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ANSYS Parametric Model for Tank DST-AY

L.J. Julyk/T.C. Mackey
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Abstract: This report documents the parametric ANSYS models developed for dome load analyses of double-shell tanks. The default model parameters are specific to the AY tanks but can be easily modified for tank-specific analysis of AN, AW, AP, AZ or SY tanks. Both axisymmetric slice and full 360 degree models are provided.

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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
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ANSYS Parametric Model for Tank DST-AY

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

Jim Radochia / Xianghong Li
JLR The Engineering Solutions Company

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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.

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Analysis performed by: Jim Radochia / Xianghong Li
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) 6/17/03
Date

CHECKLIST FOR INDEPENDENT REVIEW

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Author: Jim Radochia / Xianghong Li
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) — 6-10-03
Reviewer — Date

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

ERRATA

ANSYS Macro	Tracking #	Issue Description	Recommended Action
Set_parms.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.
Submodel.mac	2	Resulting section force and moment plot/list may only be valid for 0 degrees in 360 degree full model.	Verify proper operation for other than 0 degree position.

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1.0 OBJECTIVE/PURPOSE

The purpose of this calculation is to develop a parametric finite element analysis model of the Hanford Site underground waste storage tanks. This is not an analysis. Instead, the present calculation develops a parametric model of the double shell tank DST-AY, which is based on Buyer-supplied as-built drawings and information for the analyses of record (AOR) for Double-Shell Tanks (DSTs), encompassing the existing tank load conditions. The computer model has various parameters that can be either changed directly or easily added by a knowledgeable ANSYS user. These parameters are modified to consider field conditions, such as *in-situ* wall thickness of primary steel tank, dead and live loads, moving loads, berm loads, soil overburden depth plus surrounding soil, internal waste level and waste specific gravity, internal vapor pressure, and thermal loads within the tank.

This document contains sample calculations that demonstrate how various aspects of the parametric model function. These sample calculations in this document are not to be used for assessing the structural integrity of the DST-AY tanks at the Hanford Site.

2.0 OPEN ITEMS

There are no open items.

3.0 METHODS OF ANALYSIS

1. The ANSYS command scripting language APDL is used to develop the tank parametric models. The APDL commands are interpreted by the general purpose finite element analysis program ANSYS 7.0 [Ref_1].

2. Miscellaneous hand calculations are performed using Excel [Ref_2] spreadsheets and MathCad 7.0 [Ref 3] documents. All calculations are confirmed using either a handheld calculator or an alternate form of calculations.

3. Two sets of macros were developed to model the DST_AY tanks. Macro ***set_slice.mac*** is used to model the 2.862-degree sector of the system ("slice model"), and the macro ***build_360.mac*** is used to create the 360-degree full model ("360-degree model"). Most macros are common to both models and are identical. To invoke either model, place the set of macros to be run in the ANSYS working directory, and type either ***set_slice*** or ***build_360*** at the ANSYS command line.

4.0 INPUT DATA

The dimensions, liner plate thicknesses, rebar sizes and spacings, and size and spacings of j-bolts, studs, anchors and stiffeners for tank DST-AY were obtained from [Ref_4] through [Ref_8]. This information was used to develop a parametric structural analysis model of the tank. Figure 1 shows the general layout.

ANSYS APDL macros have been developed that build the geometry in 2D and for sweeping the cross section about the tank central axis. The reinforced concrete tank cross section is divided into regions that have different steel reinforcement ratios, where it is assumed that the thickness of each rebar layer is 1". For regions with nonzero reinforcement ratios, the element attributes include an element coordinate system and two rotation angles that identify the orientation of each rebar in up to three directions. In general, the element x-axis is parallel to the radial direction, the y-axis is parallel to the circumferential direction, and the z-axis is parallel to the meridional direction. The haunch region uses a spherical coordinate system to define the local x-direction (radially outward from the global origin at the bottom/center of the primary liner) to

represent the diagonal ties. Note that, in ANSYS, the directions used for the rebar's three volume ratios specified as real constants are not in the element coordinate system's x, y, and z directions (ESYS) respectively, but rather are oriented according to the specified theta and phi for each volume ratio relative to the element coordinate system. (However, in this model, the orientation angles used for the three rebar directions are always (0,0), (90,0), and (90,90) respectively. This means that the three directions are aligned with the x, y, and z directions respectively of each element's coordinate system (ESYS).) See the ANSYS Elements Manual and Theory Manual for SOLID65 for more detail.

4.0.1 SET_SLICE.MAC

The program flow for the splice model, including a brief description of each macro, is as follows:

- **DSTAY.MAC** – basic tank parameters & 2-D geometry, no soil geometry. Geometry divided to accommodate rebar, jbolts, construction stiffeners later. Many area components created.
- **DSTAY2.MAC** – element attribute (real, type, mat, esys) assignments (not values) to geometry (not soil)
    - **SET_RX.MAC** – selects areas within a range of x
        - **SET_REAL.MAC** – assigns real constant attribute to each area
    - **SET_RY.MAC** – selects areas within a range of y
        - **SET_REAL.MAC** - assigns real constant attribute to each area
    - **SET_REAL.MAC** - assigns real constant attribute to each area
- **DSTAY3.MAC** – identify as components: jbolt lines (line_bolt), stiffener lines (line_stiff), anchor lines (line_anch in haunch), primary liner lines (line_prim), secondary liner lines (line_secon), bottom anchor lines (line_botanch)
- **DSTAY4.MAC** – 2-D soil geometry, 2-D mesh of soil & the other 2-D solids, rotate to create 3-D geometry/mesh for slice model (no 3-D shell elements), note that soil geometry/mesh is later redefined in set_soil.mac
    - **MESH_SIZE.MAC** – sets default element size for rebar and soil elements, sets sweep angle, and sets number of divisions per quadrant
- **DSTAY5.MAC** – change all soil elements to correct material; merge nodes/keypoints at slab/rebar and tank/rebar; couple all soil nodes to corresponding structural nodes and top of slab to bottom of wall and top of slab to bottom of insulating concrete (note that all coupling is later deleted)
- **DSTAY6.MAC** – generate jbolts, studs, wall base plate, confining ring below secondary liner, confining ring for insulating concrete, construction stiffeners, and anchors (detail #9 , a-2, and a-3)

- **DSTAY7.MAC** – generate primary liner geometry and mesh, define values for all liner real constants, couple vertical displacements at liner bottom
    - **SET_PARMS.MAC** – sets values of all user-changeable parameters
- **DSTAY8.MAC** – generate secondary liner geometry and mesh, couple vertical displacements at liner bottom, couple shell horizontal displacements to sidewall, couple shell vertical displacements to dome, merge secondary liner nodes with slab top nodes
- **DSTAY9.MAC** – merge liner to jbolts/studs/anchor nodes
    - **SET_MATERIALS.MAC** – sets all material properties and liner thicknesses
    - **SET_OPTIONS.MAC** – include/not include certain nonlinear material models (nonlinear concrete, creep, nonlinear steel liner, nonlinear rebar, nonlinear soil)
    - **SET_SOIL.MAC** – create soil geometry & mesh; couple to concrete (3-D geometry, mesh, and coupling deleted later)
- delete all coupled sets
- **SET_AREAS_SLICE.MAC** – defines area components for contact definition
- add steel plate below wall (on slab)
- add nonlinear contact with coefficient of friction of 0.3 between soil/concrete, secondary liner/concrete wall, primary liner/dome, primary liner/insulating concrete, slab top/insulating concrete, and wall/slab
- merge liner/concrete nodes at centerline
- **SET_ESYS_3D.MAC** – define all rebar element real, modify secondary liner elements above 357.5 in. to be 3/8 thick
- apply axisymmetric boundary conditions
- copy jbolts, etc. for slice model, divide jbolt/bottom anchors by 2 for slice model
- couple nodes at primary/secondary liner intersection
- define soil layers including elevation and material properties
    - **SET_SLAYER.MAC** – applies soil material properties to a layer
- **SET_BACKFILL.MAC** – defines backfill region and sets linear and nonlinear material properties
- merge any coincident nodes between anchors/jbolts/studs/etc. with concrete
- merge duplicate contact elements/nodes
- modify reals of rebar elements in wall and haunch
- redefine soil geometry & elements so there are 3 horizontal layers
- redefine soil-to-concrete contact
- **APPLY_LOADS_SLICE.MAC** – reverse area normal of radiused section of secondary liner, apply parametric loads
    - **MESH_SIZE.MAC** - sets default element size for rebar and soil elements, sets sweep angle, and sets number of divisions per quadrant
- Apply constraints

4.0.2 BUILD_360.MAC

The program flow for the 360-degree model, including a brief description of each macro, is as follows:

- **DSTAY.MAC** through **DSTAY9.MAC** are first called; these macros are identical to those used in the slice model.
- ***DSTAY10.MAC*** *- extrude 2D elements 360 degrees to create 3D elements*
  - **MESH_SIZE_360.MAC** - sets default element size for rebar and soil elements, sets sweep angle, and sets number of divisions per quadrant
- ***DSTAY11.MAC***
  - correct normals of shell elements
  - add nonlinear contact with coefficient of friction of 0.3 between secondary liner/concrete wall, primary liner/dome, primary liner/insulating concrete, slab top/insulating concrete, and wall/slab
  - delete old (slice model) elements
  - add steel plate below wall (on slab)
    - **SET_ESYS_3D.MAC** - define all rebar element real, modify secondary liner elements above 357.5 in. to be 3/8 thick
  - couple ring and secondary liner nodes in vertical direction and add nonlinear contact between ring and insulating concrete
  - modify contact settings (reals and materials)
  - merge liner/concrete nodes at centerline
  - merge various nodes and couple nodes at liner intersection
  - define soil layers including elevation and material properties
    - **SET_SLAYER.MAC** - applies soil material properties to a layer
    - ***SET_BACKFILL.MAC*** *- defines backfill region* and sets linear and nonlinear material properties
  - redefine soil geometry & elements so there are 3 horizontal layers and define *soil-to-concrete* contact
  - modify reals of rebar elements in wall and haunch
  - create and assign new ESYS for rebar elements in dome and haunch
  - merge coincident contact nodes
  - **APPLY_LOADS_360.MAC** - apply constraints and parametric loads

4.0.3 General Model Assumptions

Source listings for all macros of Sections 4.0.1 and 4.0.2 are presented in Attachments 9.01 through 9.30. SOLID65 elements are used to represent the reinforced concrete regions, and SOLID45 elements are used for the soil. The tank liners, the insulating concrete confinement ring, the liner construction stiffeners and the anchors use SHELL181 elements with KEYOPT(3)=2. The J-bolts and studs use BEAM4 elements. Nonlinear contacts between various surfaces use the TARGET170 and CONTACT173 elements. Large deflection is activated.

The ANSYS concrete material model is used for the SOLID65 elements. This allows separate options for cracking and crushing, as well as variable shear transfer for open/closed cracks.

The soil elements use the Drucker-Prager constitutive model, which has internal friction angle, cohesion and dilatancy angle as material properties. A small positive value of cohesion is used to represent the Hanford cohesionless soils, and the dilatancy angle is assumed to be equal to the friction angle (this parameter induces volume changes as a function of element shear stress).

The soil region surrounding the concrete tank and foundation is coupled to the concrete using nonlinear surface-to-surface contact elements, where the sliding coefficient of friction is 0.3.

The tank liners are coupled to the structural and nonstructural concrete in a similar manner, *i.e.*, with nonlinear contact elements. A friction coefficient of 0.3 is used for these surfaces as well (except as noted below); these include contact between the following surfaces:

- secondary liner and tank
- primary liner and dome
- bottom of primary liner and top of insulating concrete
- top of slab and bottom of insulating concrete
- bottom of tank wall and top of slab (friction coefficient=0.1)
- top of slab and secondary liner
- outside perimeter of insulating concrete and ring

Coincident nodes of the secondary liner and the steel ring (along the outer perimeter of the insulating concrete) are coupled together in the vertical direction.

In regions where both connections exist through j-bolts (for example) and the surfaces are coincident (e.g., secondary liner and tank wall), the nodes of the coincident surfaces are common at the connection location. (In this example, the secondary liner and tank wall would share a common node at the location of the j-bolt.)

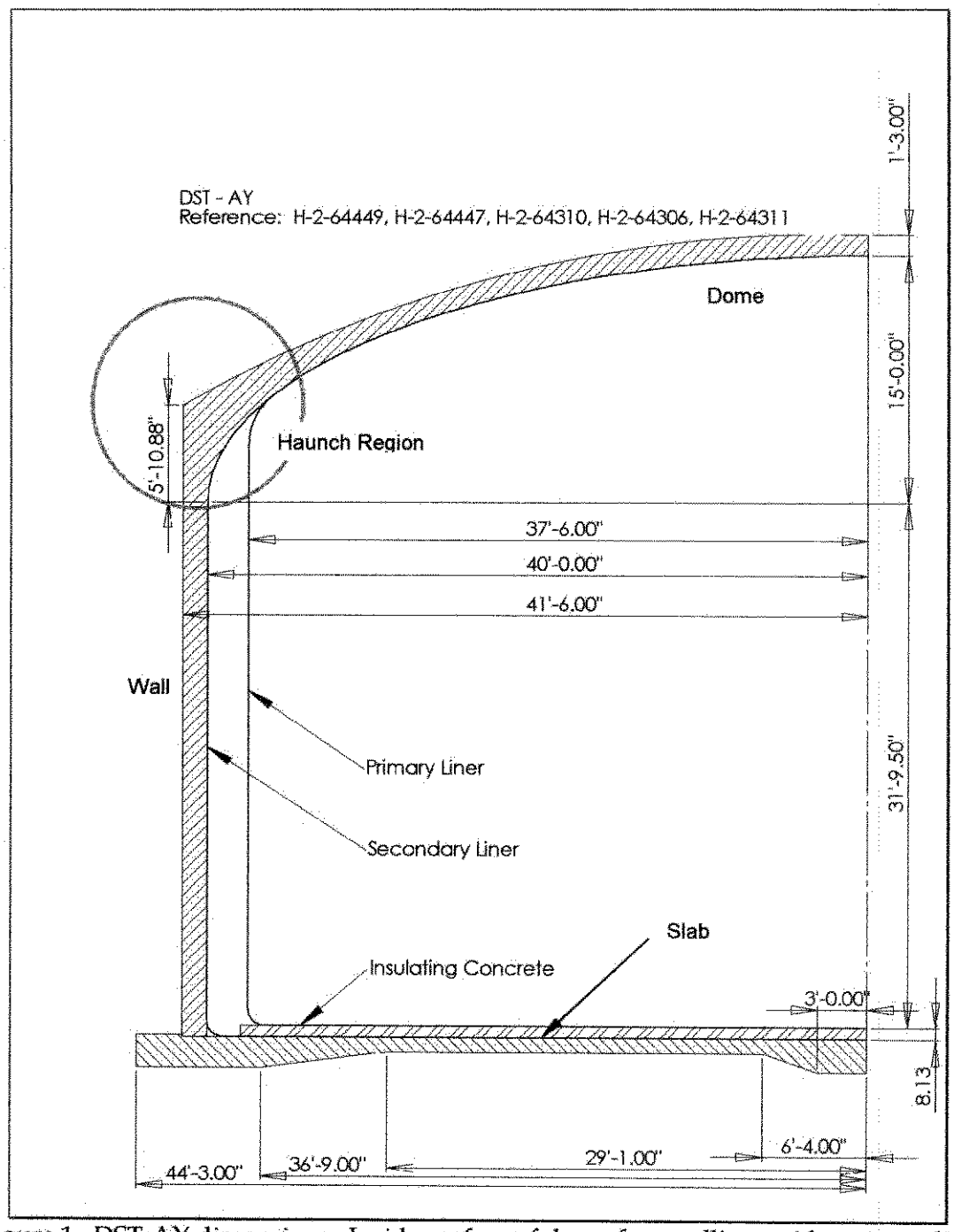

Figure 1. DST-AY dimensions. Inside surface of dome forms ellipse with major radius of 40′ and minor radius of 15′.

4.1 Concrete Creep. The concrete creep behavior is modeled in ANSYS using an explicit creep formulation for the Solid65 concrete element. Primary explicit equation 1 is used [Ref_1]. This equation is:

$$\dot{\varepsilon} = c_1 \cdot \sigma^{c2} \cdot t^{c3} \cdot e^{-(c4/T)}$$

where

$\dot{\varepsilon}$ = the change in equivalent strain with respect to time
σ = the equivalent stress
T = absolute temperature
t = time at end of substep
e = natural logarithm base
c_1 = 0.254E-6
c_2 = 1
c_3 = -0.838
c_4 = 320

4.2 Concrete Cracking. Concrete cracking behavior is specified through the following four material properties:

- Shear transfer coefficient for an open crack (between 0 and 1)
- Shear transfer coefficient for a close crack (between 0 and 1)
- Uniaxial tensile strength (psi)
- Uniaxial compressive strength (psi)

To verify the cracking/crushing behavior, a cantilever beam was analyzed (see Figure 3). It was subjected to an axial load of 24,000 lb, applied at the two rebar layers, which results in tensile stresses that exceed the concrete tensile strength (300 psi) and the rebar yield strength (10,000 psi). This model uses an implicit representation of the rebar. That is, the purple layers in Figure 3 are designated as concrete material, with elastic modulus of 27.7 x 10^6 psi and a Poisson ratio of 0.3. A bilinear isotropic (BISO) material model was used, with a yield strength of 10,000 psi, and a tangent modulus of 0 (elastic–perfectly plastic). Figure 4 shows the concrete and rebar stresses as functions of applied load (TIME equal to 1.0 corresponds to full load application). The tensile stress in the concrete adjacent to the reinforcement layer drops abruptly when its stress reaches the tensile strength of 300 psi (see Figures 5 and 6). Figure 4 shows the steel yielding at 10

ksi as expected, and Figures 6 and 7 show the final cracking pattern. The macro used to generate this example is shown in Attachment 9.22, CC3.MAC).

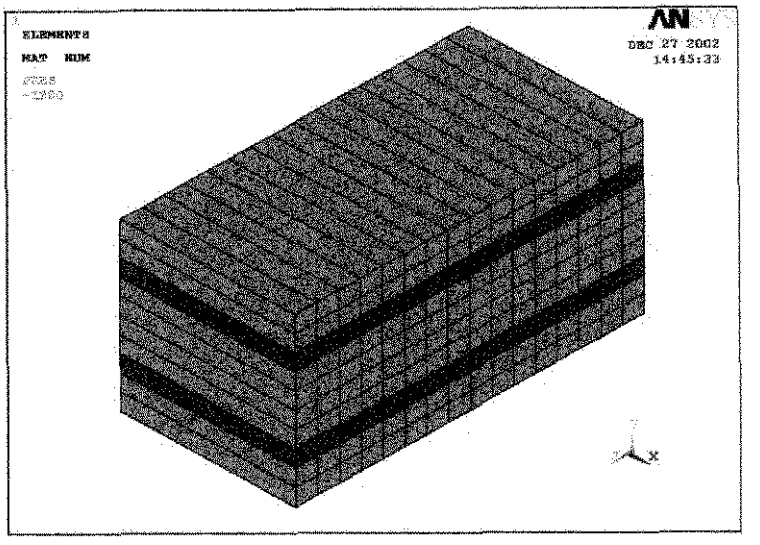

Figure 3. Finite element mesh for reinforced concrete beam, fixed on right, and tensile loads applied to the free end (left side).

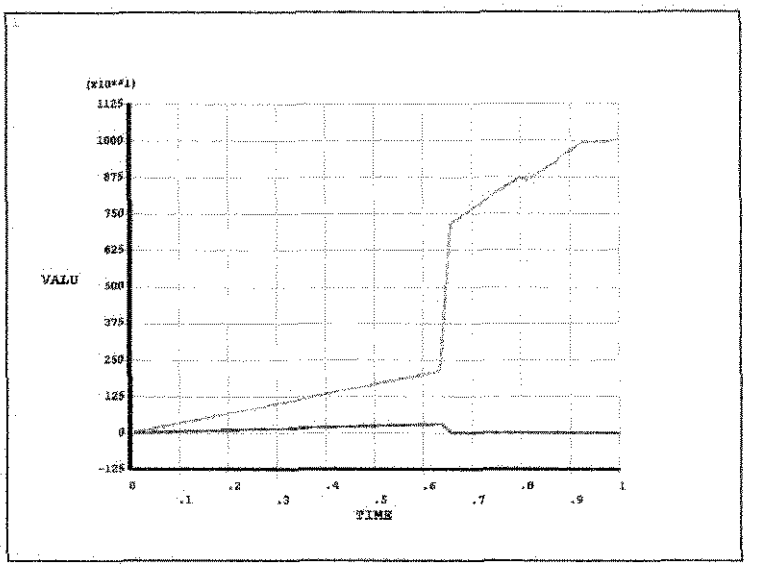

Figure 4. Chart of rebar stress (cyan) and concrete stress (purple) as function of applied load (TIME corresponds to fraction of 24,000 lb load applied.) The rebar yields when its tensile stress reaches 10,000 psi (the assigned yield strength).

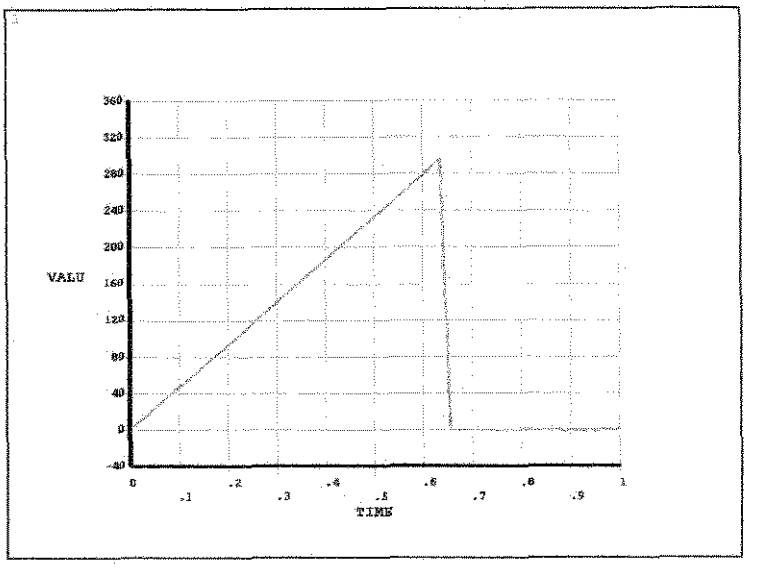

Figure 5. Chart of concrete stress (cyan) as function of applied load (TIME corresponds to fraction of 24,000 lb load applied). The tensile load is shed when the rebar region reaches a tensile stress of 300 psi (the assigned cracking stress for concrete).

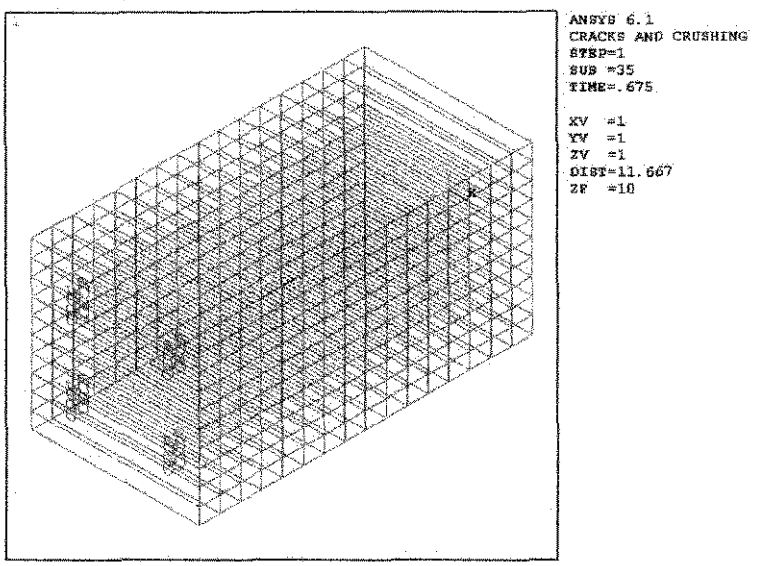

Figure 6. Cracking pattern for beam. Symbols at integration points indicate cracking (circles) and/or crushing (octahedral symbol).

