_4] Drawing H-2-44562, February 21, 1963

[Ref_5] JLR The Engineering Solutions Company, "Sample AOR Calculation using ANSYS Axisymmetric Model for Tank SST-AX", RPP-13998, March 11, 2003

7.0 ATTACHMENTS AND APPENDICES

sst_ax_slice.mac

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

SHPP,MODIF,1,100000,

/INPUT,'parm_ax','mac'

!--Create dome
/TRIAD,RTOP
wpcsys,-1,0
wpoff,,dm_r1,
csys,4
k,1,r1,-h1
k,2,r2,-h2
k,3,r3,-h3
k,4,r4,-h4
k,5,r5,-h5
k,6,r6,-h6
k,7,r7,-h7
k,8,r8,-h8
k,9,r9,-h9
k,10,r10,-h10
k,11,r11,-h11
k,12,r12,-h12
k,13,r13,-h13
k,14,r14,-h14
k,15,r15,-h15
k,16,r16,-h16
k,17,r17,-h17
k,18,r18,-h18

larc,1,2,10,dm_r1
larc,2,3,10,dm_r3
lstr,3,4
lstr,4,5
lstr,5,6
lstr,6,7
lstr,7,8
lstr,8,9
lstr,9,10
lstr,10,11
lstr,11,12
lstr,12,13
lstr,13,14
```

```
larc,14,15,10,hnch_r
larc,15,16,10,dm_r5
larc,16,17,10,dm_r4
larc,17,18,10,dm_r2
lstr,1,18
al,all

!--Cut Tank
lstr,2,17
asbl,1,19

lwpla,-1,15,1
lsbw,2
lstr,16,19
asbl,3,2
lstr,15,3
asbl,4,22
lwpla,-1,13,1
asbw,5
kwpave,4
asbw,6
kwpave,6
asbw,7
wprot,,,90
asbw,8
kwpave,13
asbw,9
kwpave,9
asbw,10
kwpave,10
asbw,11
kwpave,4
asbw,all
allsel
cm,a_tank,area

!---Create Soil Mass
wpcsys,-1,0
kwpave,1
csys,4
wpoff,,depth
rectng,0,soil_r,0,-(h9+depth+soil_h)
aovlp,all

adele,8,,,1
cmsel,u,a_tank
cm,a_soil,area

!--cut soil for different soil properties
kwpave,3
wprot,,90
```

```
asbw,all
kwpave,8
lsbw,47
lstr,8,33
asbl,all,47
cm,a_soil,area

wpcsys,-1,0
wprot,,,90
kwpave,1
wpoff,,,cload_1
lsbw,42

allsel
aplot

!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!     Cut tank for rebar regions at different depths
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
cmsel,s,a_tank

rbar_t=1.
rbar_dep1=2 !bar clearance for external rebar @ dome/wall
rbar_dep2=1.5     !bar clearance for internal rebar @ dome/wall
rbar_dep3=1.5     !bar clearance for external rebar @ slab
rbar_dep4=3.5     !bar clearance for internal rebar @ slab
rbar_dep5=2 !bar clearance for slab side
rbar_r1=2*12      !radial bar lengths in dome
rbar_r2=5*12
rbar_r3=10*12
rbar_r4=20*12
rbar_r5=28*12
rbar_r6=31*12+6
wall_slp_h=70

rbar_wll_dh1=2*12+6     !vertical rebar to wall step distance
rbar_wll_dh2=rbar_wll_dh1+2*12+6
rbar_wll_dh3=rbar_wll_dh2+3*12+4
rbar_wll_dh4=rbar_wll_dh3+5
rbar_wll_dh5=25*12-4*12
rbar_wll_dh6=25*12-3*12
rbar_wll_dh7=25*12-2*12
rbar_wll_dh8=25*12-1*12
rbar_wll_dh9=11*12
rbar_wll_dh10=rbar_wll_dh4+5