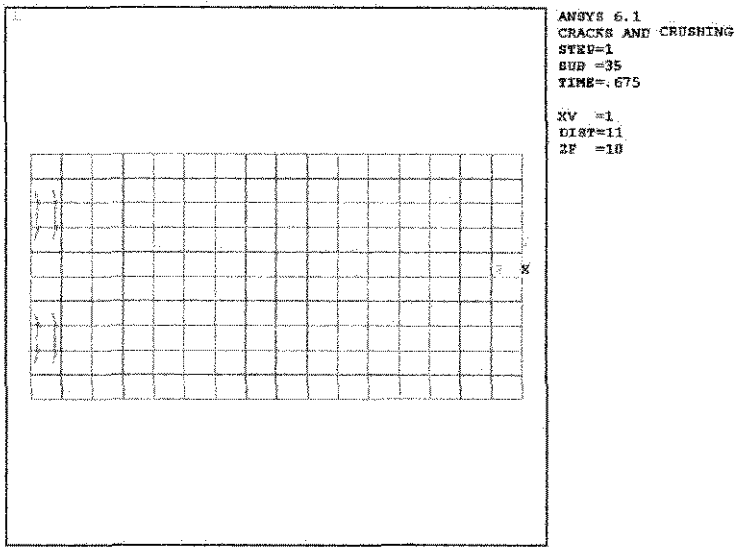

Figure 7. Side view of cracking symbols. The cracks open in a direction perpendicular to the circles (in the z-direction above).

The concrete cracking behavior was further tested in the slice model, with crushing disabled, and a tensile strength of 300 psi. Figures 8 and 9 show the locations (in red) where cracking is taking place.

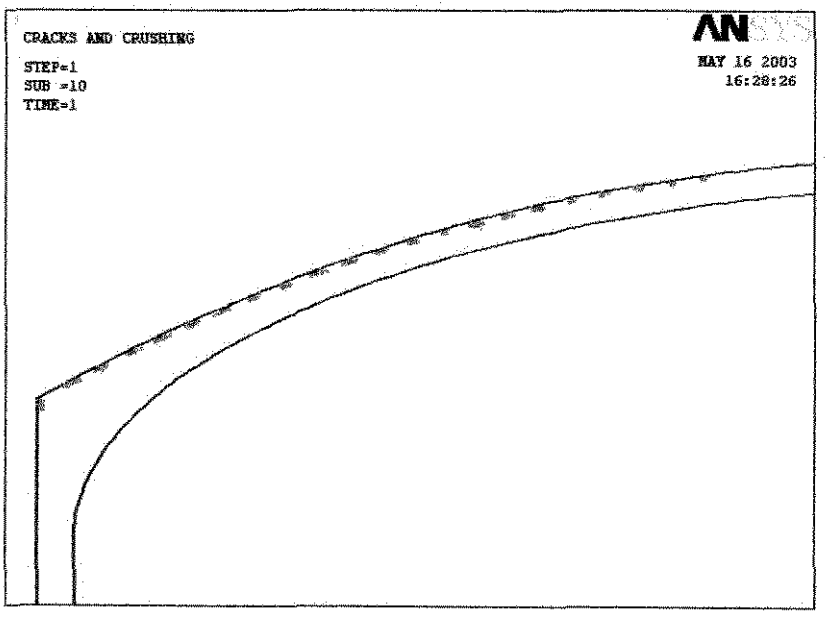

Figure 8. Locations of cracking (shown in red) in haunch/dome regions

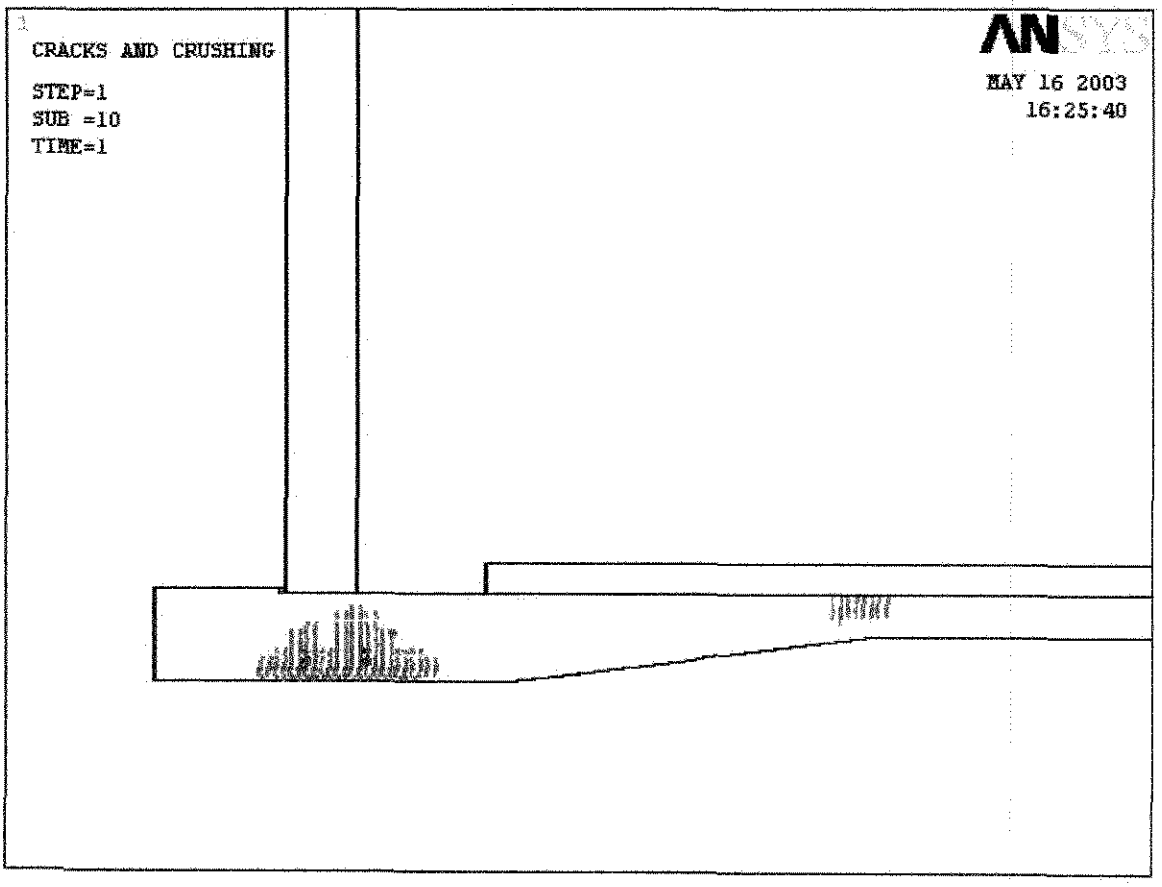

Figure 9. Locations of cracking (shown in red) in slab

4.3 Spacing of J-Bolts. Since the 3D model is based on a 2D cross section that is subsequently rotated about the central vertical axis, a 2'x2' spacing pattern for the J-bolts, when swept, results in bolts that are spaced too closely together near the tank center. Therefore, to preserve the contributory area of 4 ft^2/bolt, bolt spacing has been modified as shown in Figure 10. It is noted that all J-bolts are straight, and extend through the interior rebar layer.

DST-AY
J-Bolt Spacing

	r (in)	h (in)
Reference Location:	431.69	460.19
Spacing (in):	24.00	

Radial Position (in)	Vertical Position (in)	Angle (deg)	Spacing (in)
479	19	90	
479	43	90	24.00
479	67	90	24.00
479	91	90	24.00
479	115	90	24.00
479	139	90	24.00
479	163	90	24.00
479	187	90	24.00
479	211	90	24.00
479	235	90	24.00
479	259	90	24.00
479	283	90	24.00
479	307	90	24.00
479	331	90	24.00
479	355	90	24.00
479	379	75	24.00
473	402	65	24.00
462	424	55	24.00
449	443	45	24.00
432	460	40	24.00
412	474	35	24.00
391	486	30	24.00
369	496	25	24.00
347	504	20	24.00
324	511	15	24.00
299	515	10	25.32
272	518	9	27.52
241	522	8	30.51
206	525	7	34.86
165	527	6	41.98
107	529	5	57.22

At radial positions where R > 319 in, the chord length between j-bolts is the reference spacing. Where R < 319 in, the chord length is increased to preserve the contributary area (4 sq ft). The contributary area is calculated as $A = (r_2^2-r_1^2)*\Delta\theta/2$. If r_2^2 is known, and $\Delta\theta$ is assumed fixed, then r_1^2 can be evaluated.

The linear vertical angle is appoximated by eye from H-2-64449

(Liner Intersection)

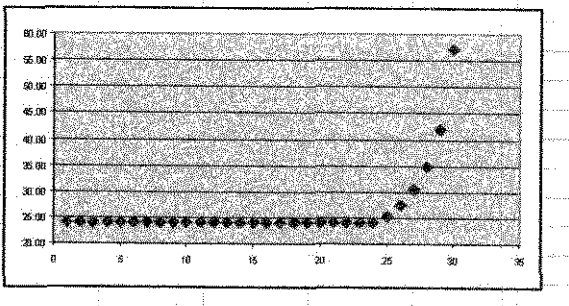

Figure 10. Modified J-bolt spacing.

4.4 Liner Thickness. Figure 11 shows the thickness of the primary and secondary liners.

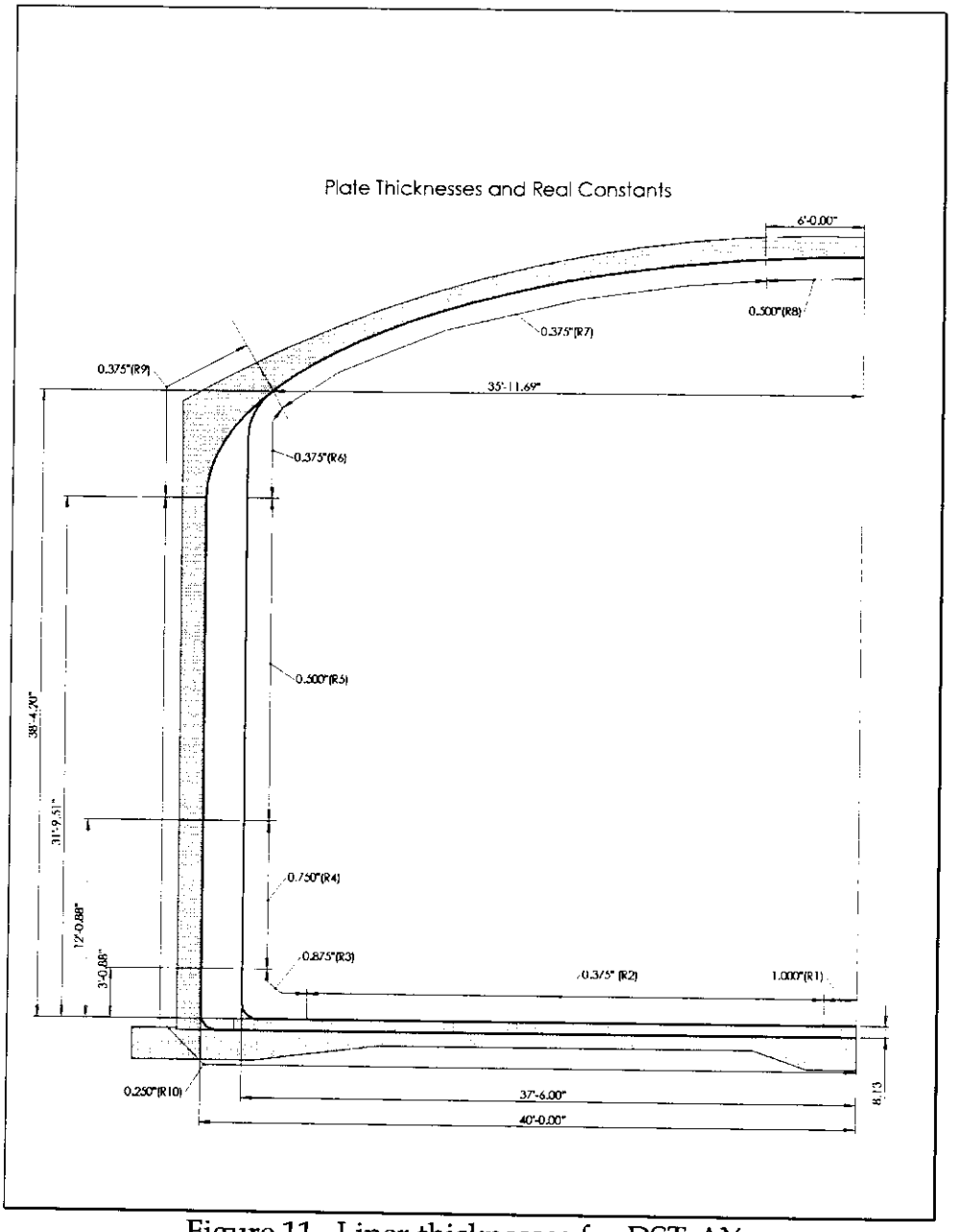

Figure 11. Liner thicknesses for DST-AY.

4.5 Real Constants. The ANSYS real constants are parameters that help to specify particular element behaviors. They also provide a convenient means for grouping elements with similar behaviors. For the liner elements (SHELL181 element type), the real constants define the shell thicknesses, and for the BEAM4 elements, they define the cross section areas, moments of inertia, and thicknesses for the bending stress calculation. The real constants for the rebar elements include the following for each of 3 possible rebar directions:

- The rebar material ID
- Steel volume ratio
- Two angles used to orient the rebar directions relative to the element coordinate system

Note that the orientation angles used in this model for the three rebar directions are always (0,0), (90,0), and (90,90) respectively. This means that the three directions are aligned with the x, y, and z directions respectively of each element's coordinate system (ESYS).

To simplify the modeling, the anchor in Detail 9 of drawing H-2-64449 has been increased in size by 10%, and anchor A-1 has been deleted. This modification will not affect the global behavior of the tank, and the anchor details can be retrieved through a submodel of this region if necessary.

All J-bolts have been assigned a circular cross section of ½" diameter. This includes the stud portion that welds to the liner. This assumption is valid for linear elastic global models; however a detailed submodel will be required to capture the plastic response of individual J-bolts.

Table 1 identifies the ranges of real constant numbers used for various regions of the model. Tables 2 through 6 show calculations of the steel volume ratios required for the concrete real constants. ("Elevation" is measured from the top of the insulating concrete.) The macro DSTAY2.MAC assigns the appropriate real constant ID to each region, and Attachment 9.15 provides the source listing for macro SET_ESYS_3D.MAC, which specifies the values of the rebar real constants. The BEAM4 real constants are specified in macro DSTAY6.MAC (Attachment 9.07).

Table 1. Mapping of Component Real Constants.

Range	Description
7	Soil
20	J-bolts
30	Anchors
40	Concrete wall baseplate steel (3/8")
41	Insulating concrete confining ring (3/16")
42	Construction stiffeners (1/2")
43	Detail 9 anchor (3/8") x 110%
44	Anchors 2 and 3 (1/4")
45	Slab steel plate below wall (1/4")
50	1" primary liner
51	3/8" primary liner
52	7/8" primary liner
53	3/4" primary liner
54	1/2" primary liner
55	1/4" secondary liner (below top of wall)
56	3/8" secondary liner (above top of wall)
61	Contact between soil and concrete
62	Contact between secondary liner and wall
63	Contact between primary liner and dome
64	Contact between primary liner and insulating concrete
65	Contact between slab top and insulating concrete
66	Contact between bottom of wall and top of slab
67	Contact between top of slab and secondary liner
68	Contact between outer perimeter of insulating concrete and ring
100 - 104	Slab bottom steel
105 - 108	Slab top steel
200 - 205, 213	Wall external steel
206 - 212	Wall internal steel
300 - 306	Dome external steel
307 - 313	Dome internal steel
400 - 404	Haunch external steel
405 - 406	Haunch internal steel
500 - 501	Haunch middle vertical steel
502	Haunch middle radial steel
503	Haunch diagonal steel (ties)
600	Insulating concrete
700	Unreinforced concrete

Table 2. Calculation of Steel Reinforcement Ratios for Slab.

DST-AY - Steel Reinforcement Ratios for Slab - Ref H-2-64306 100

Description	Elevation (in)	Radius (in)	Bottom / Radial Size	Spacing (in)	Area (in²)	Volume Ratio	Bottom / Circumferential Size	Spacing (in)	Area (in²)	Volume Ratio	Real Constant
Slab Center		0.0									
						0.0320	5	12	0.0256	0.0256	100
		57.0									
						0.0320	5	12	0.0256	0.0256	103
		90.0									
						0.0320	5	12	0.0256	0.0256	100
		330.0									
						0.0320	5	12	0.0256	0.0256	101
		360.0									
						0.0320	5	12	0.0256	0.0256	105
		378.0									
						0.0320	5	12	0.0256	0.0256	100
		435.0									
						0.0320	5	12	0.0256	0.0256	102
		441.0									
						0.1060				0.0552	103
		459.0									
						0.0980	6	8	0.0552	0.0552	104
Slab Outside Radius		531.0									

Description	Elevation (in)	Radius (in)	Top / Radial Size	Spacing (in)	Area (in²)	Volume Ratio	Top / Circumferential Size	Spacing (in)	Area (in²)	Volume Ratio	Real Constant
Slab Center		0.0									
						0.0320	5	12	0.0256	0.0256	105
		57.0									
						0.0320	5	12	0.0256	0.0256	105
		90.0									
						0.0320	5	12	0.0256	0.0256	105
		330.0									
						0.0320	5	12	0.0256	0.0256	105
		360.0									
						0.0320	5	12	0.0256	0.0256	106
		378.0									
						0.0320	5	12	0.0256	0.0256	105
		435.0									
						0.0320	5	12	0.0256	0.0256	105
		441.0									
			5	12	0.0256	0.0256				0.0552	107
		459.0									
			5	12	0.0256	0.0256	6	8	0.0552	0.0552	108
Slab Outside Radius		531.0									

Table 3. Calculation of Steel Reinforcement Ratios for Tank Wall.

DST-AY - Steel Reinforcement Ratios for Wall - Ref H-2-64310 200

Description	Elevation (in)	Radius (in)	External / Vertical Size	Spacing (in)	Area (in^2)	Volume Ratio	External / Circumferential Size	Spacing (in)	Area (in^2)	Volume Ratio	Real Constant
Top of Slab	-8.1										
			6	12.0	0.0368	0.0368	8	8	0.0982	0.0982	200
	123.0										
			6	12.0	0.0368	0.0430	8	8	0.0982	0.0982	201
			6	9.0	0.0491						
	155.0										
			6	9.0	0.0491	0.0491	8	8	0.0982	0.0982	202
	204.0										
			6	9.0	0.0491	0.0491	8	12	0.0654	0.0654	203
	279.0										
			6	9.0	0.0491	0.0573	8	12	0.0654	0.0654	213
			8	12.0	0.0654						
	311.0										
			8	12.0	0.0654	0.0654	8	12	0.0654	0.0654	204
	348.0										
			8	12.0	0.0654	0.1677	8	12	0.0654	0.0654	205
			6	6.0	0.0736						
			8	6.0	0.1309						
Dome Tangent Line	381.5										

Description	Elevation (in)	Radius (in)	Internal / Vertical Size	Spacing (in)	Area (in^2)	Volume Ratio	Internal / Circumferential Size	Spacing (in)	Area (in^2)	Volume Ratio	Real Constant
Top of Slab	-8.1										
			6	12	0.0368	0.0368	8	8	0.0982	0.0982	206
	123.0										
			6	12	0.0368	0.0430	8	8	0.0982	0.0982	207
			6	9	0.0491						
	155.0										
			6	9	0.0491	0.0491	8	8	0.0982	0.0982	208
	204.0										
			6	9	0.0491	0.0491	8	12	0.0654	0.0654	209
	279.0										
			6	9	0.0491	0.0573	8	12	0.0654	0.0654	210
			8	12	0.0654						
	311.0										
			8	12	0.0654	0.0654	8	12	0.0654	0.0654	211
	348.0										
			8	12	0.0654	0.0982	8	12	0.0654	0.0654	212
			8	6	0.1309						
Dome Tangent Line	381.5										

Table 4. Calculation of Steel Reinforcement Ratios for Tank Dome.

DST-AY - Steel Reinforcement Ratios for Dome - Ref H-2-64310, H-2-64311 300

Description	Elevation (in)	Radius (in)	External / Vertical Size	Spacing (in)	Area (in²)	Volume Ratio	External / Circumferential Size	Spacing (in)	Area (in²)	Volume Ratio	Real Constant
Construction Joint		352.5	8	6.0	0.1309	0.1309	9	4	0.2498	0.2498	300
		337.0				0.1340				0.1666	301
		320.0				0.1360				0.1666	302
		312.0				0.0570				0.1309	303
		287.0				0.0520				0.1309	304
		275.0				0.0580				0.0368	305
		239.0				0.0440	6	12	0.0368	0.0368	306
Dome Center		0.0									

Description	Elevation (in)	Radius (in)	Internal / Vertical Size	Spacing (in)	Area (in²)	Volume Ratio	Internal / Circumferential Size	Spacing (in)	Area (in²)	Volume Ratio	Real Constant
Construction Joint		352.5	8	6	0.1309	0.1309	9	4	0.2498	0.2498	307
		337.0				0.1340				0.1666	308
		320.0				0.1360				0.1666	309
		312.0				0.0570				0.1309	310
		287.0				0.0520				0.1309	311
		275.0				0.0580				0.0368	312
		239.0				0.0440	6	12	0.0368	0.0368	313
Dome Center		0.0									

Table 5. Calculation of Steel Reinforcement Ratios for Haunch.

DST-AY - Steel Reinforcement Ratios for Haunch - Ref H-2-64310, H-2-64311 400

Description	Elevation (in)	Radius (in)	External / Vertical Size	Spacing (in)	Area (in²)	Volume Ratio	External / Circumferential Size	Spacing (in)	Area (in²)	Volume Ratio	Real Constant
Dome Tangent Line	381.5										
			8	12.0	0.0654	0.2700	8	6	0.1309	0.1309	400
			6	6.0	0.0786						
			8	6.0	0.1309						
	413.6										
			8	12.0	0.0654	0.2700	9	4	0.2498	0.2498	401
			6	6.0	0.0786						
			8	6.0	0.1309						
Haunch Corner	460.5	495.5									
			8	12.0	0.0654	0.1963	9	6	0.1666	0.1666	402
			8	6.0	0.1309						
		485.0									
			8	6.0	0.1309	0.1309	9	6	0.1666	0.1666	403
		454.0									
			8	6.0	0.1309	0.1309	9	4.5	0.2221	0.2221	404
Construction Joint		387.5									

Description	Elevation (in)	Radius (in)	Internal / Vertical Size	Spacing (in)	Area (in²)	Volume Ratio	Internal / Circumferential Size	Spacing (in)	Area (in²)	Volume Ratio	Real Constant
Dome Tangent Line	381.5										
			8	6	0.1309	0.1309	8	6	0.1309	0.1309	405
	413.6										
			8	6	0.1309	0.1309	9	4.5	0.2221	0.2221	406
Haunch Corner	460.5	495.5									
			8	6	0.1309	0.1309	9	4.5	0.2221	0.2221	406
		485.0									
			8	6	0.1309	0.1309	9	4.5	0.2221	0.2221	406
		454.0									
			8	6	0.1309	0.1309	9	4.5	0.2221	0.2221	406
Construction Joint		387.5									

Table 6. Calculation of Steel Reinforcement Ratios for Haunch Middle.