rbar_spc=(t2-rbar_dep1-rbar_dep2-4*rbar_t)/3

aadd,3,4
```

```
wpcsys,-1,0
kwpave,1
wpoff,,-rbar_dep1
csys,4
k
wpoff,,-rbar_t
k

lwpla,-1,19
wpoff,,,rbar_dep1
k
wpoff,,,rbar_t
k

lwpla,-1,2,1
wpoff,,,-rbar_dep1
k
wpoff,,,-rbar_t
k

lwpla,-1,21
wpoff,rbar_dep1
k
wpoff,rbar_t
k

larc,35,37,18,dm_r1-rbar_dep1
larc,36,38,18,dm_r1-rbar_dep1-rbar_t
larc,37,39,18,dm_r3-rbar_dep1
larc,38,40,18,dm_r3-rbar_dep1-rbar_t
larc,39,41,18,dm_r3-rbar_dep1
larc,40,42,18,dm_r3-rbar_dep1-rbar_t

lwpla,-1,24,1
wpoff,,,-rbar_dep1
lsbw,53
k
wpoff,,,-rbar_t
lsbw,54
k

lstr,43,44
lstr,45,46
ldele,56,57,,1    ! finishing external dome rebar

lwpla,-1,18,1
wpoff,,,-rbar_dep2
k
wpoff,,,-rbar_t
k
```

```
lwpla,-1,19,1
wpoff,,,-rbar_dep2
k
wpoff,,,-rbar_t
k

lwpla,-1,2
wpoff,,,rbar_dep1
k
wpoff,,,rbar_t
k

lwpla,-1,15
wpoff,-rbar_dep2
k
wpoff,-rbar_t
k

lwpla,-1,24
wpoff,,,rbar_dep2
k
wpoff,,,rbar_t
k

larc,41,47,12,dm_r2+rbar_dep2
larc,42,48,12,dm_r2+rbar_dep2+rbar_t
larc,47,49,12,dm_r4+rbar_dep2
larc,48,50,12,dm_r4+rbar_dep2+rbar_t
larc,49,51,12,dm_r5+rbar_dep2
larc,50,52,12,dm_r5+rbar_dep2+rbar_t
larc,51,53,12,hnch_r+rbar_dep2
larc,52,54,12,hnch_r+rbar_dep2+rbar_t   !finishing internal dome rebar

cm,ltemp,line
cm,atemp,area
lsel,s,,,22
lsel,a,,,42
lsel,a,,,56,57
asbl,2,all
cmsel,a,ltemp
cmsel,a,atemp

lsel,s,,,51,52
lsel,a,,,59,60
asbl,1,all
cmsel,a,ltemp

lsel,s,,,53,55
lsel,a,,,58
lsel,a,,,61,64
```

```
asbl,8,all          !finish cutting area for dome/hauch rebar region

                    !in depth

cm,a_tank,area

lwpla,-1,79
asbw,5
lwpla,-1,79,1
asbw,29

lwpla,-1,81
asbw,30
lwpla,-1,81,1
asbw,31

lsla
lwpla,-1,5
wpoff,,,wall_slp_h
asbw,11
asbw,13
aadd,11,33

wpoff,-rbar_dep1
k
wpoff,-rbar_t
k
lstr,55,62
lstr,56,63
lsel,s,,,5
lsel,a,,,92
asbl,13,all
lsla

aadd,31,34
aadd,14,15
lcomb,91,97
lcomb,37,38
lcomb,39,41

lwpla,-1,95
asbw,13
asbw,31

lwpla,-1,95,1
asbw,15
asbw,13

lwpla,-1,89
asbw,35
asbw,36
```

```
asbw,15
lwpla,-1,89,1
asbw,38
asbw,39
asbw,40                    !finishing cut for wall rebar

lwpla,-1,7
wpoff,,,rbar_dep4
asbw,7
asbw,9
asbw,10
asbw,12
asbw,34
asbw,36
asbw,37
asbw,39
asbw,43

wpoff,,,rbar_t
asbw,7
asbw,9
asbw,10
asbw,34
asbw,39
asbw,44
asbw,48
asbw,50
asbw,51

lwpla,-1,130
wpoff,,,rbar_dep3
asbw,10
asbw,34
asbw,39
asbw,43
asbw,44
asbw,48
asbw,50
wpoff,,,rbar_t
asbw,62
asbw,63
asbw,64
asbw,65
asbw,66
asbw,67
asbw,68