DST-AY - Steel Reinforcement Ratios for Haunch Interior - Ref H-2-64310, H-2-64311 500

Description	Elevation (in)	Radius (in)	Vertical Size	Vertical Spacing (in)	Vertical Area (in²)	Vertical Volume Ratio	Radial Size	Radial Spacing (in)	Radial Area (in²)	Radial Volume Ratio	Real Constant
Wall Tangent Line	381.5										
	419.0	486.5									
			6	18.0	0.0245	0.0245					500
	439.0	486.5									
			4	18.0	0.0109	0.0109					501
Haunch Corner	460.5	486.5									
			6	18	0.0245	0.0245					502
Construction Joint		387.5									

Description	Elevation (in)	Radius (in)	Circumferential Size	Circumferential Spacing (Hau)	Circumferential Area (in²)	Circumferential Volume Ratio	Diagonal Ties Size	Diagonal Ties Spacing (Hau)	Diagonal Ties Area (in²)	Diagonal Ties Volume Ratio	Real Constant
Wall Tangent Line	381.5										
	419.0	486.5									
			9	8	0.1249	0.1249					500
	439.0	486.5									
			9	8	0.1249	0.1249					501
Haunch Corner	460.5	486.5									
			9	4.5	0.2221	0.2221					502
Construction Joint		387.5									

Haunch Interior, Ties Only							4	324	0.0006	0.0000	503

4.6. Material Properties. The baseline (default) material properties are obtained from the drawings [Ref_4] through [Ref_8], and the reports [Ref_9], [Ref_11], and [Ref_12]. They are summarized in Tables 7 through 12. The macro SET_MATERIALS.MAC is used to specify the material properties and material models (*e.g.*, concrete material model). The listing of this macro is provided in Attachment 9.16.

For this calculation, the soil material properties were unique to three layers - above the haunch, alongside the tank, and below the tank. (See [Ref_12].) These layers are shown in Figure 22.

Materials 61-68 specify the coefficient of friction for the contact elements. (The numbers are identical to the REALS of Table 1.) The default friction coefficient is 0.3 for all materials except for MAT66 (wall/slab interface); this uses a value of 0.1.

The insulating concrete is assumed to have the same creep behavior as the structural concrete, but creep in the two materials may be activated/deactivated independently. The shear transfer parameters for both the structural and insulating concrete are assumed values.

All material properties properties may be modified by the end-user.

Table 7. Structural Steel Material Properties (MAT1).

Property	Units	Value
Elastic Modulus	*[lbf/in²]*	27.7×10^6
Poisson Ratio		0.3
Thermal Expansion Coefficient	*[με/F]*	6.38
Unit Weight	*[lbf/ft³]*	490
Thermal Conductivity	*[BTU/hr-ft-F]*	1
Specific Heat	*[BTU/R-lbm]*	1
Yield Strength	*[lbf/in²]*	36,000
Tangent Modulus	*[% of Elastic Modulus]*	2

Table 8. Structural Concrete Material Properties (MAT2).

Property	Units	Value
Elastic Modulus	*[lbf/in²]*	3.8×10^6
Poisson Ratio		0.15
Thermal Expansion Coefficient	*[με/F]*	6.38
Unit Weight	*[lbf/ft³]*	150
Thermal Conductivity	*[BTU/hr-ft-F]*	1
Specific Heat	*[BTU/R-lbm]*	1
Open Crack Shear Transfer	*(%)*	10
Closed Crack Shear Transfer	*(%)*	98
Uniaxial Tensile Strength	*[lbf/in²]*	300
Uniaxial Crushing Strength	*[lbf/in²]*	3000
Creep Coefficients (c1 – c4)		0.254e-6 1 -0.838 320

Table 9. Tank Rebar Material Properties (MAT3).

Property	Units	Value
Elastic Modulus	*[lbf/in²]*	27.7×10^6
Poisson Ratio		0.3
Thermal Expansion Coefficient	*[με/F]*	6.38
Unit Weight	*[lbf/ft³]*	490
Thermal Conductivity	*[BTU/hr-ft-F]*	1
Specific Heat	*[BTU/R-lbm]*	1
Yield Strength	*[lbf/in²]*	60,000
Tangent Modulus	*[% of Elastic Modulus]*	0

Table 10. Slab Rebar Material Properties (MAT6).

Property	Units	Value
Elastic Modulus	*[lbf/in²]*	27.7×10^6
Poisson Ratio		0.3
Thermal Expansion Coefficient	*[με/F]*	6.38
Unit Weight	*[lbf/ft³]*	490
Thermal Conductivity	*[BTU/hr-ft-F]*	1
Specific Heat	*[BTU/R-lbm]*	1
Yield Strength	*[lbf/in²]*	40,000
Tangent Modulus	*[% of Elastic Modulus]*	0

Table 11. Insulating Concrete Material Properties (MAT4).

Property	Units	Value
Elastic Modulus	*[lbf/in²]*	0.2×10^6
Poisson Ratio		0.15
Thermal Expansion Coefficient	*[με/F]*	6.38
Unit Weight	*[lbf/ft³]*	30
Thermal Conductivity	*[BTU/hr-ft-F]*	1
Specific Heat	*[BTU/R-lbm]*	1
Open Crack Shear Transfer	*(%)*	10
Closed Crack Shear Transfer	*(%)*	98
Uniaxial Tensile Strength	*[lbf/in²]*	200
Uniaxial Crushing Strength	*[lbf/in²]*	200
Creep Coefficients (c1 – c5)		0.254e-6 1 -0.838 320

Table 12. Soil Material Properties.

Above Haunch (MAT101)

Property	Units	Value
Elastic Modulus	*[lbf/in²]*	7,000
Poisson Ratio		0.27
Thermal Expansion Coefficient	*[με/F]*	0
Unit Weight	*[lbf/ft³]*	125
Thermal Conductivity	*[BTU/hr-ft-F]*	1
Specific Heat	*[BTU/R-lbm]*	1
Cohesion	*[lbf/in²]*	0
Internal Friction Angle	*[deg]*	35.4
Dilatancy Angle	*[deg]*	35.4

Alongside Tank (MAT104)

Property	Units	Value
Elastic Modulus	*[lbf/in²]*	13,000
Poisson Ratio		0.27
Thermal Expansion Coefficient	*[με/F]*	0
Unit Weight	*[lbf/ft³]*	125
Thermal Conductivity	*[BTU/hr-ft-F]*	1
Specific Heat	*[BTU/R-lbm]*	1
Cohesion	*[lbf/in²]*	0
Internal Friction Angle	*[deg]*	35.4
Dilatancy Angle	*[deg]*	35.4

Below Tank (MAT109)

Property	Units	Value
Elastic Modulus	*[lbf/in²]*	20,000
Poisson Ratio		0.27
Thermal Expansion Coefficient	*[με/F]*	0
Unit Weight	*[lbf/ft³]*	125
Thermal Conductivity	*[BTU/hr-ft-F]*	1
Specific Heat	*[BTU/R-lbm]*	1
Cohesion	*[lbf/in²]*	0
Internal Friction Angle	*[deg]*	35.4
Dilatancy Angle	*[deg]*	35.4

4.7. Element Types. Table 13 summarizes the various element type IDs used for the DST-AY tank. Types 2 through 7 are for the initial 2D modeling, and the rest are used for the full 3D model once the 2D cross section has been swept. (After sweeping, elements of types 2 through 7 no longer exist.)

Table 13. Element Types.

Type	ANSYS Element Type	Description
1	SHELL181	Liner
2	SHELL63	Tank (2D)
3	SHELL63	Haunch (2D)
4	SHELL63	Slab (2D)
5	SHELL63	Rebar (2D)
6	SHELL63	Insulating Concrete (2D)
7	SHELL63	Soil (2D)
12	SOLID65	Tank (3D)
13	SOLID65	Haunch (3D)
14	SOLID65	Slab (3D)
15	SOLID65	Rebar (3D)
16	SOLID65	Insulating Concrete (3D)
17	SOLID45	Soil (3D)
20	BEAM4	J-bolt
21	BEAM4	Anchor
22	SHELL181	Baseplates
23	SHELL181	Confining Ring
24	SHELL181	Stiffener
25	SHELL181	Detail 9 anchor
26	SHELL181	Anchors 2 and 3
60	TARGET170	All target surfaces in contact pairs
61	CONTACT173	All contact surfaces in contact pairs

4.8. Local Coordinate Systems. The coordinate systems shown in Table 14 are used for the DST-AY models. System 22 is used to define the nodal coordinate systems (a cylindrical coordinate system), and systems 22, 191, 200-202 (slice model only), 301-324 (360-degree model only), 501-524 (360-degree model only), and 701-724 (360-degree model only), are used to define local element coordinate systems (ESYS).

Table 14. Local Coordinate Systems.

ID	Type	Origin			PAR1 - PAR2	Description
		X (in)	Y (in)	Z (in)		
0	0	0	0	0		Global Cartesian
11	1	0	381.5	0	30/80 0	Dome Inside Surface (elliptical)
22	1	0	0	0		Cylindrical (positive z-axis up)
191	2	0	0	0		Haunch Diagonal Steel
200 301-324	2	0	-683.5	0		Dome Exterior Rebar
201 501-524	2	0	-315.5	0		Dome Exterior Rebar
202 701-724	2	0	381.5	0	80/30 80/30	Dome Interior Rebar

4.9. Boundary Conditions. The nodal degrees of freedom are defined in a cylindrical coordinate system (CSYS 22; see Table 14), and the nodal constraints (specified in this system where UX is radial, UY is circumferential, and UZ is axial) are as follows:

UX = UY = 0	Radial and tangential displacements at tank centerline are zero
UX = UY = UZ = 0	All displacements at bottom of soil mass (bedrock) are zero
UX =UY= 0	All radial and tangential displacements at remote side of soil mass are zero
UY = 0	All tangential displacements are zero on the circumferential cut planes (if any)

5.0 RESULTS

The model for tank DST-AY is assembled by running the macro SET_SLICE.MAC for the slice model or BUILD_360.MAC for the 360-degree model. By doing so, the model geometry is built in 2 dimensions, and swept about the tank center vertical axis to obtain 3D geometry. The material properties and real constants are automatically defined, and loads and boundary conditions are applied. Contact elements are specified to simulate the interface between the concrete and soil, and the interface between the steel liners and the structural/nonstructural concrete. Finally, contact elements are used to represent the contact between the tank wall and the slab.

Figures 12 through 28 show the model geometry and finite element mesh. Figures 12 through 32 are for a 2.862-degree *slice* of the model This gives an element length of 24 inches in the circumferential direction at the tank inside diameter, which is equal to the j-bolt spacing. This model results in a finite element mesh having approximately 9,940 nodes and 6,410 elements.

Figures 33-41 show examples from a full 360-degree model that has approximately 118,000 nodes and 150,000 elements (a very coarse model).

Inspection of Figures 22 through 25 shows that the soil elements are not continuous with the adjacent concrete elements. Rather, the node spacing of the soil elements is 4-5 times that of concrete elements, and Figures 18 shows that the soil elements are coupled to the concrete elements through the use of nonlinear surface-to-surface contact elements. This arrangement significantly reduces the number of elements necessary to model the soil-induced loads. Additionally, it is more physically correct than using either common nodes or coupling in certain directions, where continuity across the interface would be maintained in both tension and compression, and where there would free sliding (no friction) or no sliding (infinite friction).

The element aspect ratios are high in the circumferential direction, especially at the tank outside diameter. While this degrades the solution accuracy when significant circumferential load gradients exist, the model results for loads that are predominantly radial and meridional will not be affected.

A sample calculation of the slice model was performed, where the concrete cracking/crushing/creep behavior was omitted, and liner/rebar plasticity was

disabled. The soil plasticity model (Drucker-Prager) was retained. The loads consisted of a 40 psf uniform pressure at the ground surface, a 200,000 pound central point load (applied over a 10-foot radius) at grade, and a -6 inch H2O tank internal pressure. Gravity effects were also included. A total of 10 substeps and 22 equilibrium iterations were required to complete the solution. Figures 29 through 32 show examples of the displacement response of the soil/tank (Figures 29 and 30), the liner equivalent (von Mises) stress (Figure 31), and the slab radial stress (Figure 32). Additional postprocessing functions for the slice model including section force/moment path plots are in RPP-14001 [Ref_13].

The macro SET_BERM.MAC is used to specify either linear or circular berms and/or trenches, using the parameters specified in BERM_DIMS.MAC. To simulate a berm, the file final.db from the 360-degree model is resumed. Then, a trapezoidal cross section is swept along a line or arc to create the 3D solid geometry and elements, and the elements are bonded to the ground surface. Also, the soil elastic modulus for the berm is taken as 10% of the nominal soil elastic modulus, so that berms do not significantly affect the soil stiffness. For trenches, the mass of the berm is in effect *subtracted* from the ground surface by applying a negative gravity load (i.e., the trench mass acting in the upward direction). This is an approximation to simplify the modeling and meshing of the soil, and it overestimates the soil stiffness near the trench. Figures 35 through 37 show examples of berms and trenches.

A sample thermal analysis was performed using a full model, where the ground surface is assumed to be 80 degrees F, and the insulating concrete has a temperature of 200F. The thermal conductance through all contact surfaces was taken to be very large, and all contact surfaces were modeled using the bonded-always options. Figures 38 and 39 show the resulting temperature distribution and thermal strains respectively.

A sample calculation of the full 360-degree model was performed with the same 2-D mesh density as the slice model and 15-degree elements in the circumferential direction. Results are shown in Figures 40-41. The model took a total of 10 substeps and 25 equilibrium iterations to converge. Because of the coarseness of the elements, the sparse solver was used instead of the PCG solver. It took approximately 10.5 wall-clock hours to solve.

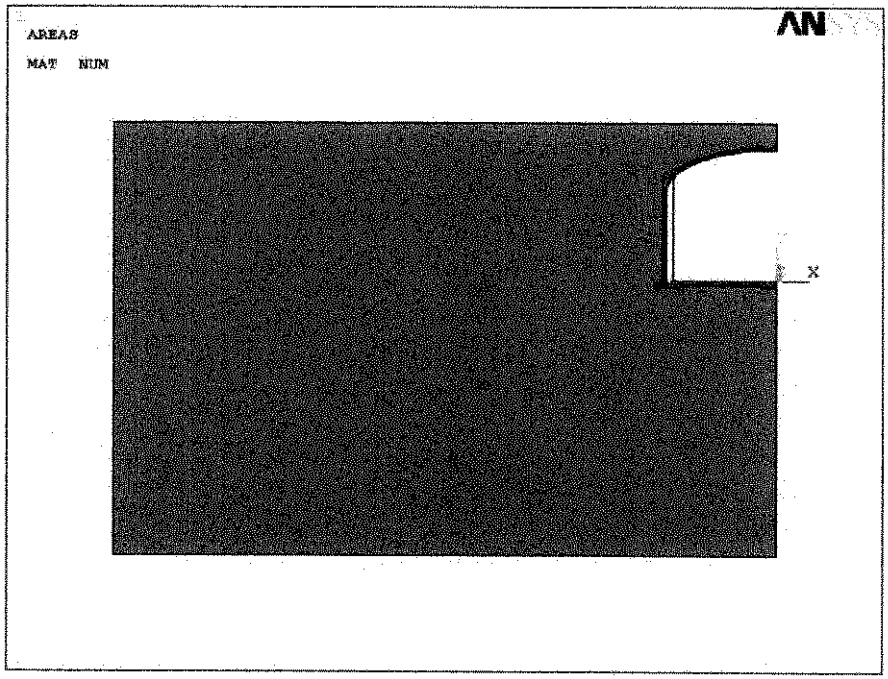

Figure 12. Cross section of model geometry showing soil (pink) and the tank, slab and liners.

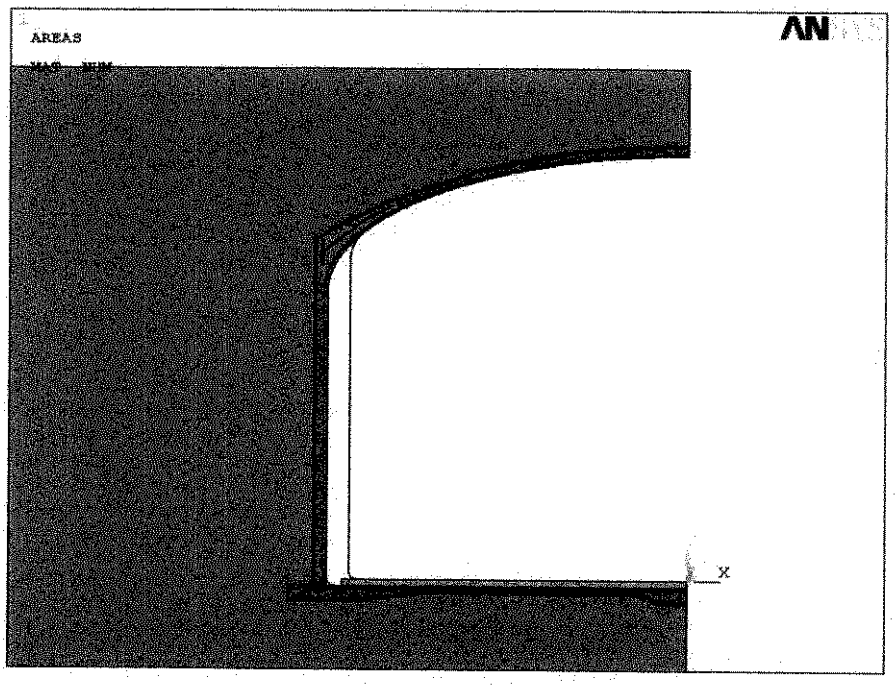

Figure 13. Close-up showing tank, liners, insulating concrete and slab.

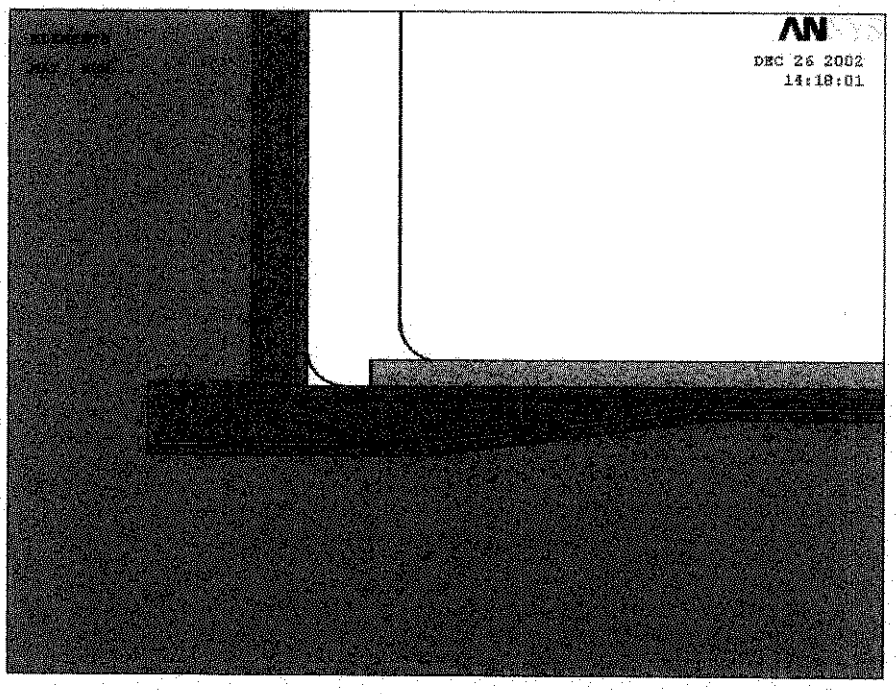

Figure 14. Close-up showing rebar in slab and bottom of tank wall.

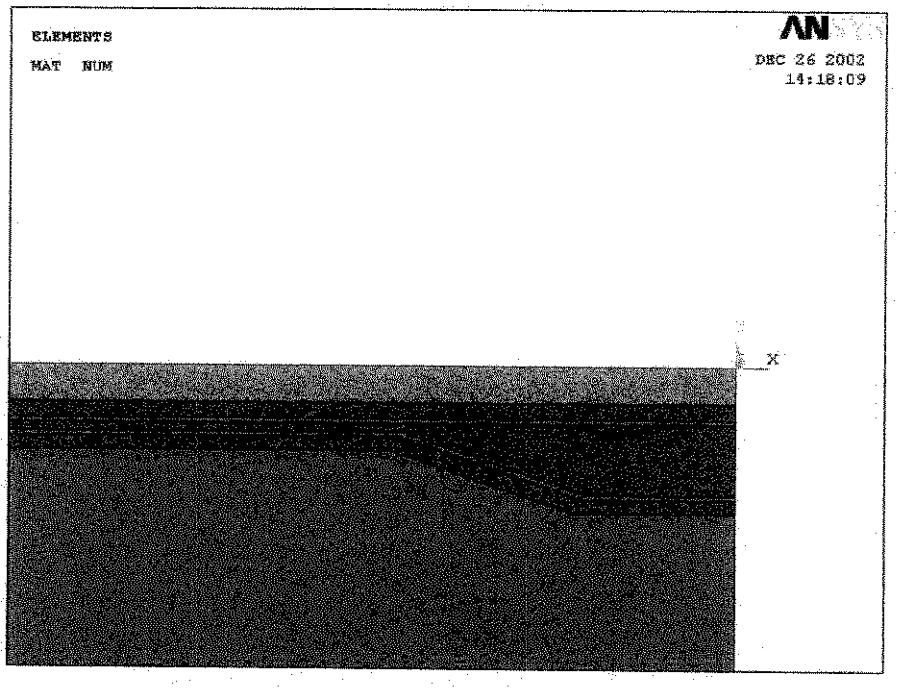

Figure 15. Close-up showing slab rebar near tank center.

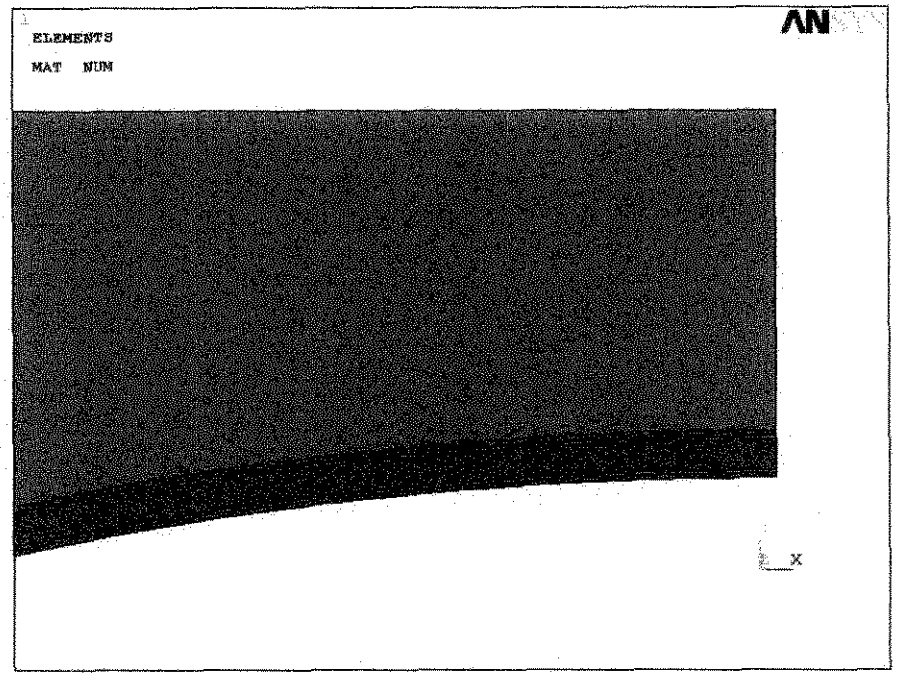

Figure 16. Close-up showing rebar near top of dome.