lwpla,-1,8
wpoff,,,rbar_dep3
asbw,9
wpoff,,,rbar_t
```

```
asbw,76
lstr,96,107
lstr,104,109

lsel,s,,,183,184
asbl,7,all
lsla

wpcsys,-1,0
kwpave,1
wprot,,,90
wpoff,,,rbar_r1
lsbw,1
lwpla,-1,189,1
asbw,3
asbw,4
asbw,18
asbw,19
asbw,20

wpcsys,-1,0
kwpave,1
wprot,,,90
wpoff,,,rbar_r2
lsbw,189
lwpla,-1,200,1
asbw,3
asbw,80
asbw,82
asbw,83
asbw,84

wpcsys,-1,0
kwpave,1
wprot,,,90
wpoff,,,rbar_r3
lsbw,199
lwpla,-1,211,1
asbw,3
asbw,20
asbw,80
asbw,82
asbw,89

wpcsys,-1,0
kwpave,1
wprot,,,90
wpoff,,,rbar_r4
lsbw,20
lwpla,-1,221,1
asbw,2
```

```
asbw,21
asbw,22
asbw,23
asbw,24

wpcsys,-1,0
kwpave,1
wprot,,,90
wpoff,,,rbar_r5
lsbw,21
lwpla,-1,232,1
asbw,1
asbw,25
asbw,26
asbw,27
asbw,28            !finishing cut dome for bar lengthes

cm,a_tank,area
lwpla,-1,27
wpoff,,,rbar_wll_dh1
asbw,11
asbw,13
asbw,15
asbw,33
asbw,41

kwpave,5
wpoff,,,rbar_wll_dh2
asbw,15
asbw,105
asbw,106
asbw,107
asbw,109

kwpave,5
wpoff,,,rbar_wll_dh3
asbw,14
asbw,31
asbw,35
asbw,38
asbw,42

kwpave,5
wpoff,,,rbar_wll_dh4
asbw,14
asbw,31
asbw,35
asbw,38
asbw,109

kwpave,5
```

```
wpoff,,,rbar_wll_dh5
asbw,14
asbw,31
asbw,35
asbw,38
asbw,42

kwpave,5
wpoff,,,rbar_wll_dh6
asbw,14
asbw,35
asbw,38
asbw,109
asbw,127

kwpave,5
wpoff,,,rbar_wll_dh7
asbw,14
asbw,35
asbw,38
asbw,42
asbw,134

kwpave,5
wpoff,,,rbar_wll_dh8
asbw,14
asbw,35
asbw,38
asbw,42
asbw,127

kwpave,5
wpoff,,,rbar_wll_dh9
asbw,31
asbw,125
asbw,126
asbw,128
asbw,129          !finish cut wall for bar length

lwpla,-1,6,1
wpoff,,,-rbar_dep5
asbw,34
asbw,40
asbw,58
asbw,63
asbw,71
wpoff,,,-rbar_t
asbw,34
asbw,40
asbw,58
asbw,63
```

```
asbw,150          !finish cut rebar region for slab side

lwpla,-1,36,1
wpoff,,,2*12
asbw,46
asbw,54
asbw,76
asbw,78
asbw,79

wpoff,,,-4*12
asbw,9
asbw,47
asbw,55
asbw,68
asbw,77                  !finishing cut rbar length for slab

lwpla,-1,253
kwpave,5
wpoff,,,rbar_wll_dh10
asbw,31
asbw,125
asbw,126
asbw,127
asbw,149

lwpla,-1,391
wpoff,,,rbar_spc
asbw,31
asbw,35
asbw,37
asbw,48
asbw,61
asbw,67
asbw,75
asbw,114
asbw,118
asbw,122
asbw,130
asbw,138
asbw,142
asbw,147
asbw,171

wpoff,,,rbar_t
asbw,31
asbw,35
asbw,37
asbw,48
asbw,61
asbw,67
```

```
asbw,142
asbw,147
asbw,175
asbw,182
asbw,183
asbw,184
asbw,185
asbw,186
asbw,187

wpoff,,,rbar_spc
asbw,31
asbw,35
asbw,48
asbw,61
asbw,67
asbw,147
asbw,171
asbw,175
asbw,184
asbw,193
asbw,197
asbw,200
asbw,201
asbw,203
asbw,204

wpoff,,,rbar_t
asbw,31
asbw,35
asbw,48
asbw,61
asbw,67
asbw,147
asbw,171
asbw,175
asbw,184
asbw,187
asbw,193
asbw,197
asbw,200
asbw,201
asbw,203
asbw,107
asbw,33

wpoff,,,-rbar_t
asbw,235
asbw,236

!---cut haunch region for radial rebars
```

```
hnch_rbar_dr1=4*12+4.5
hnch_rbar_dr2=hnch_rbar_dr1+3*12+6
hnch_rbar_dh=30

wpcsys,-1,0
kwpave,3
wprot,,,90
wpoff,,,-hnch_rbar_dr1
lsbw,232
lwpla,-1,530,1
asbw,100
asbw,101
asbw,102
asbw,103
asbw,104

wpcsys,-1,0
kwpave,3
wprot,,,90
wpoff,,,-hnch_rbar_dr2
lsbw,530
lwpla,-1,541,1
asbw,100
asbw,101
asbw,102
asbw,103
asbw,236

wpcsys,-1,0

kwpave,3
wprot,,90
wpoff,,,hnch_rbar_dh
lsbw,23
lstr,15,305
lwpla,-1,23
wprot,,,90
asbw,239
asbw,240
asbw,241
asbw,242
asbw,243


!--extra cut on dome
wpcsys,-1,0
kwpave,1
wprot,,,90
wpoff,,,rbar_r6
lsbw,541
lwpla,-1,562,1
```

```
asbw,244
asbw,245
asbw,246
asbw,247
asbw,248

LSTR,       3,      43
LSTR,      43,      45
asbl,250,551
asbl,251,574
lwpla,-1,574
wprot,,,90
asbw,249
asbw,252
asbw,253

!--cut for dome circular bar region
wpcsys,-1,0
wprot,,,90
kwpave,1
wpoff,,,354.75
lsbw,540
lwpla,-1,581,1
asbw,100
asbw,101
asbw,102
asbw,103
asbw,104
cm,a_tank,area

!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!--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,,,167
asel,a,,,47
aatt,mat_conc,100,type_2d_rebar

asel,s,,,169
asel,a,,,68
aatt,mat_conc,101,type_2d_rebar

asel,s,,,161
aatt,mat_conc,102,type_2d_rebar

asel,s,,,37
asel,a,,,46
asel,a,,,53,56,3
asel,a,,,57
```

```
asel,a,,,59,60
asel,a,,,156
asel,a,,,175
asel,a,,,179
asel,a,,,214
asel,a,,,228
aatt,mat_conc,103,type_2d_rebar

asel,s,,,34
asel,a,,,40
asel,a,,,58
aatt,mat_conc,104,type_2d_rebar

asel,s,,,78
aatt,mat_conc,105,type_2d_rebar

asel,s,,,164
aatt,mat_conc,106,type_2d_rebar

asel,s,,,31
asel,a,,,62
asel,a,,,69
asel,a,,,72,74
asel,a,,,158
asel,a,,,180
asel,a,,,194
asel,a,,,207
asel,a,,,221
aatt,mat_conc,107,type_2d_rebar

asel,s,,,36
asel,a,,,66
aatt,mat_conc,108,type_2d_rebar

asel,s,,,52
asel,a,,,70
aatt,mat_conc,109,type_2d_rebar


!--- Wall rebar (layer 1 interior)
asel,s,,,38
asel,a,,,139
asel,a,,,143
aatt,mat_conc,203,type_2d_rebar

asel,s,,,145
asel,a,,,109
aatt,mat_conc,202,type_2d_rebar

asel,s,,,13
asel,a,,,32
```

```
asel,a,,,106
asel,a,,,113
asel,a,,,119
asel,a,,,123
asel,a,,,126
asel,a,,,173
aatt,mat_conc,201,type_2d_rebar