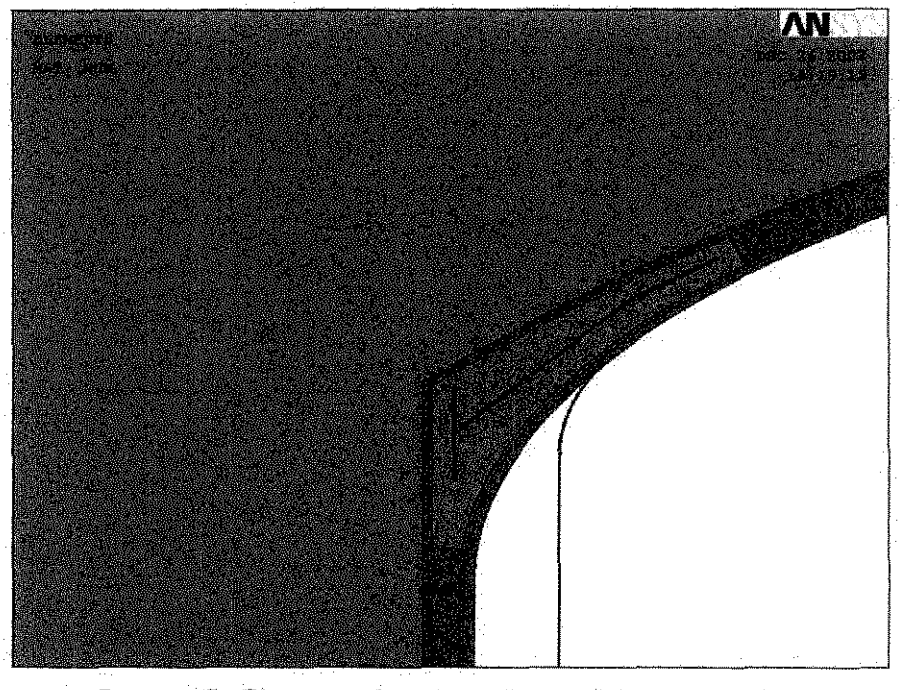

Figure 17. Close-up showing rebar and liners near haunch.

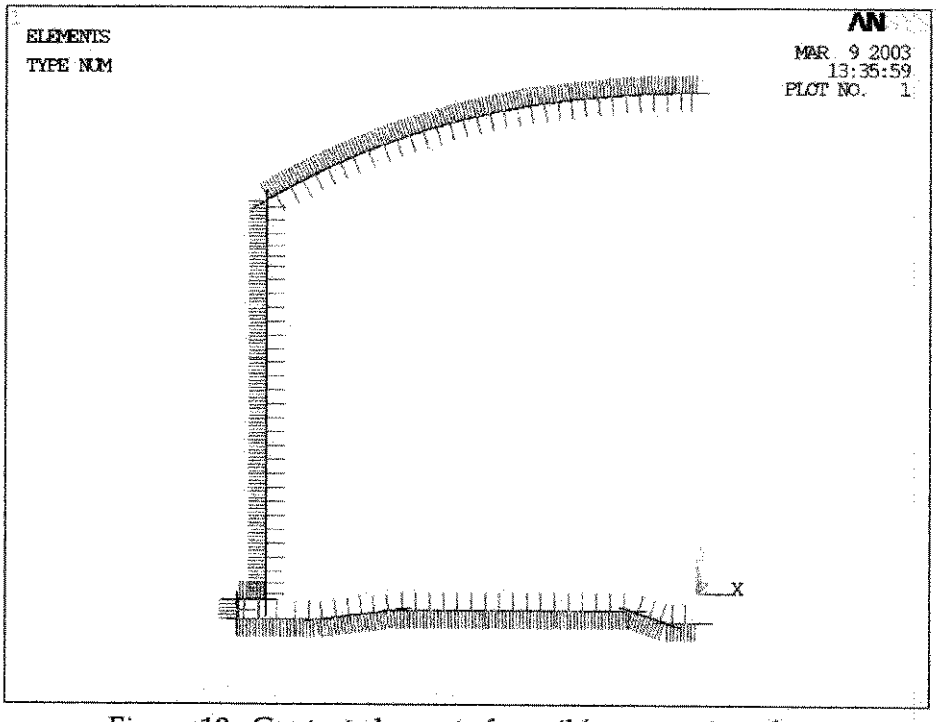

Figure 18. Contact elements for soil/concrete interface.

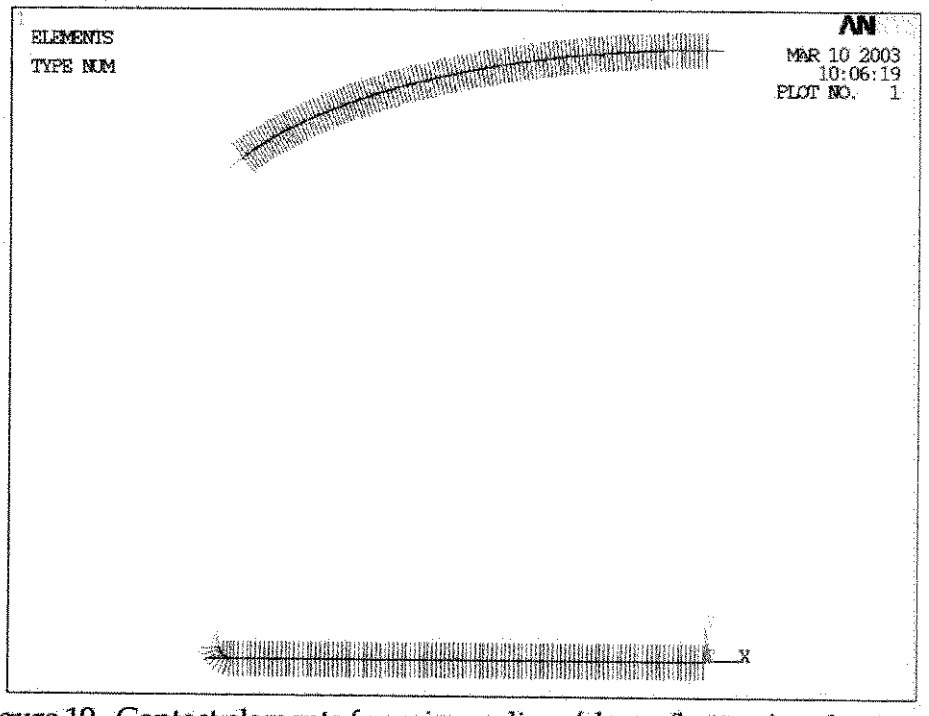

Figure 19. Contact elements for primary liner/dome (bottom) and primary liner/insulating concrete (top) interfaces.

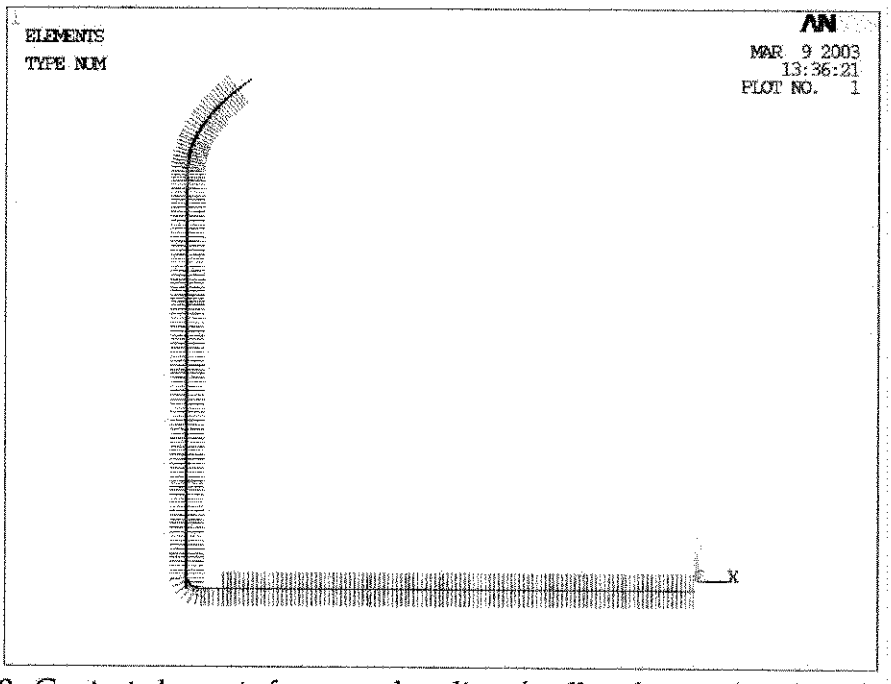

Figure 20. Contact elements for secondary liner/wall and secondary liner/slab (top) interfaces.

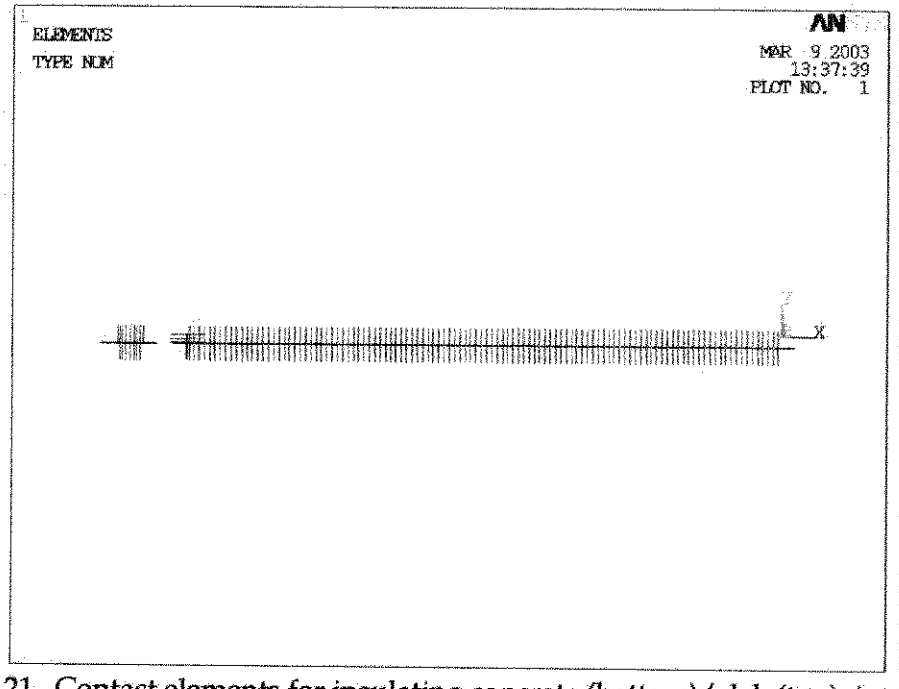

Figure 21. Contact elements for insulating concrete (bottom)/slab (top), insulating concrete (outer perimeter)/ring, and wall (bottom)/slab (top) interfaces.

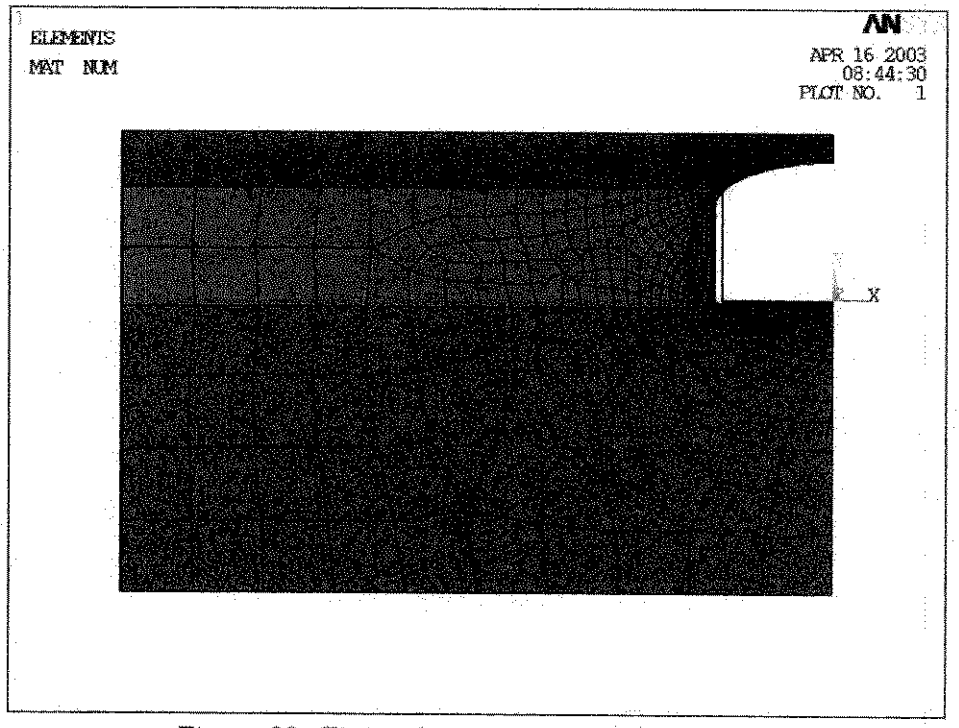

Figure 22. Finite element mesh of slice model.

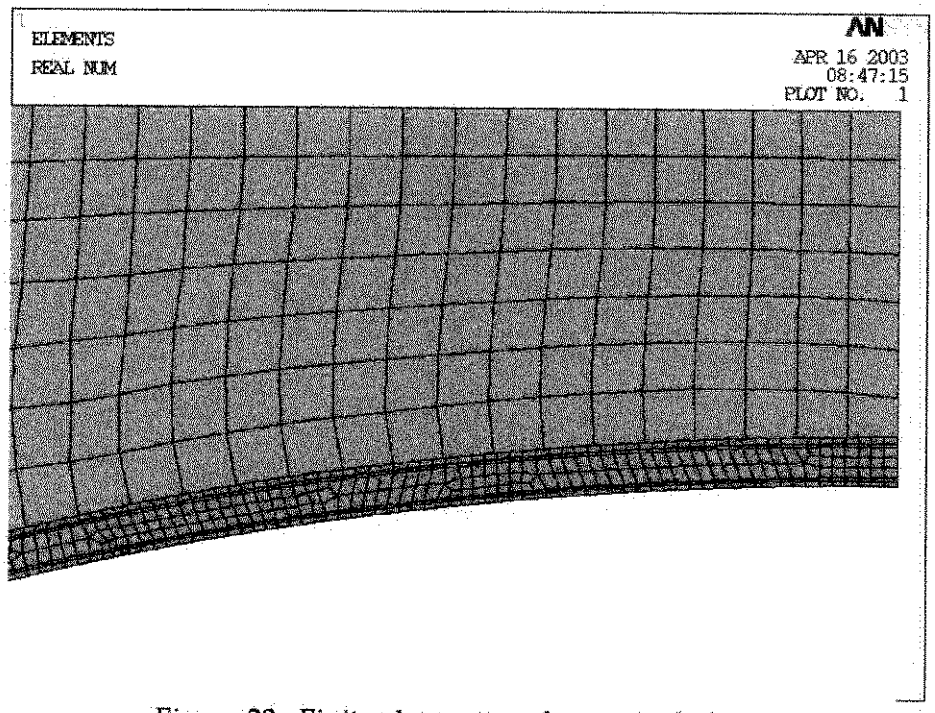

Figure 23. Finite element mesh near tank dome.

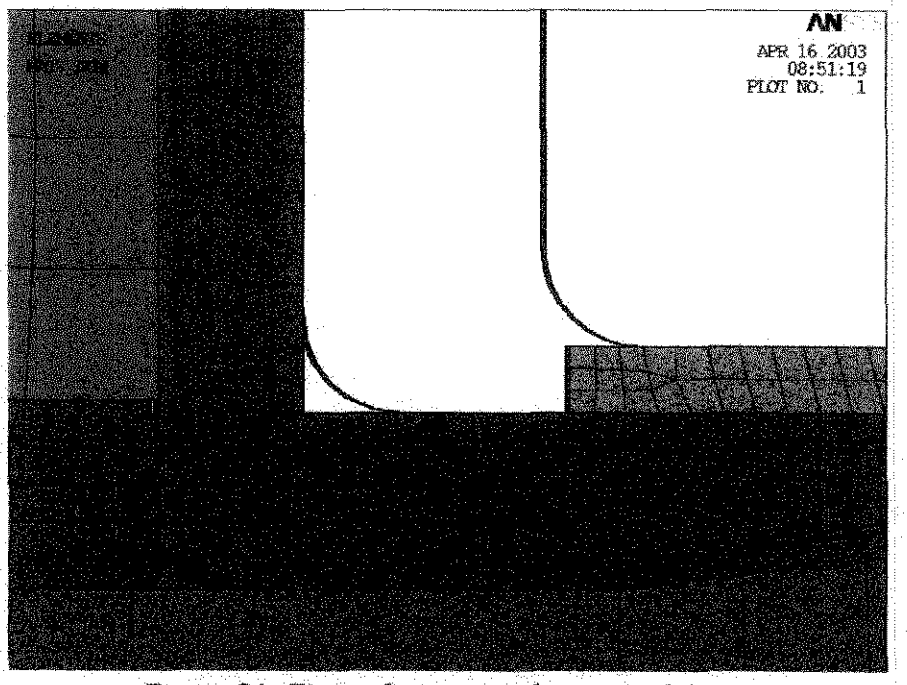

Figure 24. Finite element mesh near tank base.

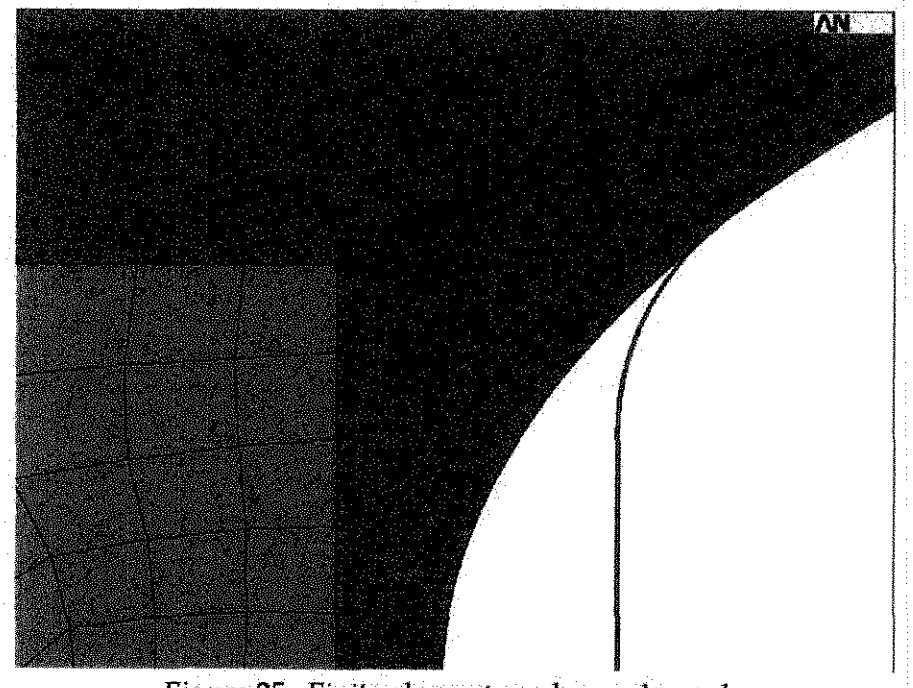

Figure 25. Finite element mesh near haunch.

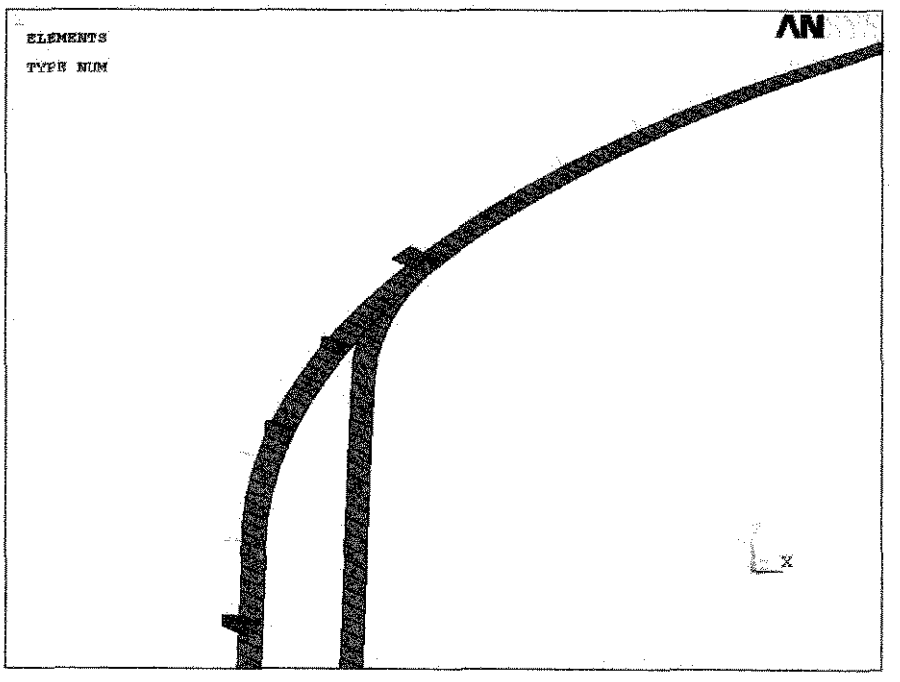

Figure 26. Finite element mesh near haunch, showing liners, anchors and j-bolts.

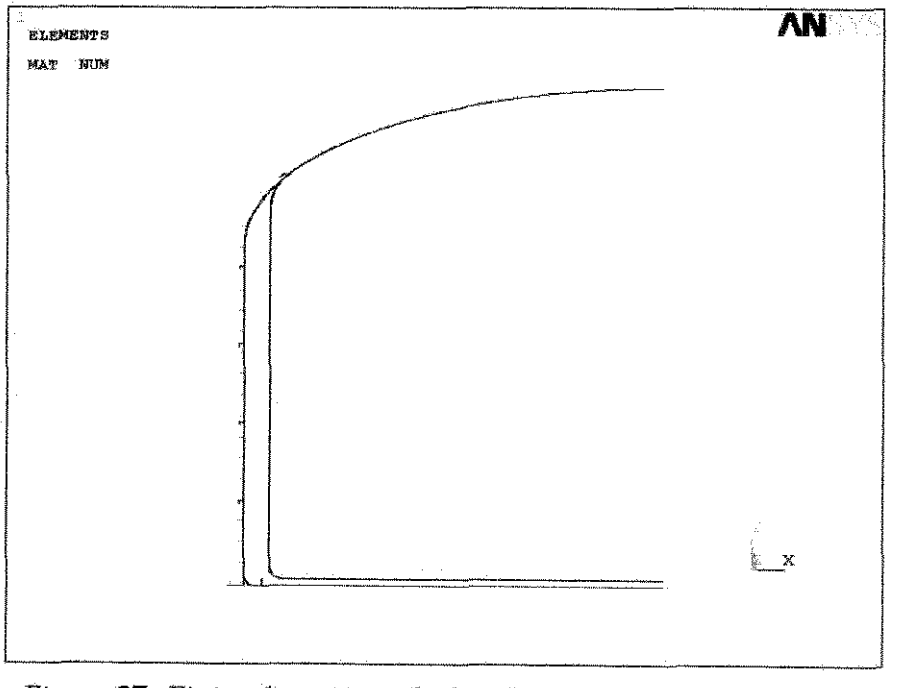

Figure 27. Finite element mesh showing liners, j-bolts and stiffeners.

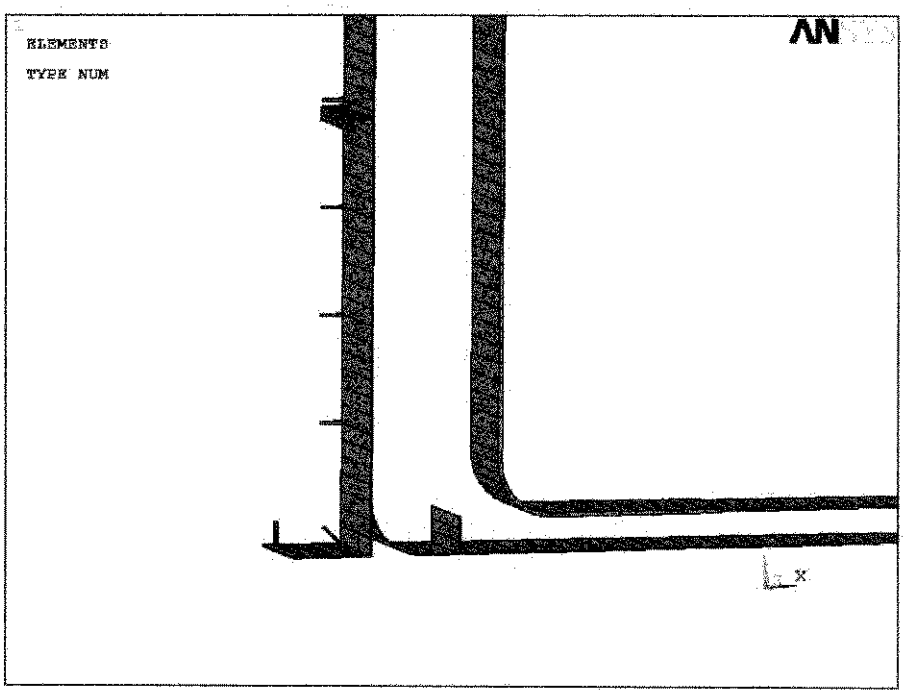

Figure 28. Finite element mesh near base of wall showing liners, wall base steel and anchors, j-bolts, insulating concrete and confining ring.