!Wall rebar layer 2
asel,s,,,33
asel,a,,,223,227
asel,a,,,230,234
aatt,mat_conc,205,type_2d_rebar

asel,s,,,238
aatt,mat_conc,204,type_2d_rebar

!wall rebar layer 3
asel,s,,,142
asel,a,,,183
asel,a,,,185,186
asel,a,,,190
asel,a,,,196
asel,a,,,198
asel,a,,,202
aatt,mat_conc,205,type_2d_rebar

asel,s,,,199
asel,a,,,182
aatt,mat_conc,204,type_2d_rebar

!wall rebar layer 4
asel,s,,,128
asel,a,,,132,136,2
asel,a,,,140
aatt,mat_conc,207,type_2d_rebar

asel,s,,,5
asel,a,,,15
asel,a,,,116
asel,a,,,120
asel,a,,,127
asel,a,,,174
aatt,mat_conc,206,type_2d_rebar

asel,s,,,28
asel,a,,,111
aatt,mat_conc,208,type_2d_rebar

!---External dome rebar
asel,s,,,4
```

```
aatt,mat_conc,300,type_2d_rebar

asel,s,,,87
aatt,mat_conc,301,type_2d_rebar

asel,s,,,92
aatt,mat_conc,302,type_2d_rebar

asel,s,,,20
asel,a,,,97
aatt,mat_conc,303,type_2d_rebar

asel,s,,,21
asel,a,,,25
aatt,mat_conc,304,type_2d_rebar

asel,s,,,253
aatt,mat_conc,305,type_2d_rebar

asel,s,,,264
asel,a,,,255
aatt,mat_conc,306,type_2d_rebar

asel,s,,,244
asel,a,,,250
aatt,mat_conc,307,type_2d_rebar

asel,s,,,240
asel,a,,,260
aatt,mat_conc,308,type_2d_rebar


!---Interna dome rebar
asel,s,,,19
aatt,mat_conc,300,type_2d_rebar

asel,s,,,83
aatt,mat_conc,301,type_2d_rebar

asel,s,,,94
aatt,mat_conc,302,type_2d_rebar

asel,s,,,82
asel,a,,,99
aatt,mat_conc,303,type_2d_rebar

asel,s,,,23,27,4
aatt,mat_conc,304,type_2d_rebar

asel,s,,,101
aatt,mat_conc,305,type_2d_rebar
```

```
asel,s,,,266
asel,a,,,257
aatt,mat_conc,306,type_2d_rebar

asel,s,,,242
asel,a,,,246
asel,a,,,263
asel,a,,,252
aatt,mat_conc,309,type_2d_rebar


!----Haunch interior region
asel,s,,,249
asel,a,,,262
aatt,mat_conc,500,type_2d_rebar

asel,s,,,245
asel,a,,,256
asel,a,,,265
aatt,mat_conc,501,type_2d_rebar

asel,s,,,241
aatt,mat_conc,502,type_2d_rebar

allsel

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

!-- tank mesh
cmsel,s,a_tank
allsel,below,area

esize,tank_size
type,type_tank
mat,mat_tank

lsel,s,,,27
lsel,a,,,523
lsel,a,,,529
lccat,all
lsla

lsel,s,,,4
lsel,a,,,24
lccat,all
lsla
```

```
lsel,s,,,414
lsel,a,,,452
lsel,a,,,481
lccat,all
lsla

lcomb,555,579
lcomb,561,580

mshkey,1
amesh,all

!-- soil mesh
cmsel,s,a_soil
allsel,below,area

esize,soil_esize
type,type_2d_soil

mopt,trans,1.25
mopt,expnd,1.25

lesize,45,,,10,4
lesize,46,,,20,4
lesize,50,,,8
lesize,43,,,25,4
lesize,47,,,25,4

mshkey,0
amesh,all

wpcsys,-1,0
kwpave,1
csys,4
cmsel,s,a_soil
asel,r,loc,y,-h3,999999
cm,t_soil,area
esla
emodif,all,mat,mat_tsoil

cmsel,s,a_soil
asel,r,loc,y,-h4,-h8
cm,m_soil,area
esla
emodif,all,mat,mat_msoil

cmsel,s,a_soil
asel,r,loc,y,-h8,-99999
cm,b_soil,area
esla
```

```
emodif,all,mat,mat_bsoil

allsel
!dele concatenated 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

![[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
!
!     3D mesh by rotation, reassign general elem. attr.
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
allsel
type,type_3d_soil
extopt,attr,1,1,1
extopt,esize,1
vrotat,all,,,,,,12,18,slice_ang

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

cmsel,s,t_soil
vsla
eslv
emodif,all,mat,mat_tsoil

cmsel,s,m_soil
vsla
eslv
emodif,all,mat,mat_msoil

cmsel,s,b_soil
vsla
eslv
emodif,all,mat,mat_bsoil
```

```
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 ratio are from error-and-try process
!
a=452
b=145.5
wpcsys,-1,0
kwpave,41
wpoff,,-b
cswpla,100,2,b/a,b/a

!--- csys 101 sperical: external dome/haunch
a=600
b=250

wpcsys,-1,0
kwpave,35
wpoff,,-b
cswpla,101,2,b/a,b/a

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

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

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

!--- dome rebar
asel,s,,,19
asel,a,,,23
asel,a,,,27
asel,a,,,82,83
asel,a,,,94
asel,a,,,99
asel,a,,,101
asel,a,,,242
asel,a,,,246,249,3
asel,a,,,252
asel,a,,,257
asel,a,,,262,263
asel,a,,,266
vsla
eslv
emodif,all,esys,100

asel,s,,,4
asel,a,,,20,21
asel,a,,,25
asel,a,,,87
asel,a,,,92
asel,a,,,97
asel,a,,,244
asel,a,,,250
asel,a,,,255
asel,a,,,253
asel,a,,,264
vsla
eslv
emodif,all,esys,101

asel,s,,,240
asel,a,,,260
asel,a,,,241
asel,a,,,245
asel,a,,,256
asel,a,,,265
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

!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!     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,.0368,.1262,.1027,.0,.1262,.1184,.1
vry(1)=.0256,.0368,.0368,.0368,.0295,.0368,.0368,.0368,0,0
vrz(1)=0.,0.,0.,0.,.0   ,0    ,0    ,0    ,.0   ,0
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_srebar,vrz(i),90,90
*enddo

!redefine real constant for inclined slab rebars (r105 and r106)
r,105,mat_srebar,vrx(6),0,-20.6,mat_srebar,vry(6)
rmore,90,0,mat_srebar,vrz(6),90,90

r,106,mat_srebar,vrx(7),0,-20.6,mat_srebar,vry(7)
rmore,90,0,mat_srebar,vrz(7),90,90

!wall
vrx=
vrz=
vry=
rc=
*dim,vrx,,20
*dim,vry,,20
*dim,vrz,,20
*dim,rc,,20
vrz(1)=.0354,.0707,.1745,.0,.0,.0436,.0873,.0436
vry(1)=.1571,.1571,.1571,.0785,.1571,.1571,.1571,.1571
```

```
rc(1)=201,202,203,204,205,206,207,208
*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

!redefine real constant for inclined wall rebar (r208)
r,rc(8),mat_null,0,0,0,mat_rebar,vry(8)
rmore,90,0,mat_rebar,vrz(8),0,97.3


!dome and haunch
vrx=
vrz=
vry=
rc=
*dim,vrx,,20
*dim,vry,,20
*dim,vrz,,20
*dim,rc,,20
vry(1)=.0893,.0510,.0476,.0476,.0595,.0496,.0468,.0813,0,.0406
vrz(1)=.0368,.0368,.0368,.0368,.0368,.0368,.0000,.0736,0
rc(1)=300,301,302,303,304,305,306,307,308
*do,i,1,10
      r,rc(i),mat_null,0,0,0,mat_rebar,vry(i)
      rmore,90,0,mat_rebar,vrz(i),90,90
*enddo