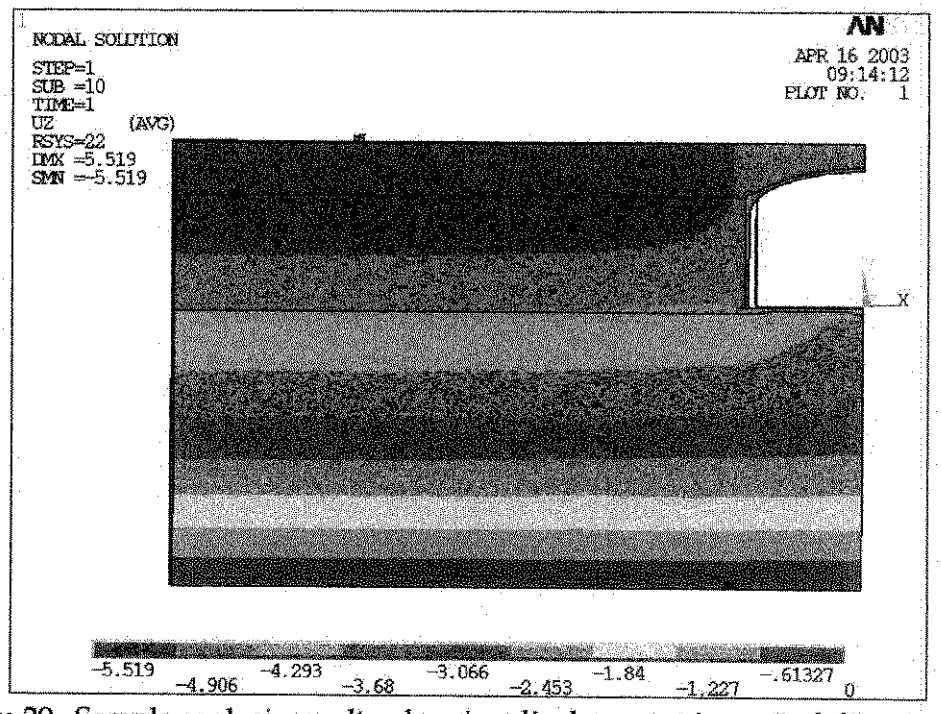

Figure 29. Sample analysis results, showing displacement in vertical direction (in).

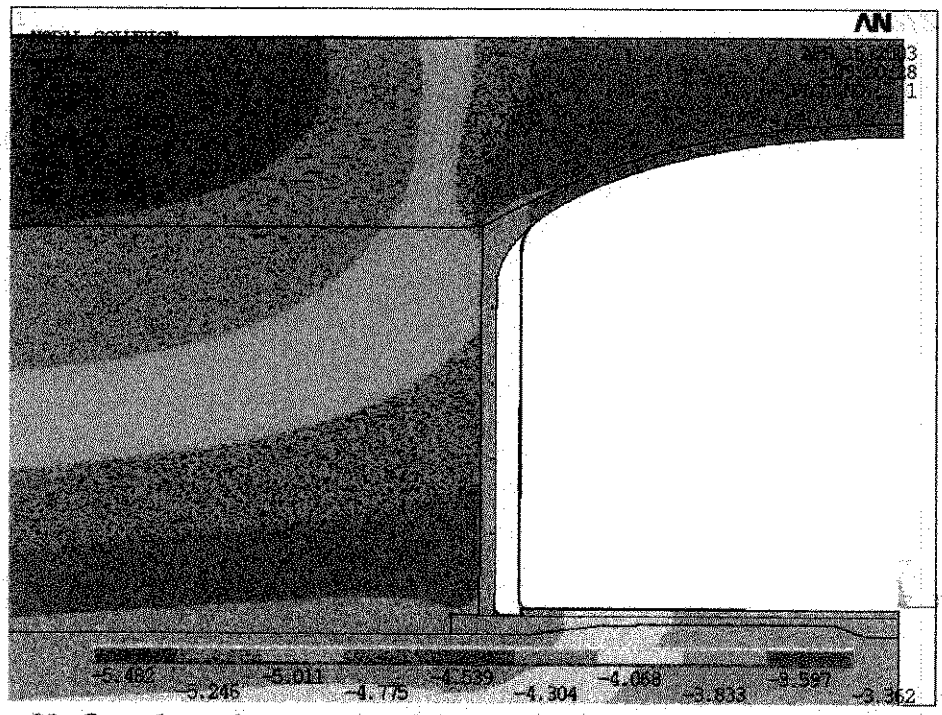

Figure 30. Sample analysis results, showing close-up of vertical displacement (in).

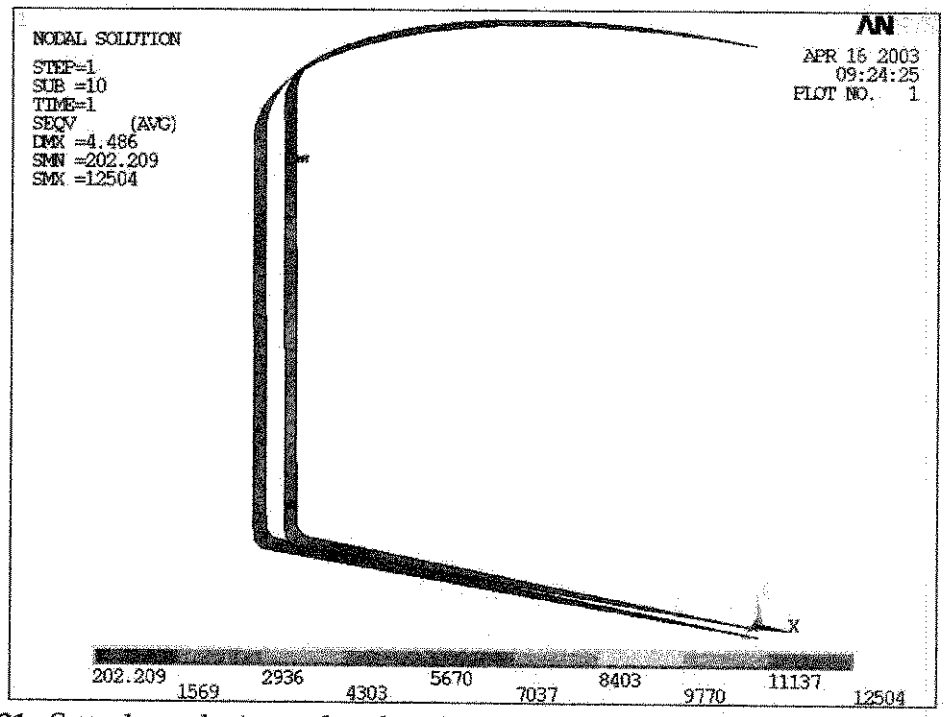

Figure 31. Sample analysis results, showing close-up of equivalent stress in liners (psi).

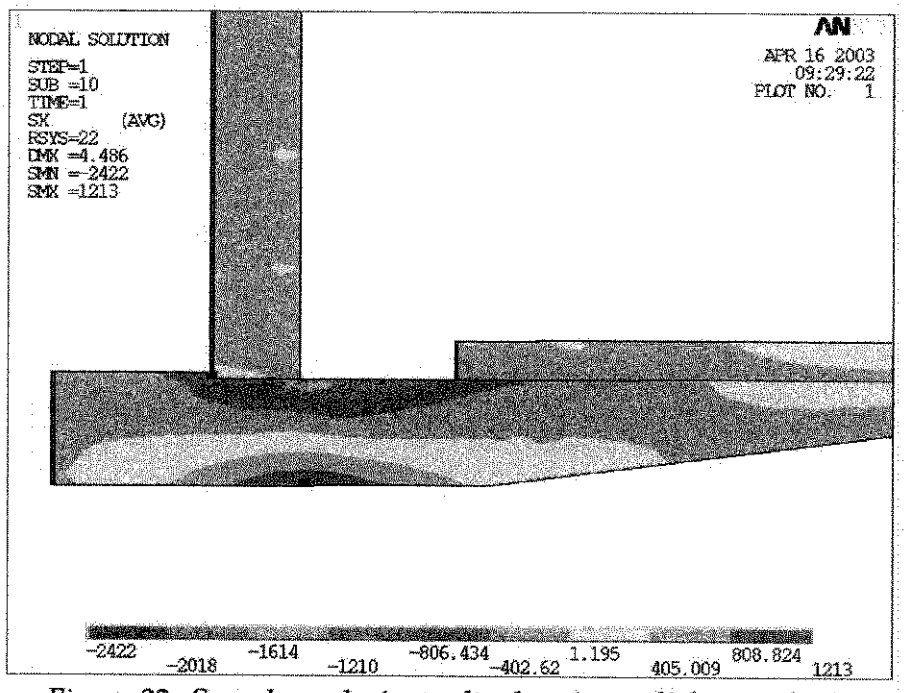

Figure 32. Sample analysis results showing radial stress (psi).

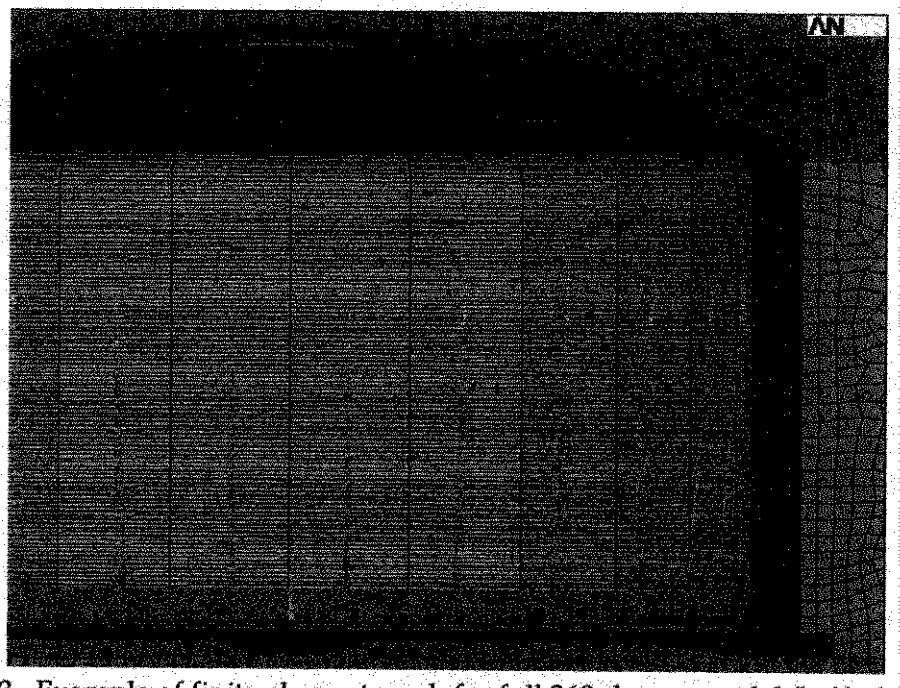

Figure 33. Example of finite element mesh for full 360-degree model (half of model is shown).

Figure 34. Alternate view of full model.

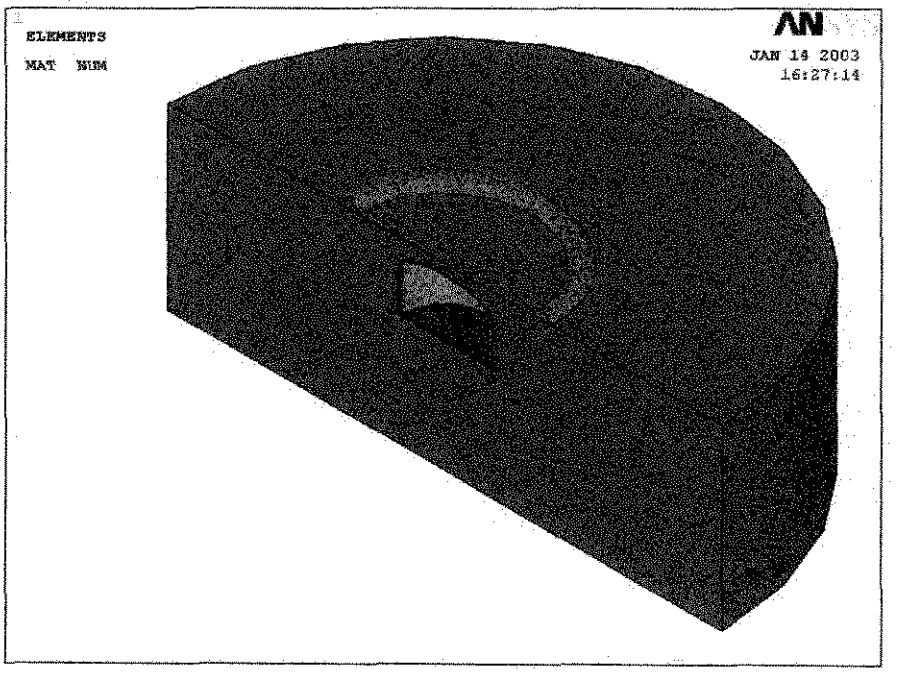

Figure 35. Example showing circular berm.

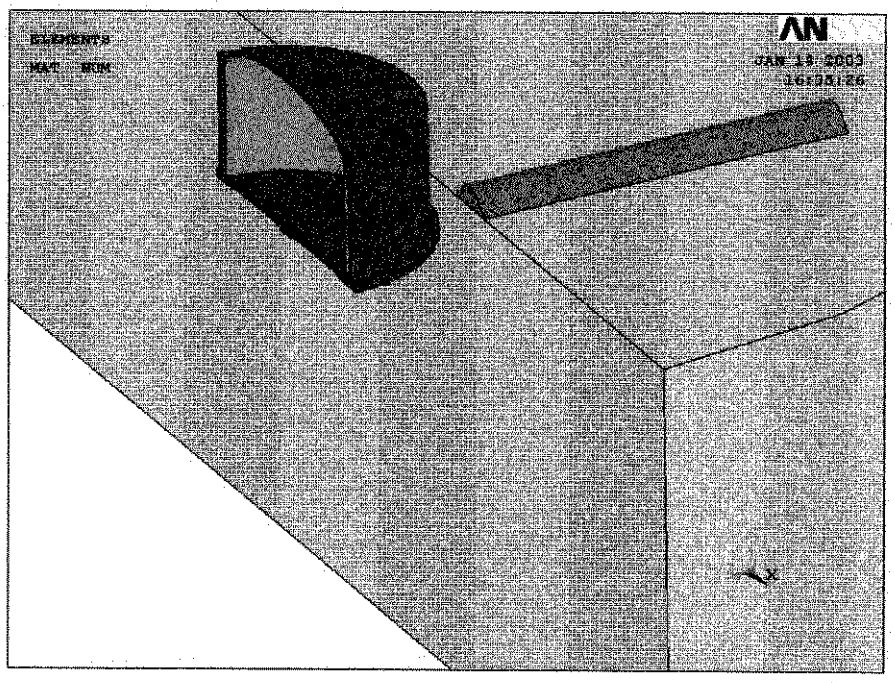

Figure 36. Example showing linear/offset berm.

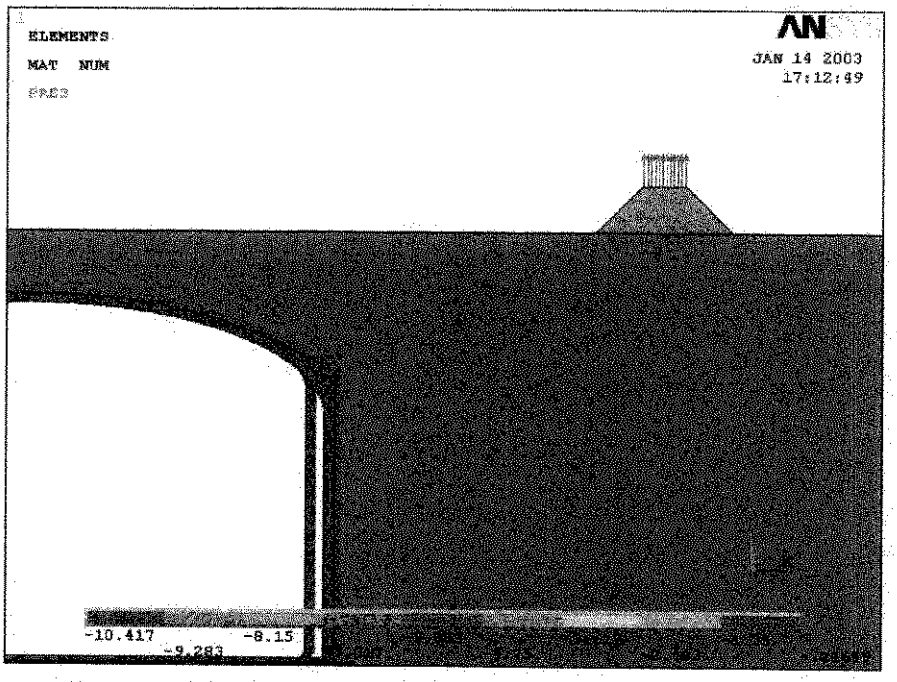

Figure 37. Example showing trench representation (i.e., a berm that produces uplift force at ground surface).

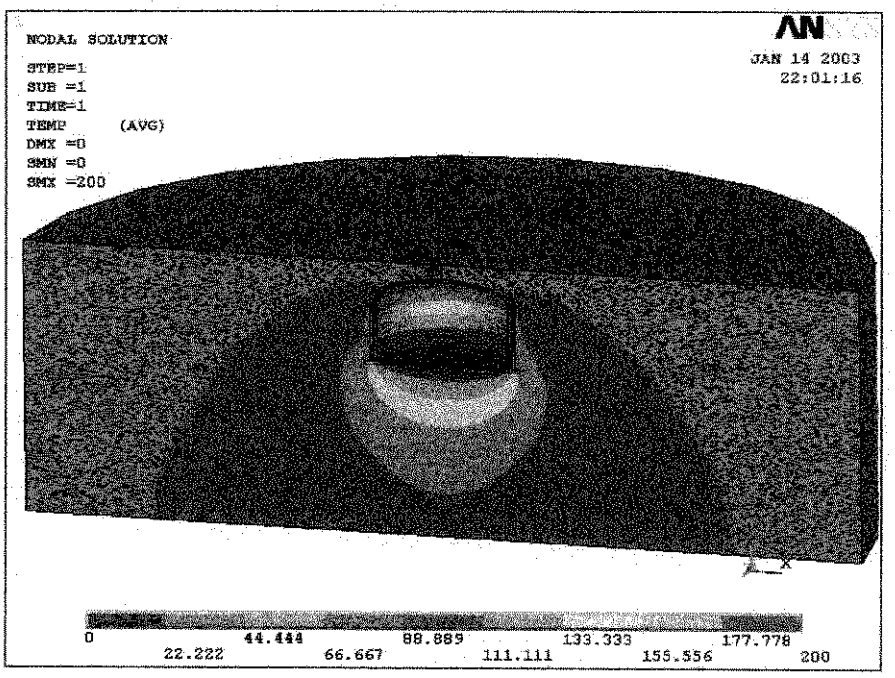

Figure 38. Sample thermal analysis results showing nodal temperatures (degrees F).

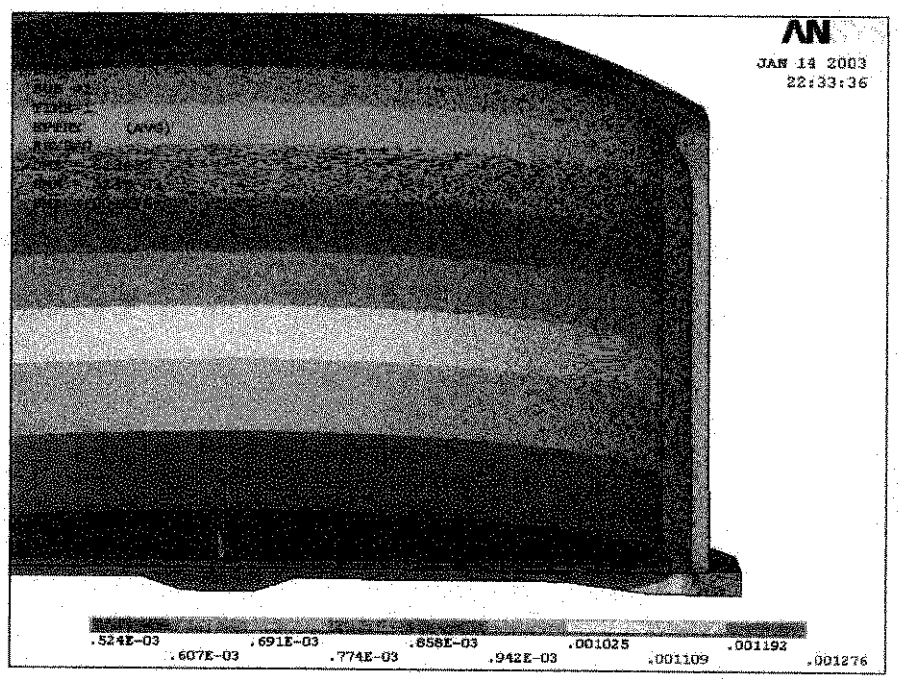

Figure 39. Sample thermal analysis results showing thermal strains in the vertical direction.

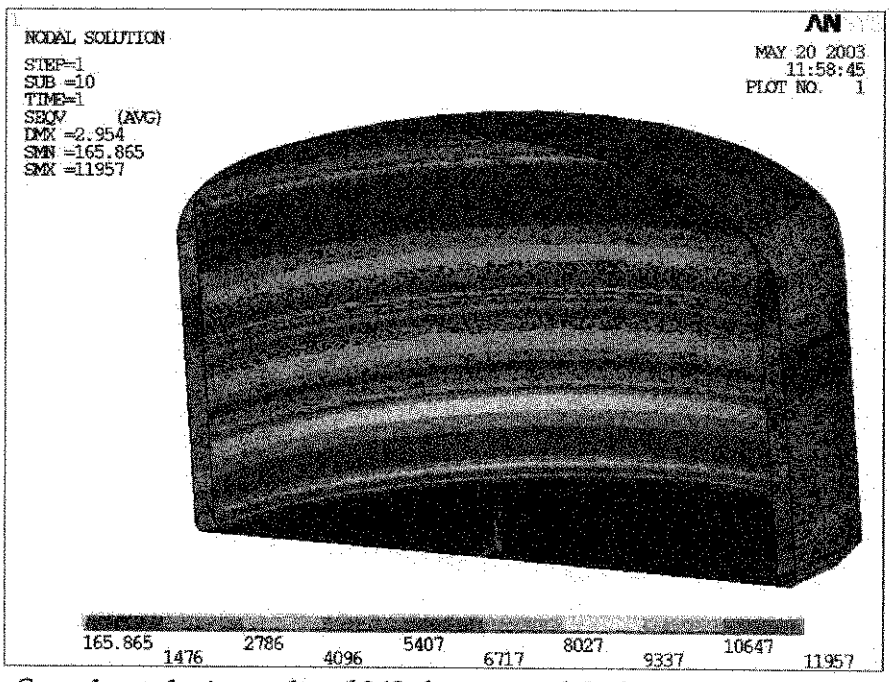

Figure 40. Sample analysis results of 360-degree model, showing close-up of equivalent stress in liners (psi) with half of model cut away.