!haunch core
vrx=
vrz=
vry=
rc=
*dim,vrx,,20
*dim,vry,,20
*dim,vrz,,20
*dim,rc,,20

r,500,mat_rebar,.0018,0,0,mat_rebar,0.0023
rmore,45,0,mat_rebar,.0323,0,90

r,501,mat_rebar,.0,0,0,mat_rebar,0.0143
rmore,90,0,mat_rebar,.0,90,90

r,502,mat_rebar,.0,0,0,mat_rebar,0.0375
rmore,90,0,mat_rebar,.0013,90,90

allsel

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

```
!     Assign real constants to 3D elements
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
*do,i,100,120
    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

*do,i,500,510
    asel,s,real,,i
    vsla
    eslv
    emodif,all,real,i
*enddo

allsel

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

asel,s,,,270,273,3
```

```
asel,a,,,294,303
asel,a,,,308
asel,a,,,318
asel,a,,,347,369
asel,a,,,374,389
cm,tk_cnt_area,area
lsla
nsla,,1
esln
type,22
real,21
mat,21
esurf

asel,s,,,1114,1125
asel,a,,,1130,1153
asel,a,,,1159,1175
cm,soil_cnt_area,area
lsla
nsla,,1
esln
type,21
esurf

allsel
aclear,all

/pnum,real,1
/num,1

csys,110
allsel
nrotat,all
csys,0

!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
!
!     set up AOR loadings and solve
!
!]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
slice_load_ax
allsel
finish
/filname,sst_ax_slice
/title,SST-AX slice model
/solu
nlgeom,on
nsubst,10,100,5
save
solve
```

parm_ax.mac

```
!--Define parameters for SST-AX tank
!--dimensions are in INCH and DEG
*afun,deg

t1=15  !tank wall thichness at bottom
t2=24      !tank wall thickness at top

dm_r1=118*12+9  !inch, radius of outer inboard dome surface
dm_r2=117*12+6  !inch, radius of inner inboard dome surface
dm_r3=86*12     !inch, radius of outer outboard dome surface
dm_r4=70*12     !inch, radius of inner outboard dome surface
dm_r5=26•12+6

hnch_r=3*12+9+9/16      !inch, big haunch radius

depth=13.84*12
soil_r=80*12
soil_h=40*12

!--following are dimensions for essential kp to
!  create the tank, starting from dome apex
r1=0
h1=0

r2=13*12+1+5/8
h2=(118*12+9)*(1-cos(6.522))

r3=r2+25*12+7+7/8
h3=15+144-(5*12+6+3/8)

r4=r3
h4=144+7*12+6

r5=r4+(t2-t1)
h5=h4

r6=r5
h6=h5+25*12

r7=r6+4*12
h7=h6

r8=r7
h8=h7+36

r9=r6-t2-48
h9=h8

r10=r9-4*12
```

```
h10=h9-18

r11=0
h11=h10

r12=0
h12=h7

r13=r6-t2
h13=h12

r14=r13
h14=144+15

r18=0
h18=15

r17=13*12
h17=8+5/8+15

r16=r17+13*12
h16=h17+(24+8+9/16)

r15=r14-(11+3/4)
h15=h14-27.75

!---Parameters for materials
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]

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]
```

```
!--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=45
slice_ang=3

!---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_ax.mac

```
finish
/prep7
!--set BCs
wpcsys,-1,0
kwpave,1
csys,4
asel,s,loc,x,soil_r
lsla
nsla,,1
d,all,ux,0

allsel
asel,s,loc,y,-h8-soil_h
lsla
nsll,,1
d,all,uz,0

allsel
nsel,s,loc,x,0
d,all,ux,0

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

asel,s,,,1112,1113
lsla
nsla,,1
esln
sf,all,pres,p_uniform

p_cload=ff/(3.14159*cload_l**2)
asel,s,,,1113
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
csys,110
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_ax_slice.mac