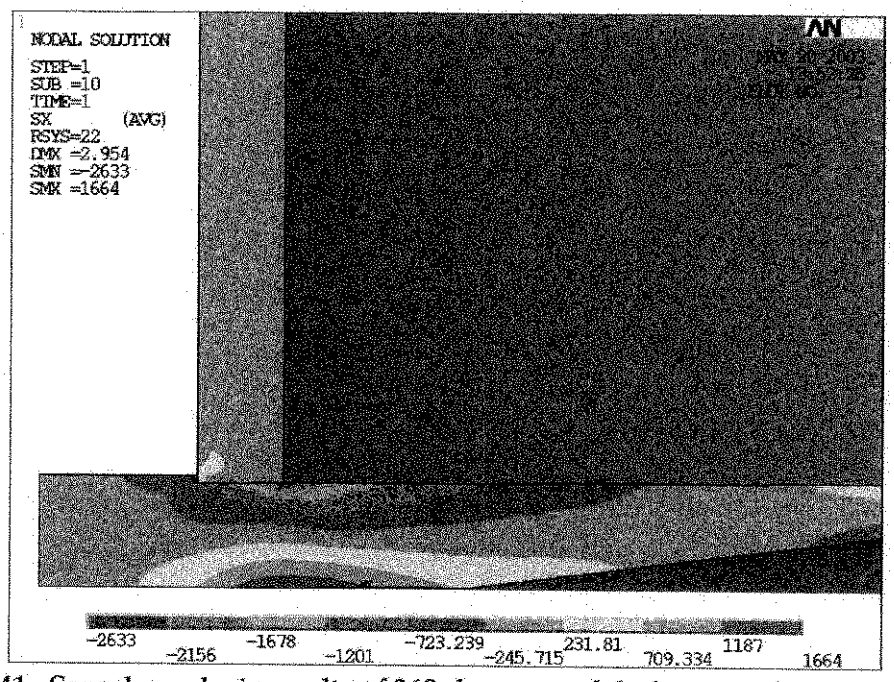

Figure 41. Sample analysis results of 360-degree model, showing close-up of radial stress in tank (psi) with half of model cut away.

6.0 CONCLUSIONS

A parametric model of the DST AY tanks has been developed which is capable of generating an appropriate finite element mesh of the tank, liners, foundation and surrounding soil, and solving for the nonlinear static response of the tank subjected to gravity loads, point and distributed ground surface loads, thermal loads, and internal pressures (vacuums).

The users can analyze a full 3D model of the tank, slab and soil or a slice of the full model that represents axisymmetric behavior. These options are invoked by running either **BUILD_360.MAC** or **SET_SLICE.MAC** respectively.

The model allows the user to enable soil plasticity using the Drucker-Prager constitutive model, concrete cracking/crushing using the ANSYS concrete material model, creep, rebar plasticity using the ANSYS bilinear isotropic material model, and liner/anchor/j-bolt plasticity using the ANSYS bilinear isotropic material model. By default, all nonlinear material models are disabled except for the soil Drucker-Prager model.

The present revision is capable of evaluating the effects of various field conditions, both axisymmetric and non-symmetric, as described in Section 1.0. The default parameters represent nominal load conditions and material properties.

7.0 RECOMMENDATIONS

None.

8.0 REFERENCES

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

[Ref_2] Excel 2002 v10.2614.3311, Microsoft Corp.

[Ref_3] MathCad Standard 7.0. MathSoft, Inc.

[Ref_4] Drawing H-2-64449, Rev 6, *Tank Elevation & Details*, 6/11/70.

[Ref_5] Drawing H-2-64447, Rev 7, *Tank Plan & Penetration Schedule*, 3/9/71.

[Ref_6] Drawing H-2-64310, Rev 1, *Concrete Tank Section and Details*, 3/24/70.

[Ref_7] Drawing H-2-64311, Rev 1, *Concrete Dome Reinforcement Plan and Details*, 3/24/70.

[Ref_8] Drawing H-2-64306, Rev 4, *Tank Foundation Plan*, 12/4/68.

[Ref_9] Document # SD-WM-DA-207, *Concrete Structural Analysis Tools & Properties for Hanford Site Waste Tank Evaluation*, p50.

[Ref_10] Compaq Visual FORTRAN Professional Edition 6.1.0.

[Ref_11] Document #ARH-R-172, *Analysis of Underground Waste Storage Tanks 241SY at Hanford WA [Prepared by Blume]*.

[Ref_12] M&D Professional Services, "Dome Load Evaluation for Hanford 241-C Farm 100-Series Tanks", Document Number RPP-14249, January 14, 2003.

[Ref_13] JLR The Engineering Solutions Company, "Sample AOR Calculation using ANSYS Parametric Model for Tank DST-AY", Document Number RPP-14001, April 18, 2003

9.0 ATTACHMENTS

Attachment 9.01. Listing of ANSYS input macro SET_SLICE.MAC

```
dstay
dstay2
dstay3
dstay4
dstay5
dstay6
dstay7
dstay8
dstay9

/prep7

/psymb,esys,0

allsel
cpdele,all,all

!get misc area components for applying loads, etc.
/input,set_areas_slice,mac

!add steel plate below wall (on slab)
r,45,1/4
csys,22
vsel,s,mat,,2
aslv
asel,r,loc,z,-8.125
asel,r,loc,x,480,498
aatt,1,45,22
mat,1
real,45
amesh,all

!use separate nodes for insulating concrete/outer ring
allsel
mat,1
type,23
real,41
asel,s,,,154
cm,a_ins_outer,area
aclear,all
agen,2,all
asel,s,,,567
cm,a_ring,area
amesh,all
nrot,all
```

```
allsel

!define contact elements
et,60,170      !target
et,61,173      !contact
mp,mu,61,.3
mp,mu,62,.3
mp,mu,63,.3
mp,mu,64,.3
mp,mu,65,.3
mp,mu,66,.1
mp,mu,67,.3
mp,mu,68,.3

/psf,pres,0
/pbc,all,0

!secondary liner contact
r,62,,,.1,.1
real,62
type,60
mat,62
cmsel,s,aconc_shell
csys,0
asel,u,loc,y,460,99999
nsla,,1
esln
esel,r,mat,,2
esurf
type,61
cmsel,s,area_secon
csys,0
asel,u,loc,y,-99999,3.87
nsla,,1
esln
esurf

!primary liner contact with dome
r,63,,,.1,.1
real,63
type,60
mat,63
cmsel,s,aconc_shell
asel,r,loc,y,460,99999
nsla,,1
esln
esel,r,mat,,2
esurf
type,61
cmsel,s,area_prim
```

```
asel,r,loc,y,460,99999
nsla,,1
esln
esurf

!primary liner contact with insulating concrete
r,64,,,.1,.1
real,64
type,60
mat,64
cmsel,s,area_insul_top
nsla,,1
esln
esel,r,mat,,4
esurf
type,61
cmsel,s,area_prim
csys,0
asel,r,loc,y,0,13
nsla,,1
esln
esurf

!couple ring and secondary liner nodes
!  in vertical direction
!cmsel,s,area_insul_bot
cmsel,s,area_secon
cmsel,a,a_ring
csys,0
asel,u,loc,y,20,9999
nsla,,1
nsel,r,loc,y,-8.2,-8.0
cpintf,uz,.1

!slab top/insulating concrete
r,65,,,.1,.1
real,65
type,60
mat,65
cmsel,s,slab_top
nsla,,1
esln
esurf
type,61
cmsel,s,area_insul_bot
nsla,,1
esln
esurf

!wall/slab contact
```

```
r,66,,,.1,.1
real,66
type,60
mat,66
asel,s,,,1065,1071
cm,slab_top_wall,area
nsla,,1
esln
esel,r,mat,,2
esurf
type,61
asel,s,,,225
asel,a,,,763
asel,a,,,971
asel,a,,,976
asel,a,,,992
cm,wall_bot,area
nsla,,1
esln
esel,r,mat,,2
esurf

!top of slab/secondary liner contact
r,67,,,.1,.1
real,67
type,60
mat,67
cmsel,s,slab_top
nsla,,1
esln
esurf
type,61
cmsel,s,area_secon
csys,0
asel,u,loc,y,20,9999
nsla,,1
esln
esurf

!outer perimeter of insulating concrete/ring contact
r,68,,,.1,.1
real,68
type,60
mat,68
cmsel,s,a_ins_outer
nsla,,1
esln
esurf
type,61
cmsel,s,a_ring
```

```
nsla,,1
esln
esurf

allsel
!esel,s,type,,60
!nsle
!nummrg,node
!nummrg,elem
!esel,s,type,,61
!nsle
!nummrg,elem

max_mat=100
max_real=1000

!define the local coordinate systems and rebar orientations
/input,set_esys_3d,mac

!merge liner/concrete nodes at dome centerline
ksel,s,,,2
ksel,a,,,349
nslk
nummrg,node
allsel

!copy jbolts, etc for slice model
csys,22
esel,s,type,,20,21
cm,e_bolt0,elem
egen,2,500000,all,,,0,0,0,0,0,,swp_th
esel,s,mat,,1
esel,u,real,,45
nsle
nummrg,node

!divide jbolt/bottom anchors properties by 2 for slice model
r,20,.19635/2,.3068e-2/2,.3068e-2/2,.5,.5
r,30,.19635/2,.3068e-2/2,.3068e-2/2,.5,.5

esel,s,type,,20,21
cmsel,u,e_bolt0
nsle
nsel,r,,,500000,999999
cm,ntemp,node

vsel,s,mat,,2
vsel,a,mat,,6
csys,0
vsel,u,loc,y,-9999,-8.12
```

```
cm,vtemp,volu
*get,nv,volu,,count
*do,i,1,nv
      *get,iv,volu,,num,min
      eslv
      nsle
      cmsel,a,ntemp
      nummrg,node
      cm,ntemp,node
      cmsel,s,vtemp
      vsel,u,,,iv
      cm,vtemp,volu
*enddo

!couple nodes at primary/secondary liner intersection
ksel,s,,,305
ksel,a,,,312
ksel,a,,,532
ksel,a,,,909
nslk
cp,next,all,all

!couple nodes at primary/secondary liner intersection
ksel,s,,,20
ksel,a,,,229
ksel,a,,,313
ksel,a,,,533
nslk
cp,next,all,all

r,41,3/16          !insulating concrete confining ring thickness


/prep7

esel,s,mat,,5
nsle,,1
csys,0
*get,top_elev,node,,mxloc,y
cm,soil_elem,elem

*do,i,1,18
      set_slayer,soil_z0(i),soil_z1(i),soil_emod(i),soil_pr(i),soil_gam(i),backfill_phi
*enddo

!set backfill material above dome
/input,set_backfill,mac
```

```
!make sure anchors/jbolts/studs etc are merged with concrete
esel,s,mat,,2
esel,a,type,,20,26
vsel,s,,,152      !exclude slab concrete
eslv,u
esel,u,type,,1
esel,u,real,,45   !added to prevent coincident nodes at tank/slab from merging
nsle,,1
nummrg,node

!merge duplicate contact elements/nodes
esel,s,type,,61
nsle
nummrg,node
nummrg,elem

allsel
/psf,pres,0
/pbc,all,0
/pnum,mat,1
/numb,1
eplot

!modify reals of rebar elements in wall
!  to correct for vertical offset error in wall
!  elements of 8.125 inches
csys,0
!
esel,s,real,,200,205 !external wall rebar elements
mat,2
type,15
esys,22
y_cor=8.125
*get,e_tot,elem,,count
  *do,i,1,e_tot
    *get,e_number,elem,,num,min
      *if,centry(e_number),ge,0-y_cor,and,centry(e_number),lt,123-y_cor,then
          real,200
          emod,e_number
      *endif
      *if,centry(e_number),ge,123-y_cor,and,centry(e_number),lt,155-y_cor,then
          real,201
          emod,e_number
      *endif
      *if,centry(e_number),ge,155-y_cor,and,centry(e_number),lt,204-y_cor,then
          real,202
          emod,e_number
      *endif
      *if,centry(e_number),ge,204-y_cor,and,centry(e_number),lt,279-y_cor,then
          real,203
          emod,e_number
```

```
      *endif
      *if,centry(e_number),ge,279-y_cor,and,centry(e_number),lt,311-y_cor,then
          real,213
          emod,e_number
      *endif
      *if,centry(e_number),ge,311-y_cor,and,centry(e_number),lt,348-y_cor,then
          real,204
          emod,e_number
      *endif
      *if,centry(e_number),ge,348-y_cor,and,centry(e_number),lt,382-y_cor,then
          real,205
          emod,e_number
      *endif
    esel,u,,,e_number
  *enddo
allsel
!
esel,s,real,,206,212 !internal wall rebar elements
mat,2
type,15
esys,22
y_cor=8.125
*get,e_tot,elem,,count
  *do,i,1,e_tot
    *get,e_number,elem,,num,min
      *if,centry(e_number),ge,0-y_cor,and,centry(e_number),lt,123-y_cor,then
          real,206
          emod,e_number
      *endif
      *if,centry(e_number),ge,123-y_cor,and,centry(e_number),lt,155-y_cor,then
          real,207
          emod,e_number
      *endif
      *if,centry(e_number),ge,155-y_cor,and,centry(e_number),lt,204-y_cor,then
          real,208
          emod,e_number
      *endif
      *if,centry(e_number),ge,204-y_cor,and,centry(e_number),lt,279-y_cor,then
          real,209
          emod,e_number
      *endif
      *if,centry(e_number),ge,279-y_cor,and,centry(e_number),lt,311-y_cor,then
          real,210
          emod,e_number
      *endif
      *if,centry(e_number),ge,311-y_cor,and,centry(e_number),lt,348-
y_cor,then
          real,211
          emod,e_number
      *endif
      *if,centry(e_number),ge,348-y_cor,and,centry(e_number),lt,382-y_cor,then
```

```
          real,212
          emod,e_number
      *endif
    esel,u,,,e_number
  *enddo
allsel

!modify reals of elements in haunch to
!  correct from 12" to 30" above dome tangent error
mat,2
type,15
esel,s,real,,400,401
nsle
nsel,r,loc,y,381.5,413.6
esln,r,1
esys,22
real,400
emod,all
!
esel,s,real,,405,406
nsle
nsel,r,loc,y,381.5,413.6
esln,r,1
esys,202
real,405
emod,all
allsel

!modify reals of elements in haunch to
!  correct from 44" to 12" in corner
csys,22
mat,2
type,15
esys,201
esel,s,real,,403
nsle
nsel,r,loc,x,0,487
esln,r,1
real,404
emod,all
csys,0
allsel

!modify soil elements so there are 3 horizontal layers
!  modify 2D geometry and mesh
esel,s,mat,,5
esel,a,mat,,101,118
nsle
vsln
aslv
```

```
lsla
ksll
vclear,all
vdel,all
cm,a_soil,area
csys,22
asel,u,loc,y,180
asel,u,loc,y,-180
adel,all,,,1
cmsel,s,a_soil
csys,0
aadd,all
kwpave,1200
wprot,0,0,90
asbw,470
kwpave,1186
asbw,161
aadd,455,460
lcomb,956,967
lcomb,917,962
lcomb,915,2189
lcomb,914,963
kwpave,1205
wpoff,0,point_rad
wprot,0,90
lsbw,19
type,type_soil
real,7
kesize,all,300
ksel,r,loc,x,-700,1
ksel,r,loc,y,-200,999
kesize,all,16
ksll
mshkey,0
smrt,off
mat,101
amesh,160
mat,104
amesh,458
mat,109
amesh,161
!rotate 2D soil geometry/mesh to create 3D
type,type_soil+10
esize,,num_div
mat,101
ksel,a,,,iktop
ksel,a,,,ikbot
vrot,160,,,,,,ikbot,iktop,swp_sl,1
mat,104
vrot,458,,,,,,ikbot,iktop,swp_sl,1
```

```
mat,109
vrot,161,,,,,,ikbot,iktop,swp_sl,1
nummrg,node
nummrg,kp
aclear,all
csys,22
nrot,all
csys,0

!soil_concrete contact
asel,s,,,478
asel,a,,,485
asel,a,,,488
asel,a,,,499,500
asel,a,,,510,512
asel,a,,,522
asel,a,,,531,532
asel,a,,,534
asel,a,,,539
cm,asoil,area !soil areas of contact with tank
allsel
r,61,,,50,50 !make 500x higher due to TB
real,61
type,61
mat,61
cmsel,s,aconc_soil
nsla,,1
esln
esurf
type,60
cmsel,s,asoil
nsla,,1
esln
esurf

allsel
finish

/solution

!apply loads
/input,apply_loads_slice,mac
allsel

/solution
!constrain boundaries
csys,0
nsel,s,loc,x,0 !along global y axis
d,all,ux,0
d,all,uy,0
```

```
allsel
*get,xmn,node,,mnloc,x
*get,ymn,node,,mnloc,y
*get,ymx,node,,mxloc,y

nsel,s,loc,y,ymn
d,all,ux,0,,,,uy,uz

ksel,s,loc,x,xmn
ksel,r,loc,z,0
lslk,,1
asll
asel,u,loc,z,0
nsla,,1
d,all,ux,0
d,all,uy,0

asel,s,loc,y,ymn
nsla,,1
d,all,ux,0,,,,uy,uz
allsel

!apply axisymmetric boundary conditions
csys,22
nsel,s,loc,y,180-.01,180+.01
nsel,a,loc,y,180+swp_th-.01,180+swp_th+.01
csys,0
nsel,a,loc,x,0
d,all,uy,0
d,all,rotx,0
d,all,rotz,0
allsel

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

!solcontrol,off
neqit,50
time,1
nlgeom,on
cnvtol,f,,.001,2
cnvtol,m,,.001,2
nsubst,10,100,10
!outres,all,all
allsel
save

solve,,,,,noch
```

Attachment 9.02. Listing of ANSYS input macro DSTAY.MAC

```
finish
/clear
/prep7

or=12*41.5   !outer concrete wall
ir=12*40     !inside secondary tank liner
ir2=12*37.5  !centerline of primary tank liner
h1=0         !elevation of centerline of primary liner
h2=-8.125    !elevation of centerline of secondary liner
h3=381.5     !elevation to beginning of haunch region
h4=h3+70.875 !elevation to top of wall
h5=h3+15*12  !elevation to bottom of dome
h6=h5+15     !elevation to top of dome

covext=2
covint1=4
covint2=1.5
rat_mid=.6

r1=105*12+.25
th1=7+(45+14/60)/60
r2=74*12+4
th2=22+(25+6/60)/60
r3=44.375

pi=acos(-1)
*afun,deg

k,1,0,h6
k,2,0,h5
k,3,0,0
k,4,-ir2,0
k,5,ir2,h3+36+6+13/16
k,6,-r1*sin(th1),h6-r1+r1*cos(th1)
larc,6,1,3,r1

rectng,-ir2,0,h2,h1
rectng,-or,-ir,h2,h3
rectng,-or,-ir,h3,h4

larc,18,6,3,r2
local,11,1,0,h3,0,,,,3/8
l,13,2

csys,0
l,1,2
k,,-ir2,0
```

```
k,,-ir2,h3+36+6+13/16
l,19,20
kwpave,20
wprot,,-90
wpoff,,,72+6+11/16-36-6-13/16
lsbw,15
larc,20,21,3,r3

nummrg,kp
lfillt,17,4,12
l,7,12
lfillt,7,21,12
ldiv,21,.51
l,16,12
adrag,5,,,,,,21

al,8,19,14,1,18,16,13
aovlap,all
aadd,3,6
aadd,1,4
allsel
numcmp,all

! The following were added to modify the insulating concrete outer
!    radius to 447 inches
kmod,4,-444
kmod,7,-444
kmod,21,-447
kmod,22,-447
kmod,18,-447

*get,ik,kp,,num,max

k,ik+1,0,h2-24
k,ik+2,-36,h2-24
k,ik+3,-76,h2-10.5
k,ik+4,-29*12-1,h2-10.5
k,ik+5,-36*12-9,ky(ik+4)-11.5
k,ik+6,-44*12-3,ky(ik+5)
k,ik+7,kx(ik+6),ky(ik+6)+12+11.5
k,ik+8,-or-1,ky(ik+7)
k,ik+9,kx(ik+8),ky(ik+8)-1.5
k,ik+10,-or,ky(ik+9)
k,ik+11,-ir,ky(ik+9)
k,ik+12,-ir+1,ky(ik+9)
a,ik+1,ik+2,ik+3,ik+4,ik+5,ik+6,ik+7,ik+8,ik+9,ik+10,ik+11,ik+12,8


k,36,kx(13)+5.7+1,ky(13)+39.3-1
k,37,kx(11)+covext,ky(11)
```

```
k,38,kx(37)+1,ky(37)
k,39,kx(17)+covext,ky(17)-.707
k,40,kx(39)+1,ky(39)-.707
k,41,kx(6),ky(6)-covext
k,42,kx(41),ky(41)-1
k,43,kx(1),ky(1)-covext
k,44,kx(1),ky(43)-1

larc,39,41,3,74*12
larc,41,43,3,105*12
larc,40,42,3,74*12-1
larc,42,44,3,105*12-1
a,37,38,40,42,44,43,41,39

k,45,kx(12)-covint1,ky(12)
k,46,kx(45)-1,ky(45)
k,47,kx(13)-covint1,ky(13)
k,48,kx(47)-1,ky(47)
k,49,kx(36),ky(36)
k,50,kx(49)-1.414,ky(49)
k,51,0,ky(2)+covint2
k,52,0,ky(51)+1
larc,48,50,3,74
larc,47,49,3,73
csys,11
l,50,52
l,49,51
csys,0

a,45,46,48,50,52,51,49,47
lplot

covtop=3.5
covbot=3
k,60,kx(28)+3,ky(28)+covbot
k,61,kx(60),ky(60)+1
k,62,kx(29)+3,ky(8)-covtop
k,63,kx(62),ky(62)-1
k,64,0,ky(8)-covtop
k,65,0,ky(64)-1
k,74,0,ky(23)+covbot+1
k,75,0,ky(23)+covbot
k,66,kx(24)+.707*covbot,ky(24)+covbot
k,67,kx(66)+.707,ky(66)+1
k,68,kx(25)+.707*covbot,ky(25)+covbot
k,69,kx(68)+.707,ky(68)+1
k,70,kx(26)-.707*covbot,ky(26)+covbot
k,71,kx(70)-.707,ky(70)+1
k,72,kx(27)-.707*covbot,ky(27)+covbot
k,73,kx(72)-.707,ky(72)+1
```

```
a,60,61,73,71,69,67,74,75,66,68,70,72
a,62,64,65,63

lplot

k,80,kx(14)+11+.5,ky(14)+36
k,81,kx(80),ky(40)
k,82,kx(80),.5*(ky(80)+ky(81))
k,83,kx(14)+72,ky(14)+98
k,84,kx(14)+103,ky(14)+113
k,85,kx(84),ky(84)+1
k,86,kx(83),ky(83)+1
k,87,kx(82),ky(82)+1
k,88,kx(81)-1,ky(81)
k,89,kx(80)-1,ky(80)
a,80,82,87,81,88,89
a,82,83,84,85,86,87

lplot

ldiv,11,.34
csys,0
wpcsys,-1
kwpave,35
wprot,,-90
wprot,,,60
asel,s,,,3
asbw,all
wpcsys,-1
kwpave,14
wpoff,,12
wprot,,-90
asbw,all

allsel
aovlap,all
lplot


!divide slab rebar at radial locations
*dim,sr,,8
sr(1)=57,90,330,360,378,435,441,459
asel,s,,,7,8
csys,0
wpcsys,-1
wprot,,,-90
*do,i,1,8
      wpoff,,,sr(i)
      asbw,all
      wpoff,,,-sr(i)
```

```
*enddo


!divide wall rebar
*dim,wr,,6
wr(1)=123,155,204,279,311,348
asel,s,,,15,16
csys,0
wpcsys,-1
wprot,,-90
kwpave,3
*do,i,1,6
      wpoff,,,wr(i)
      asbw,all
      wpoff,,,-wr(i)
*enddo

!divide dome rebar
*dim,dr,,6
dr(1)=337,320,312,287,275,239
asel,s,,,18
asel,a,,,28
csys,0
wpcsys,-1
wprot,,,-90
kwpave,3
*do,i,1,6
      wpoff,,,dr(i)
      asbw,all
      wpoff,,,-dr(i)
*enddo



!divide at bent bar, top of haunch
wpcsys,-1
kwpave,17
wpoff,48*cos(30)
wprot,,,-90
asel,s,,,30
asbw,all

allsel
l,40,39
asbl,66,119

allsel
nummrg,all
numcmp,all
lplot
```

```
!j-bolts
*dim,jx,,35
*dim,jy,,35
*dim,jdeg,,35
jx(1)=479,479,479,479,479,479,479,479,479,479
jx(11)=479,479,479,479,479,479,473,462,449,432
jx(21)=412,391,369,347,324,299,272,241,206,165
jx(31)=107,479,479,479,479
jy(1)=19,43,67,91,115,139,163,187,211,235
jy(11)=259,283,307,331,355,379,402,424,443,460
jy(21)=474,486,496,504,511,515,518,522,525,527
jy(31)=529,89.5,89.5*2,89.5*3,89.5*4
jdeg(1)=90,90,90,90,90,90,90,90,90,90
jdeg(11)=90,90,90,90,90,90,75,55,45,40
jdeg(21)=35,30,25,20,15,10,9,8,7,6,5
jdeg(31)=1,90,90,90,90

csys,0
j_length=5
asel,s,,,14
asel,a,,,16
asel,a,,,18,19
asel,a,,,21
asel,a,,,24
asel,a,,,28,29
asel,a,,,31
asel,a,,,42
asel,a,,,48
asel,a,,,50
asel,a,,,52
asel,a,,,53
asel,a,,,54
asel,a,,,56
asel,a,,,58
asel,a,,,60
asel,a,,,62
asel,a,,,64


*do,i,1,35
      wpcsys,-1
      wpave,-jx(i),jy(i)
      wprot,jdeg(i)
      wprot,,,90
      asbw,all
*enddo

!bottom anchors
lanch=5+3/16
```

```
ldiv,238,.14
kgen,2,37,,,0,lanch,0
a,12,275,276,37
allsel
aovlap,all

!flange of construction stiffeners
asel,s,,,146
*do,i,32,35
      wpcsys,-1
      wpave,-jx(i),jy(i)
      wprot,jdeg(i)
      wprot,,,90
      wpoff,,,-3
      asbw,all
*enddo

save,temp1,db

asel,s,,,14
asel,a,,,21
asel,a,,,31
asel,a,,,56
asel,a,,,96
asel,a,,,104,107
asel,a,,,109

csys,0
wpcsys,-1
wpoff,,381.5+6.25
wprot,,-90
asbw,all
wpoff,,,24+1.25
asbw,all
wpoff,,,24
asbw,all

asel,s,,,21
asel,a,,,152
kwpave,290
wprot,,,90
wpoff,,,-1.875
asbw,all
kwpave,293
wpoff,,,-2.375
asbw,all

ldiv,337,1-6/24.47

allsel
```

```
aadd,14,151
aadd,105,106
aadd,153,154
aadd,107,150

lplot


!inside layer of rebar
*dim,as1,,53
as1(1)=14,18,19,24,28,29,31,42,48,50
as1(11)=52,53,54,58,60,62,64,70,72,74
as1(21)=76,77,78,80,82,85,86,88,90,92
as1(31)=94,96,97,99,103,111,113,115,116,118
as1(41)=120,122,126,127,129,131,139,140,141,143
as1(51)=148,149,152
asel,s,,,as1(1)
*do,i,2,53
      asel,a,,,as1(i)
*enddo
cm,as1,area

!outside layer of rebar
*dim,as2,,18
as2(1)=15,23,30,45,46,47,49,51,55,57
as2(11)=59,61,63,65,66,67,68,145
asel,s,,,as2(1)
*do,i,2,18
      asel,a,,,as2(i)
*enddo
cm,as2,area

!bottom layer of slab
*dim,as3,,9
as3(1)=4,5,8,11,36,37,39,41,44
asel,s,,,as3(1)
*do,i,2,9
      asel,a,,,as3(i)
*enddo
cm,as3,area

!top layer of slab
*dim,as4,,9
as4(1)=1,3,6,7,13,35,38,40,43
asel,s,,,as4(1)
*do,i,2,9
      asel,a,,,as4(i)
*enddo
cm,as4,area
```

```
!haunch
asel,s,,,33
cm,haunch,area

!concrete insulation
asel,s,,,2
cm,cinsul,area

!slab
asel,s,,,32
cm,slab,area

!haunch vertical steel
asel,s,,,9
cm,hvert,area

!haunch radial
asel,s,,,10
cm,hrad,area

!concrete
allsel
cmsel,u,hrad
cmsel,u,hvert
cmsel,u,slab
cmsel,u,cinsul
cmsel,u,haunch
cmsel,u,as4
cmsel,u,as3
cmsel,u,as2
cmsel,u,as1
cm,conc,area

allsel
lplot
save,temp2,db
```

Attachment 9.03. Listing of ANSYS input macro DSTAY2.MAC

```
resume,temp2,db
/prep7

mat_liner=1
mat_conc=2
mat_rebar=3
mat_insul=4
mat_soil=5
mat_haunch=6

type_liner=1        !liner shells
type_tank=2         !tank concrete
type_haunch=3       !haunch concrete
type_slab=4         !slab concrete
type_rebar=5        !rebar
type_insul=6        !insulating concrete
type_soil=7         !soil

et,type_liner,181,,,2
et,type_tank,63
et,type_haunch,63
et,type_slab,63
et,type_rebar,63
et,type_insul,63
et,type_soil,63

et,type_liner+10,181,,,2
et,type_tank+10,65
et,type_haunch+10,65
et,type_slab+10,65
et,type_rebar+10,65
et,type_insul+10,65
et,type_soil+10,45

!define local element coordinate systems for rebar regions
cmsel,s,as1
cmsel,a,as2
cmsel,a,as3
cmsel,a,as4
cmsel,a,hrad
cmsel,a,hvert
*get,narea,area,,count
cm,atemp,area
cm,atemp0,area

*afun,deg
ics=100
```

```
*do,i,1,narea
      *get,ia,area,,num,min
      asel,s,,,ia
      lsla
      ksll
      csys,0
      *get,minx,kp,,mnloc,x
      *get,maxx,kp,,mxloc,x
      *get,miny,kp,,mnloc,y
      *get,maxy,kp,,mxloc,y
      theta=90
      *if,minx,ne,maxx,then
            theta=atan((maxy-miny)/(maxx-minx))
      *endif
      wpcsys,-1
      kwpave,all
      wprot,theta
      cswplan,ics,0
      aatt,mat_rebar,,type_rebar,ics
      cmsel,s,atemp
      asel,u,,,ia
      cm,atemp,area
      ics=ics+1
*enddo

!define spherical coordinate system for haunch, with center at global origin
csys,0
wpcsys,-1
local,ics,2
asel,s,,,33
aatt,mat_conc,604,type_haunch,ics


!set real constants for rebar
csys,0
wpcsys,-1
!wall external
set_ry,-8,123,200,'as2'
set_ry,123,155,201,'as2'
set_ry,155,204,202,'as2'
set_ry,204,311,203,'as2'
set_ry,311,348,204,'as2'
set_ry,348,382,205,'as2'


!wall internal
csys,0
wpcsys,-1
set_ry,-8,123,206,'as1'
set_ry,123,155,207,'as1'
```

```
set_ry,155,204,208,'as1'
set_ry,204,279,209,'as1'
set_ry,279,311,210,'as1'
set_ry,311,348,211,'as1'
set_ry,348,382,212,'as1'


!slab bottom
csys,0
wpcsys,-1
set_rx,-57,0,100,'as3'
set_rx,-90,-57,101,'as3'
set_rx,-330,-90,100,'as3'
set_rx,-360,-330,101,'as3'
set_rx,-378,-360,100,'as3'
set_rx,-435,-378,100,'as3'
set_rx,-441,-435,102,'as3'
set_rx,-459,-441,103,'as3'
set_rx,-999,-459,104,'as3'

!slab top
csys,0
wpcsys,-1
set_rx,-57,0,105,'as4'
set_rx,-90,-57,105,'as4'
set_rx,-330,-90,105,'as4'
set_rx,-360,-330,105,'as4'
set_rx,-378,-360,106,'as4'
set_rx,-435,-378,105,'as4'
set_rx,-441,-435,105,'as4'
set_rx,-459,-441,107,'as4'
set_rx,-999,-459,108,'as4'

!dome external
csys,0
wpcsys,-1
set_rx,-392,-336,300,'as2'
set_rx,-336,-321,301,'as2'
set_rx,-321,-311,302,'as2'
set_rx,-311,-288,303,'as2'
set_rx,-288,-275,304,'as2'
set_rx,-275,-239,305,'as2'
set_rx,-239,-0,306,'as2'

!dome internal
csys,0
wpcsys,-1
set_rx,-392,-336,307,'as1'
set_rx,-336,-321,308,'as1'
set_rx,-321,-311,309,'as1'
```

```
set_rx,-311,-288,310,'as1'
set_rx,-288,-275,311,'as1'
set_rx,-275,-239,312,'as1'
set_rx,-239,-0,313,'as1'

!haunch external
csys,0
wpcsys,-1
cmsel,s,as2
asel,r,loc,y,381.5,413.6
set_real,400
cmsel,s,as2
asel,r,loc,y,413.6,460.5
set_real,401
cmsel,s,as2
asel,r,loc,y,460.5,999
asel,r,loc,x,-495.5,-485
set_real,402
cmsel,s,as2
asel,r,loc,y,460.5,999
asel,r,loc,x,-485,-454
set_real,403
cmsel,s,as2
asel,r,loc,y,460.5,999
asel,r,loc,x,-454,-385.5
set_real,404

!haunch_internal
set_ry,381.5,413.6,405,'as1'
set_ry,413.6,493,406,'as1'

lsel,all
ksel,all
asel,s,,,9
ldiv,74,.465
l,299,85
*get,ics,area,9,attr,esys
asbl,9,329
cm,hvert,area
aatt,mat_rebar,,type_rebar,ics

!haunch middle (vertical)
asel,s,,,150
set_real,500
asel,s,,,107
set_real,501

!haunch middle (radial)
asel,s,,,10
set_real,502
```

```
asel,s,,,2
aatt,mat_insul,600,type_insul,0

asel,s,,,33
aatt,mat_haunch,503,type_haunch,ics

allsel
asel,u,mat,,mat_insul
asel,u,mat,,mat_rebar
asel,u,mat,,mat_haunch
aatt,mat_conc,700,type_tank,0
cm,atemp,area
asel,r,loc,y,-999,-8.125
aatt,mat_conc,700,type_slab,0
cmsel,s,atemp
asel,u,type,,type_slab
aatt,mat_conc,700,type_tank,0

asel,s,,,27
l,38,17
asbl,27,446
aatt,mat_conc,700,type_tank,0

allsel
/pnum,mat,1
/numb,1
aplot

/color,pbak,off
save,dstay2,db
```

Attachment 9.04. Listing of ANSYS input macro DSTAY3.MAC

```
resume,dstay2,db
/prep7

!identify jbolt lines
FLST,5,60,4,ORDE,57
FITEM,5,120
FITEM,5,124
FITEM,5,165
FITEM,5,201
FITEM,5,240
FITEM,5,244
FITEM,5,-245
FITEM,5,249
FITEM,5,-250
FITEM,5,254
FITEM,5,-255
FITEM,5,259
FITEM,5,-260
FITEM,5,264
FITEM,5,-265
FITEM,5,269
FITEM,5,-270
FITEM,5,274
FITEM,5,-275
FITEM,5,279
FITEM,5,-280
FITEM,5,284
FITEM,5,-285
FITEM,5,289
FITEM,5,-290
FITEM,5,294
FITEM,5,-295
FITEM,5,298
FITEM,5,-300
FITEM,5,304
FITEM,5,309
FITEM,5,311
FITEM,5,322
FITEM,5,-323
FITEM,5,326
FITEM,5,-327
FITEM,5,334
FITEM,5,-335
FITEM,5,339
FITEM,5,341
FITEM,5,-342
FITEM,5,347
FITEM,5,352
```

```
FITEM,5,355
FITEM,5,359
FITEM,5,-360
FITEM,5,364
FITEM,5,-365
FITEM,5,369
FITEM,5,-370
FITEM,5,373
FITEM,5,-374
FITEM,5,379
FITEM,5,-382
FITEM,5,387
FITEM,5,392
FITEM,5,414
LSEL,S, , ,P51X
lsel,a,,,308
lsel,a,,,317
cm,line_bolt,line

FLST,5,12,4,ORDE,12
FITEM,5,258
FITEM,5,278
FITEM,5,298
FITEM,5,386
FITEM,5,399
FITEM,5,404
FITEM,5,409
FITEM,5,413
FITEM,5,-414
FITEM,5,423
FITEM,5,426
FITEM,5,429
LSEL,S, , ,P51X
cm,line_stiff,line

FLST,5,7,4,ORDE,7
FITEM,5,326
FITEM,5,332
FITEM,5,-333
FITEM,5,339
FITEM,5,439
FITEM,5,445
FITEM,5,450
LSEL,S, , ,P51X
cm,line_anch,line

FLST,5,17,4,ORDE,17
FITEM,5,4
FITEM,5,9
FITEM,5,12
```

```
FITEM,5,14
FITEM,5,345
FITEM,5,-346
FITEM,5,350
FITEM,5,-351
FITEM,5,358
FITEM,5,363
FITEM,5,368
FITEM,5,375
FITEM,5,378
FITEM,5,385
FITEM,5,390
FITEM,5,-391
FITEM,5,395
LSEL,S, , ,P51X
cm,line_prim,line

FLST,5,35,4,ORDE,35
FITEM,5,2
FITEM,5,18
FITEM,5,-19
FITEM,5,21
FITEM,5,53
FITEM,5,183
FITEM,5,199
FITEM,5,243
FITEM,5,248
FITEM,5,253
FITEM,5,263
FITEM,5,268
FITEM,5,273
FITEM,5,281
FITEM,5,283
FITEM,5,288
FITEM,5,293
FITEM,5,303
FITEM,5,310
FITEM,5,315
FITEM,5,331
FITEM,5,338
FITEM,5,398
FITEM,5,400
FITEM,5,403
FITEM,5,405
FITEM,5,408
FITEM,5,410
FITEM,5,-411
FITEM,5,433
FITEM,5,438
FITEM,5,441
```

```
FITEM,5,447
FITEM,5,-448
FITEM,5,451
LSEL,S, , ,P51X
cm,line_secon,line

lsel,s,,,319
lsel,a,,,416
cm,line_botanch,line

allsel

save,dstay3,db
```

Attachment 9.05. Listing of ANSYS input macro DSTAY4.MAC

```
resume,dstay3,db
/prep7

!copy areas for overlapping with soil
cm,a_orig,area
agen,2,all
cmsel,u,a_orig
cm,a_new,area

csys,0
ksel,s,loc,x,0
cm,ktemp,kp
*get,ymx,kp,,mxloc,y
*get,ymn,kp,,mnloc,y
ksel,r,loc,y,ymx
*get,iktop,kp,,num,min
cmsel,s,ktemp
ksel,r,loc,y,ymn
*get,ikbot,kp,,num,min

htop=12  !8.3*12
radsoil=550 !240*12
depthsoil=60  !155*12
csys,0
wpcsys,-1
asel,none
rectng,-radsoil,0,ymn-depthsoil,ymx+htop
cm,as0,area
allsel
asba,as0,a_new
asel,s,,,305
adele,all,,,1
asel,s,,,304
cm,soil,area

aatt,mat_soil,1,type_soil
/input,mesh_size,mac

!the following were added to give better elements in area 10
asel,s,,,10
lsla
lccat,79,80 !note discrete line numbers used!!!!
lccat,76,77 !note discrete line numbers used!!!!
!

!eesize=8
asel,s,type,,type_rebar
esize,eesize
```

```
amesh,all
ldele,449    !delete concatenated line - note line numbers used
ldele,452    !delete concatenated line - note line numbers used


asel,invert
asel,u,type,,type_soil
esize,eesize
amesh,all
asel,s,type,,type_soil
asel,a,mat,,mat_conc
lsla
ksll
nummrg,kp
save,temp0,db

resume,temp0,db
/prep7

asel,s,mat,,mat_soil
esize,soil_size   !120
smrtsize,6
lsel,s,,,899            !vertical line above dome center
lesize,all,,,4
lsel,s,,,900            !vertical line below dome center
lesize,all,,,8
esize,soil_size  !20
amesh,all

extopt,esize,1
type,17
vrotat,all,,,,,,ikbot,iktop,swp_sl,1
save,temp0a,db

asel,s,type,,type_slab
asel,a,type,,type_insul
cm,atemp,area
agen,2,all
cm,aaa,area
cmsel,s,atemp
aclear,all
adele,all,,,1

allsel
aslv,u
*get,na,area,,count
cm,atemp,area
*do,i,1,na
      *get,ia,area,,num,min
      asel,s,,,ia
```

```
      *get,imat,area,ia,attr,mat
      *get,ireal,area,ia,attr,real
      *get,itype,area,ia,attr,type
      *get,isys,area,ia,attr,esys
      mat,imat
      real,ireal
      type,itype+10
      esys,isys
      ksel,all
      vrotat,ia,,,,,,ikbot,iktop,swp_sl,1
      cmsel,s,atemp
      asel,u,,,ia
      cm,atemp,area
*enddo
save,temp3,db

allsel
aclear,all
save,dstay4,db
```

Attachment 9.06. Listing of ANSYS input macro DSTAY5.MAC

```
resume,dstay4,db
/prep7


vsel,s,mat,,1
cm,vtemp,volu
vgen,2,all
cm,vvv,volu
cmsel,s,vtemp
vclear,all
vdele,all,,,1
cmsel,s,vvv
eslv
emodif,all,mat,mat_soil


!rotate all nodes to cylindrical coordinate system (22)
csys,0
wpcsys,-1
wprot,,-90
cswplan,22,1
allsel
nrotate,all

csys,0
!merge slab/rebar nodes/kps
vsel,s,type,,type_rebar+10
vsel,r,loc,y,-999,-11
vsel,a,type,,type_slab+10
vsel,u,mat,,1
eslv
nsle
aslv
lsla
ksll
nummrg,node
nummrg,kp

!merge tank/rebar nodes/kps
vsel,s,type,,type_rebar+10
vsel,r,loc,y,-8,999
vsel,a,type,,type_tank+10
vsel,a,type,,type_haunch+10
vsel,u,mat,,1
aslv
lsla
ksll
nsla,,1
```

```
nummrg,node
nummrg,kp

!couple soil to concrete exterior
esel,s,mat,,mat_soil
nsle
ksln
lslk,,1
asll,,1
cm,asoil,area
vsel,s,type,,type_tank+10
aslv
asel,r,ext
cm,atank,area
vsel,s,type,,type_slab+10
aslv
asel,r,ext
cm,aslab,area
vsel,s,type,,type_insul+10
aslv
cm,ainsul,area

ksel,s,,,11
ksel,a,,,309
ksel,a,,,332
ksel,a,,,1120
nslk
cm,ncoup,node

!top of dome
csys,0
cmsel,s,atank
cmsel,a,asoil
asel,r,loc,y,452,999
lsla
nsla,,1
cmsel,u,ncoup
cpintf,uz,.1

!side of tank
cmsel,s,atank
cmsel,a,asoil
asel,r,loc,y,-8.125,452
lsla
nsla,,1
cpintf,ux,.1

!top of slab
cmsel,s,aslab
cmsel,a,asoil
```

```
asel,r,loc,y,-6.7,-6.6
lsla
nsla,,1
cpintf,uz,.1

!side of slab
cmsel,s,aslab
cmsel,a,asoil
asel,r,loc,y,-31,-6.7
asel,r,loc,x,-999,-529
lsla
nsla,,1
cpintf,ux,.1

!bottom of slab
cmsel,s,aslab
cmsel,a,asoil
asel,r,loc,x,-530,0
asel,r,loc,y,-999,-18.5
lsla
nsla,,1
cpintf,uz,.1

!couple top of slab / bottom of wall
cmsel,s,aslab
cmsel,a,atank
lsla
nsla,,1
cpintf,uz,.1

!couple top of slab / bottom of insulating concrete
vsel,s,mat,,mat_insul
cm,vtemp,volu
vgen,2,all
cm,volu_insul,volu
cmsel,s,vtemp
vclear,all
vdele,all,,,1
cmsel,s,volu_insul
aslv
cm,ainsul,area
cmsel,s,aslab
cmsel,a,ainsul
lsla
nsla,,1
cpintf,uz,.1

save,dstay5,db
```

Attachment 9.07. Listing of ANSYS input macro DSTAY6.MAC

```
resume,dstay5,db
/prep7

!generate j-bolts
type_bolt=20
et,type_bolt,4
area_bolt=3.14159*.5**2/4
iy=3.14159*.5••4/64
iz=iy
ty=.5
tz=.5
r,20,area_bolt,iy,iz,ty,tz
real,20
mat,mat_liner
type,type_bolt
csys,0
cmsel,s,line_bolt
lsel,u,loc,y,381.5+24,381.5+24+72
lmesh,all

!generate studs
type_stud=21
et,type_stud,4
area_stud=3.14159*.5**2/4
iy=3.14159*.5**4/64
iz=iy
ty=.5
tz=.5
r,30,area_stud,iy,iz,ty,tz
cmsel,s,line_botanch
real,30
mat,mat_liner
type,type_stud
lmesh,all

!generate wall base plate
asel,s,,,225
asel,a,,,763
asel,a,,,971
asel,a,,,976
asel,a,,,992
cm,baseplate,area
type_baseplate=22
et,type_baseplate,181,,,2
r,40,.375
mat,mat_liner
type,type_baseplate
real,40
```

```
amesh,all

!generate confining ring below 12" secondary liner fillet
ksel,s,loc,x,-480-.01,-480+.01
ksel,r,loc,y,-8.2,6.9
lslk,,1
asll
asel,u,loc,z,0
cm,confineplate,area
type_confine=23
et,type_confine,181,,,2
r,41,3/16
type,type_confine
real,41
mat,mat_liner
amesh,all

!generate confining ring for insulating concrete
csys,0
ksel,s,loc,x,-448,-447 !modified for new ins concrete outer radius
ksel,r,loc,y,-8.125,0
lslk,,1
asll
asel,u,loc,z,0
cm,confinering,area
type_confine=23
type,type_confine
real,41
mat,mat_liner
amesh,all

!generate construction stiffeners
cmsel,s,line_stiff
asll
asel,u,loc,z,0
cm,stiff_area,area
type_stiff=24
et,type_stiff,181,,,2
type,type_stiff
r,42,.5
real,42
mat,mat_line
amesh,all

!generate anchors a-2, a-3, and detail #9 (use #9 to represent
!both the 6x4x3/8 anchor and anchor a-1; increase thickness by 10%)
lsel,s,,,326
lsel,a,,,339
lsel,a,,,445
asll
```

```
asel,u,loc,z,0
cm,detail9,area
type_anchor=25
et,type_anchor,181,,,2
type,type_anchor
r,43,.375*1.1
real,43
mat,mat_liner
amesh,all

lsel,s,,,332
lsel,a,,,333
lsel,a,,,439
lsel,a,,,450
asll
asel,u,loc,z,0
cm,anchors2and3,area
type_a23=26
et,type_a23,181,,,2
type,type_a23
r,44,.25
real,44
mat,mat_liner
amesh,all

allsel
save,dstay6,db
```