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

/post1
set,last

!-----Displacement contours
allsel
plnsol,u,sum
plpng

esel,s,mat,,mat_conc
/rep
plpng

/dscale
allsel
/pnum,mat,1
/num,1
/edge,,1
pldisp,2
plpng

esel,s,mat,,mat_conc
/rep
plpng

allsel

/edge
/dscale,,1
plnsol,s,eqv
plpng

esel,s,mat,,mat_conc
/rep
plpng
```

```
/gresume,smisc_plt,plt
esel,s,mat,,mat_conc
/dscale,,1
/edge
plesol,smisc,2
plpng

plesol,smisc,4
plpng

plesol,smisc,6
plpng

!--------------Section force/moment path plots
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,,,188
lsel,a,,,200
lsel,a,,,210,211
lsel,a,,,221,222
lsel,a,,,233
lsel,a,,,525
lsel,a,,,562,563
lsel,a,,,581,582
nsll,,1
cm,nd_out,node

lsel,s,,,20,22
lsel,a,,,194
lsel,a,,,203
lsel,a,,,216
lsel,a,,,225
lsel,a,,,549
lsel,a,,,573
```

```
lsel,a,,,575
lsel,a,,,240
lsel,a,,,591

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,617,45
```

```
csys,4
asel,r,loc,y,0,99999
asel,a,,,251,252
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

    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
```

```
!===============upper thinner wall
lsel,s,,,25
lsel,a,,,552
nsll,,1
cm,nd_out,node

lsel,s,,,14
lsel,a,,,26
nsll,,1
cm,nd_in,node

cmsel,s,a_tank
wpcsys,-1,0
kwpave,21
cmsel,u,dome_area
csys,4
asel,r,loc,y,0,9999
cm,upwall_area,area
lsla
nsla,,1
cm,upwall_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

nodeout(1)=
nodein(1)=

!--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


!--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

    nwpla,-1,nodeout(ii),nodein(ii)
    csys,4
    cmsel,s,upwall_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

!==============Lower thicker wall
lsel,s,,,253,254
lsel,a,,,258
lsel,a,,,268
lsel,a,,,287
lsel,a,,,304
lsel,a,,,312
lsel,a,,,329
lsel,a,,,331,332
lsel,a,,,341
lsel,a,,,396
nsll,,1
cm,nd_out,node

lsel,s,,,5
lsel,a,,,38
lsel,a,,,182
lsel,a,,,247
lsel,a,,,262
lsel,a,,,273
lsel,a,,,282
lsel,a,,,308
lsel,a,,,317
lsel,a,,,326
lsel,a,,,336
lsel,a,,,390
nsll,,1
cm,nd_in,node

cmsel,s,a_tank
wpcsys,-1,0
kwpave,6
cmsel,u,dome_area
cmsel,u,upwall_area
csys,4
asel,r,loc,y,0,9999
cm,lowwall_area,area
lsla
nsla,,1
cm,lowwall_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

nodeout(1)=
nodein(1)=

!--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
```

```
    nwpla,-1,nodeout(ii),nodein(ii)
    csys,4
    cmsel,s,lowwall_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,,,32
lsel,a,,,121
lsel,a,,,184
lsel,a,,,374
lsel,a,,,385
nsll,,1
cm,nd_out,node

lsel,s,,,33
lsel,a,,,137
lsel,a,,,345
lsel,a,,,367
lsel,a,,,381
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

nodeout(1)=
nodein(1)=

!--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,upwall_area
cmsel,u,lowwall_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_ax,plt
axial_path
plpng

shear_path
```

```
plpng

hoop_path
plpng

moment_path
plpng

!----Output path data to file

/sys,del path_ax.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_ax,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_ax.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
```

smisc_plt.plt

```
/NOPR
/RESET
/DEVICE,VECT,OFF
! General Graphics Settings
/NUM,  1
/PLOP,INFO, 3
/TRIAD,RTOP
/GTHIC,CURV,  2
/GROPT,CURL,  1
/PNUM,MAT , 1
/COL, NUM ,YGRE, 3
/TRLCY,ON
/TXTRE,ON
/COL, PBAK,0, 1,  4
! Window Settings
/VIEW,1,  0.0000    ,  0.0000    ,  1.0000
/FOC, 1,  241.69    ,  1101.4    , -26.405
/DIST,1,  357.35
/TYPE,1, 6
/EDG, 1, 0,  45.000
/CONT,1,  9,AUTO
/DSCA,1,  1.0000
/GO
```