Attachment 9.08. Listing of ANSYS input macro DSTAY7.MAC

```
resume,dstay6,db
/prep7

!primary liner
allsel
aslv
lsla
cmsel,s,line_prim
lsel,a,,,458
cm,ltemp,line

asll
asel,u,loc,z,0
ksll
nummrg,kp
cm,line_prim,line
cm,area_prim,area
asel,none
ksel,s,loc,x,0
ksel,r,loc,y,ymx
*get,iktop,kp,,num,min
ksel,s,loc,x,0
ksel,r,loc,y,ymn
*get,ikbot,kp,,num,min
ksel,all
cmsel,s,ltemp
cmsel,s,area_prim
lsla,u
arotat,all,,,,,,ikbot,iktop,swp_sl,1
lsla
ksll
nummrg,kp
aatt,mat_liner,,type_liner
esize,4

lsel,s,,,9        !radiused part of primarly liner
lsel,a,,,460
lesize,all,,,8,,1

lsel,s,,,464,465
lesize,all,,,1,,1
amesh,all

cm,atemp,area
agen,2,all
cm,area_liner_prim,area
cmsel,s,atemp
aclear,all
```

```
vsel,all
aslv,u
adele,all,,,1

*dim,yt,,10
yt(1)=1,3/8,7/8,3/4,1/2,3/8,1/2
/input,set_parms,mac
r,50,r50
r,51,r51
r,52,r52
r,53,r53
r,54,r54
r,55,r55

!1" lid at tank bottom
cmsel,s,area_liner_prim
esla
cm,etemp,elem
nsla,,1
cm,ntemp,node
nsel,r,loc,x,-24,0
nsel,r,loc,y,-999,10
esln
cmsel,r,etemp
emodif,all,real,50

!3/8" bottom (on top of insulating concrete)
cmsel,s,ntemp
nsel,r,loc,x,-450+48,-24
nsel,r,loc,y,-999,10
esln
cmsel,r,etemp
emodif,all,real,51

!7/8" at fillet
cmsel,s,ntemp
nsel,r,loc,x,-450,-450+48
nsel,r,loc,y,-999,36.89
esln
cmsel,r,etemp
emodif,all,real,52

!3/4" vertical run
cmsel,s,ntemp
nsel,r,loc,x,-450
nsel,r,loc,y,36.88,144.89
esln
cmsel,r,etemp
emodif,all,real,53
```

```
!1/2" vertical run
cmsel,s,ntemp
nsel,r,loc,x,-450
nsel,r,loc,y,144.88,381.5
esln
cmsel,r,etemp
emodif,all,real,54

!3/8" upper reaches of liner
cmsel,s,ntemp
nsel,r,loc,x,-450,-72.1
nsel,r,loc,y,381.6,999
esln
cmsel,r,etemp
emodif,all,real,51

!1/2" at top/center
cmsel,s,ntemp
nsel,r,loc,x,-72,0
nsel,r,loc,y,381.6,999
esln
cmsel,r,etemp
emodif,all,real,54

!couple vertical displacements at liner bottom
!(first rotate the shell nodes)
esel,s,type,,type_liner
nsle
csys,22
nrotate,all
csys,0
asel,s,loc,y,0
nsla,,1
cpintf,uz,.1
cm,liner_insul_cp_z,node

allsel
save,dstay7,db
```

Attachment 9.09. Listing of ANSYS input macro DSTAY8.MAC

```
resume,dstay7,db
/prep7

!create shell elements for secondary liner
cmsel,s,line_secon
asll
asel,u,loc,z,0
cm,atemp,area
lsel,s,,,21
lsel,a,,,19
asel,none
arotat,all,,,,,,ikbot,iktop,swp_sl,1
cmsel,a,atemp
asel,a,,,155,156
cm,area_secon,area
lsla
ksll
nummrg,kp

lesize,460,,,1,,1
lesize,9,,,6,,1
lesize,19,,,6,,1
aatt,mat_liner,55,type_liner
amesh,all

cm,atemp,area
agen,2,all
cm,area_secon,area
cmsel,s,atemp
aclear,all
aslv,u
adele,all,,,1

ksel,s,loc,x,0
ksel,r,loc,y,ymx
*get,iktop,kp,,num,min
ksel,s,loc,x,0
ksel,r,loc,y,ymn
*get,ikbot,kp,,num,min
ksel,all

!couple vertical displacements at liner bottom
!(first rotate the shell nodes)
esel,s,type,,type_liner
nsle
csys,22
nrotate,all
```

```
csys,0

!couple shell horizontal displacements to sidewall

esel,s,type,,type_liner
nsle
cm,ntemp,node
esel,s,mat,,mat_conc
nsle
cmsel,a,ntemp
cm,ntemp,node
nsel,r,loc,y,-2,460
cmsel,u,ncoup
cpintf,ux,.1
cm,liner_wall_cp_x,node

!couple shell vertical displacement to dome
cmsel,s,ntemp
nsel,r,loc,y,460,999
cpintf,uz,.1
cm,liner_dome_cp_z,node

!merge secondary liner nodes with slab top nodes
cmsel,s,area_secon
csys,0
asel,r,loc,y,-8.125
asel,a,,,1073,1074      !slab top
asel,a,,,155,156        !insulation bottom
lsla
nsll,,1
cpdele,all,all
cpintf,uz,.1


allsel
save,dstay8,db
```

Attachment 9.10. Listing of ANSYS input macro DSTAY9.MAC

```
finish
resume,dstay8,db
/prep7

allsel
mpdele,all,all
tbdele,all,all
set_materials
set_options

acel,0,386,0
!set_rebar

allsel

!merge coincident nodes between liners and jbolts/studs/anchors
esel,s,type,,type_bolt
esel,a,type,,type_stiff
esel,a,type,,type_anchor
esel,a,type,,type_a23
esel,a,type,,type_stud
esel,a,type,,type_liner
esel,a,type,,59
nsle,,1
nummrg,node

set_soil
!note that soil elements are later cleared
!  and redefined in set_slice.mac
!set_loads

allsel
ddele,all,all

*get,xmn,node,,mnloc,x
*get,ymn,node,,mnloc,y
*get,ymx,node,,mxloc,y

csys,22
allsel

save,dstay9,db
```

Attachment 9.11. Listing of ANSYS input macro APPLY_LOADS_SLICE.MAC

```
/prep7
allsel
sfdele,all,all
sfedele,all,all,all
sfgrad,pres
fdele,all,all
esel,s,type,,59
edele,all

!reverse area normal (radiused section of secondary liner)
!asel,s,,,280
!arev,all

!/input,define_loads,mac
/input,mesh_size,mac

!40 psf pressure on ground surface
csys,0
*get,ymx,kp,,mxloc,y
asel,s,loc,y,ymx
lsla
nsla,,1
esel,all
sf,all,pres,pres_surf/144

!200K point load at center
csys,22
nsel,r,loc,x,0,point_rad
sf,all,pres,point_cent/(pi*point_rad**2)+pres_surf/144

!liner pressure loads
p_annulus=pres_annulus/12*62.4/144
p_internal=pres_int/12*62.4/144

!waste depth and unit weight
hw1=height_waste1
gammaw1=gamma_waste1
hw2=height_waste2
gammaw2=gamma_waste2
hw3=height_waste3
gammaw3=gamma_waste3

*if,abs(gammaw1),lt,1e-3,then
      gammaw1=1e-6
*else
      gammaw1=gammaw1*62.4/1728
*endif
*if,abs(gammaw2),lt,1e-3,then
```

```
      gammaw2=1e-6
*else
      gammaw2=gammaw2*62.4/1728
*endif
*if,abs(gammaw3),lt,1e-3,then
      gammaw3=1e-6
*else
      gammaw3=gammaw3*62.4/1728
*endif

zz4=0
zz3=hw1
zz2=zz3+hw2
zz1=zz2+hw3
zz0=460
pp0=p_internal
pp1=p_internal-p_annulus
pp2=pp1+hw3*gammaw3
pp3=pp2+hw2*gammaw2
pp4=pp3+hw1*gammaw1

/pbc,all,0
/psf,pres,,2
/psym,esys,0
allsel

!primary liner
esel,s,real,,50,54
nsle
cm,nliner,node

!top reaches of dome
allsel
csys,0
cmsel,s,nliner
nsel,r,loc,y,zz0,9999
sfgrad,pres
sf,all,pres,pp0

!space between top of fluid and prim/secon liner intersection
cmsel,s,nliner
nsel,r,loc,y,zz1,zz0
sf,all,pres,pp1

!waste region 3
cmsel,s,nliner
nsel,r,loc,y,zz2,zz1
esln
esel,r,type,,1
nsle,,1
```

```
sfgrad,pres,0,y,zz1,(pp1-pp2)/hw3
sf,all,pres,pp1

!waste region 2
cmsel,s,nliner
nsel,r,loc,y,zz3,zz2
esln
esel,r,type,,1
nsle,,1
sfgrad,pres,0,y,zz2,(pp2-pp3)/hw2
sf,all,pres,pp2

!waste region 1
cmsel,s,nliner
nsel,r,loc,y,zz4,zz3
esln
esel,r,type,,1
nsle,,1
sfgrad,pres,0,y,zz3,(pp3-pp4)/hw1
sf,all,pres,pp3

!annulus
esel,s,type,,1
nsle,,1
cmsel,u,nliner
nsel,u,loc,y,-9999,-8.124
esln
esel,r,type,,1
nsle,,1
cm,nsecon,node
esln
esel,r,type,,1
sfgrad,pres
sf,all,pres,p_annulus

cmsel,s,nliner
cmsel,a,nsecon
esln
/psf,pres,,2
nplot
```

Attachment 9.12. Listing of ANSYS input macro MESH_SIZE.MAC

```
eesize=4            !default element size for rebar [in]
soil_size=20        !default element size for soil elements [in]
swp_th=2.862        !single element sweep angle [deg]
swp_sl=2.862        !slice model sweep angle [deg]
num_div=1           !number of divisions per quadrant
```

Attachment 9.13. Listing of ANSYS input macro SET_AREAS_SLICE.MAC

```
asel,s,,,163,171
asel,a,,,192
asel,a,,,194
asel,a,,,197
asel,a,,,203
asel,a,,,206
asel,a,,,237
asel,a,,,251
asel,a,,,268
cm,area_prim,area

asel,s,,,162
asel,a,,,278
asel,a,,,280
asel,a,,,283
asel,a,,,294,296
asel,a,,,304
asel,a,,,315
asel,a,,,342
asel,a,,,354,355
asel,a,,,361
asel,a,,,363
asel,a,,,366,367
asel,a,,,372,375
asel,a,,,378,383
asel,a,,,404
asel,a,,,410
asel,a,,,416
asel,a,,,421
asel,a,,,426
asel,a,,,436
asel,a,,,440
asel,a,,,446
asel,a,,,448
asel,a,,,452
asel,a,,,772
cm,area_secon,area

cmsel,a,area_prim
cmsel,a,area_secon
nsla,,1
esln
sfdele,all,all
sfedele,all,all,all

asel,s,,,280
nsla,,1
esln
```

```
arev,all

asel,s,,,491,492
asel,a,,,499,500
asel,a,,,510,512
asel,a,,,519
asel,a,,,521,522
asel,a,,,524,525
asel,a,,,529
cm,asoil,area

asel,s,,,208
asel,a,,,234
asel,a,,,279
asel,a,,,331,332
asel,a,,,1038
asel,a,,,1057,1063
cm,aconc_soil,area

asel,s,,,1073,1074
cm,slab_top,area

asel,s,,,254
asel,a,,,283
asel,a,,,514
asel,a,,,611
asel,a,,,622
asel,a,,,642
asel,a,,,652
asel,a,,,663
asel,a,,,669
asel,a,,,685
asel,a,,,696
asel,a,,,706,726,10
asel,a,,,741
asel,a,,,752
asel,a,,,759
asel,a,,,772
asel,a,,,776
asel,a,,,779
asel,a,,,786
asel,a,,,789
asel,a,,,800,810,5
asel,a,,,821,831,10
asel,a,,,846,866,10
asel,a,,,878
asel,a,,,882
asel,a,,,889
asel,a,,,904
asel,a,,,915
```

```
asel,a,,,925,955,5
asel,a,,,986,987
asel,a,,,1014
cm,aconc_shell,area

asel,s,,,27
asel,a,,,153
asel,a,,,157
cm,area_insul_top,area

asel,s,,,155,156
cm,area_insul_bot,area
```

Attachment 9.14. Listing of ANSYS input macro SET_BACKFILL.MAC

```
csys,22
cmsel,s,soil_elem
nsle,,1
nsel,r,loc,x,0,498
nsel,r,loc,z,452,999
esln

emodif,all,mat,5
soil_ex=backfill_e                  !elastic modulus [psi]
soil_prxy=backfill_pr               !Poisson ratio
soil_alpx=backfill_cte              !thermal expansion coefficient [me/F]
soil_gamma=backfill_gamma           !unit weight [lbf/ft^3]
soil_kx=backfill_kx                 !thermal conductivity [BTU/hr/ft/F]
soil_c=backfill_c                   !specific heat [BTU/R/(lbf-sec^2/in)]
soil_cohesion=0                     !drucker-prager constant (assume small number) [psi]
soil_friction=backfill_phi          !internal friction angle [deg]
soil_dilat=backfill_dil             !dilatancy angle [deg]

soil_alpx=soil_alpx*1e-6            !in/in/F
soil_dens=soil_gamma/1728/386       !lb-sec^2/in^4
soil_kx=soil_kx/3600/12             !BTU/sec-in-degreeF

mp,ex,5,soil_ex
mp,dens,5,soil_dens
mp,prxy,5,soil_prxy
mp,alpx,5,soil_alpx
mp,kxx,5,soil_kx
mp,c,5,soil_c
tb,dp,5
tbdata,1,soil_cohesion,soil_friction,soil_dilat
```

Attachment 9.15. Listing of ANSYS input macro SET_ESYS_3D.MAC

```
/prep7
!define reinforced concrete real constants

!---Create local coordinate systems for esys
!--spherical 1
wpcsys,-1,0       !spherical
kwpave,1
wpoff,,-1260
cswpla,200,2

wpcsys,-1,0       !spherical
kwpave,1
wpoff,,-892
cswpla,201,2

csys,0                  !ellipcal coordinate
wpcsys,-1
rat=40/15
k,10000,0,h3,0
kwpave,10000
wprot,90
cswplan,202,2,rat,rat


esel,s,real,,100,108  !slab
esel,r,type,,15
emodif,all,esys,22

esel,s,real,,200,213    !vertical wall
esel,r,type,,15
emodif,all,esys,22

esel,s,real,,300,306    !inner exterior dome
esel,r,type,,15
nsle
csys,22
nsel,r,loc,x,0,170
esln
esel,r,type,,15
emodif,all,esys,200

esel,s,real,,300,306    !outer exterior dome
esel,r,type,,15
nsle
csys,22
nsel,r,loc,x,170,9999
esln
esel,r,type,,15
```

```
emodif,all,esys,201

esel,s,real,,307,313     !interior dome
esel,r,type,,15
emodif,all,esys,202


esel,s,real,,401,402     !vertical haunch
esel,r,type,,15
emodif,all,esys,22

esel,s,real,,403,404     !exterior haunch
esel,r,type,,15
emodif,all,esys,201

esel,s,real,,405,406     !interior haunch
esel,r,type,,15
emodif,all,esys,202

esel,s,real,,500,501     !vertical mid haunch
esel,r,type,,15
emodif,all,esys,22

esel,s,real,,502  !spherical mid haunch
esel,r,type,,15
emodif,all,esys,201

esel,s,real,,503  !tie bar haunch
emodif,all,esys,191



mat_null=0

mat_srebar=6       !slab rebar

!slab bottom
vrx=
vrz=
rc=
*dim,vrx,,20
*dim,vry,,20
*dim,vrz,,20
*dim,rc,,20
vrx(1)=.0320,.0320,.0320,.0320,.0320,.0320,.0320,.1060,.0980
vry(1)=.0256,.0256,.0256,.0256,.0256,.0256,.0256,.0552,.0552
rc(1)=100,101,100,101,100,100,102,103,104
*do,i,1,9
      r,rc(i),mat_srebar,vrx(i),0,0,mat_srebar,vry(i)
      rmore,90,0,mat_null,0,90,90
```

```
*enddo

!slab top
vrx(1)=.0320,.0320,.0320,.0320,.0320,.0320,.0320,.0256,.0256
vry(1)=.0256,.0256,.0256,.0256,.0256,.0256,.0256,.0552,.0552
rc(1)=105,105,105,105,106,105,105,107,108
*do,i,1,9
      r,rc(i),mat_srebar,vrx(i),0,0,mat_srebar,vry(i)
      rmore,90,0,mat_null,0,90,90
*enddo

!wall external
vrz(1)=.0368,.0430,.0491,.0491,.0573,.0654,.1677
vry(1)=.0982,.0982,.0982,.0654,.0654,.0654,.0654
rc(1)=200,201,202,203,213,204,205
*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

!wall internal
vrz(1)=.0368,.0430,.0491,.0491,.0573,.0654,.0982
vry(1)=.0982,.0982,.0982,.0654,.0654,.0654,.0654
rc(1)=206,207,208,209,210,211,212
*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

!dome external
vry(1)=.1309,.1340,.1360,.0570,.0520,.0580,.0440
vrz(1)=.2498,.1666,.1666,.1309,.1309,.0368,.0368
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

!dome internal
vry(1)=.1309,.1340,.1360,.0570,.0520,.0580,.0440
vrz(1)=.2498,.1666,.1666,.1309,.1309,.0368,.0368
rc(1)=307,308,309,310,311,312,313
*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 external-vertical
vrz(1)=.2700,.2700
vry(1)=.1309,.2498
```

```
rc(1)=400,401
*do,i,1,2
      r,rc(i),mat_null,0,0,0,mat_rebar,vry(i)
      rmore,90,0,mat_rebar,vrz(i),90,90
*enddo

!haunch external-exterior
vry(1)=.1963,.1309,.1309
vrz(1)=.1666,.1666,.2221
rc(1)=402,403,404
*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 internal
vry(1)=.1309,.1309,.1309,.1309,.1309
vrz(1)=.1309,.2221,.2221,.2221,.2221
rc(1)=405,406,406,406,406
*do,i,1,5
      r,rc(i),mat_null,0,0,0,mat_rebar,vry(i)
      rmore,90,0,mat_rebar,vrz(i),90,90
*enddo

!haunch middle
r,500,mat_rebar,.0006,0,0,mat_rebar,.1249,
rmore,90,0,mat_rebar,.0245,90,90

r,501,mat_rebar,.0006,0,0,mat_rebar,.1249,
rmore,90,0,mat_rebar,.0109,90,90

r,502,mat_rebar,.0006,0,0,mat_rebar,.0245
rmore,90,0,mat_rebar,.2221,90,90

!haunch core (ties only)
r,503,mat_rebar,.0006,0,0,mat_null,0
rmore,90,0,mat_null,0,90,90


!secondary liner above 357.5"
r,56,r56
esel,s,real,,55
nsle,,1
csys,0
nsel,r,loc,y,357.5,99999
esln,,1
esel,r,type,,1
emodif,all,real,56
```

Attachment 9.16. Listing of ANSYS input macro SET_MATERIALS.MAC

```
!specify all material properties
/prep7

![1]         steel (for liner, jbolts, studs, anchors, bearing plates)
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

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
tb,biso,mat_liner
tbdata,1,steel_yield,steel_tang*steel_ex

![2]              structural concrete
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

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

tb,concr,mat_conc
tbdata,1,conc_open,conc_closed,conc_crack,conc_crush

![3]              rebar
rebar_alpx=rebar_alpx*1e-6          !in/in/F
rebar_dens=rebar_gamma/1728/386     !lb-sec^2/in^4
rebar_kx=rebar_kx/3600/12           !BTU/sec-in-degreeF

mp,ex,mat_rebar,rebar_ex
mp,dens,mat_rebar,rebar_dens
mp,prxy,mat_rebar,rebar_prxy
mp,alpx,mat_rebar,rebar_alpx
mp,kxx,mat_rebar,rebar_kx
mp,c,mat_rebar,rebar_c

tb,biso,mat_rebar
tbdata,1,rebar_yield,rebar_tang*rebar_ex

![4]              insulating concrete
```

```
insul_alpx=insul_alpx*1e-6          !in/in/F
insul_dens=insul_gamma/1728/386     !lb-sec^2/in^4
insul_kx=insul_kx/3600/12           !BTU/sec-in-degreeF

mp,ex,mat_insul,insul_ex
mp,dens,mat_insul,insul_dens
mp,prxy,mat_insul,insul_prxy
mp,alpx,mat_insul,insul_alpx
mp,kxx,mat_insul,insul_kx
mp,c,mat_insul,insul_c

tb,concr,mat_insul
tbdata,1,insul_open,insul_closed,insul_crack,insul_crush


![5]              soil
! These soil properties for material 5 are overwritten later
!soil_ex=575000   !elastic modulus [psi]
!soil_prxy=0.1    !Poisson ratio
!soil_alpx=0            !thermal expansion coefficient [me/F]
!soil_gamma=125   !unit weight [lbf/ft^3]
!soil_kx=1        !thermal conductivity [BTU/hr/ft/F]
!soil_c=1         !specific heat [BTU/R/(lbf-sec^2/in)]
!soil_cohesion=0  !drucker-prager constant (assume small number) [psi]
!soil_friction=35.4!internal friction angle [deg]
!soil_dilat=35.4  !dilatancy angle [deg]

!soil_alpx=soil_alpx*1e-6     !in/in/F
!soil_dens=soil_gamma/1728/386      !lb-sec^2/in^4
!soil_kx=soil_kx/3600/12            !BTU/sec-in-degreeF

!mp,ex,mat_soil,soil_ex
!mp,dens,mat_soil,soil_dens
!mp,prxy,mat_soil,soil_prxy
!mp,alpx,mat_soil,soil_alpx
!mp,kxx,mat_soil,soil_kx
!mp,c,mat_soil,soil_c
!tb,dp,mat_soil
!tbdata,1,soil_cohesion,soil_friction,soil_dilat


!set mat_haunch materials equal to mat_conc material
vsel,s,mat,,mat_haunch
eslv
emodif,all,mat,mat_conc
mpdele,all,mat_haunch

!set slab rebar material properties
vsel,s,mat,,mat_rebar
eslv
```

```
nsle
nsel,r,loc,y,-999,-8.125
esln,,1
esel,r,mat,,mat_rebar
mat_srebar=6
emodif,all,mat,mat_srebar

![6]              slab rebar
srebar_alpx=srebar_alpx*1e-6        !in/in/F
srebar_dens=srebar_gamma/1728/386   !lb-sec^2/in^4
srebar_kx=srebar_kx/3600/12         !BTU/sec-in-degreeF

mp,ex,mat_srebar,srebar_ex
mp,dens,mat_srebar,srebar_dens
mp,prxy,mat_srebar,srebar_prxy
mp,alpx,mat_srebar,srebar_alpx
mp,kxx,mat_srebar,srebar_kx
mp,c,mat_srebar,srebar_c
tb,biso,smat_srebar
tbdata,1,srebar_yield,srebar_tang*srebar_ex

allsel
esel,s,mat,,3
esel,a,mat,,6
emodif,all,mat,2
allsel

!modify liner thicknesses for corrosion reduction
r50=1-corrosion   !shell thickness (in) (R1 of Figure 11 in RPP-13990)
r51=3/8-corrosion !shell thickness (in) (R2,R6,R7,R9 of Figure 11 in RPP-13990)
r52=7/8-corrosion !shell thickness (in) (R3 of Figure 11 in RPP-13990)
r53=3/4-corrosion !shell thickness (in) (R4 of Figure 11 in RPP-13990)
r54=1/2-corrosion !shell thickness (in) (R5,R8 of Figure 11 in RPP-13990)
r55=1/4-corrosion !shell thickness (in) (R10 of Figure 11 in RPP-13990)
r56=3/8-corrosion !shell thickness (in) of secondary liner above 357.5 in
```

Attachment 9.17. Listing of ANSYS input macro SET_OPTIONS.MAC

```
/prep7

!remove structural concrete CONCR material model
  *if,conc_crack,eq,-1,and,conc_crush,eq,-1,then
    tbdele,concr,mat_conc
  *endif

!remove concrete CREEP material model
  *if,creep_ID,eq,0,then
    tbdele,creep,mat_conc
  *endif

!remove insulating concrete CONCR material model
  *if,insul_crack,eq,-1,and,insul_crush,eq,-1,then
    tbdele,concr,mat_insul
  *endif

!remove insulating concrete CREEP material model
  *if,creep_ID_ins,eq,0,then
    tbdele,creep,mat_insul
  *endif

!remove liner BISO material model
tbdele,BISO,mat_liner

!remove rebar BISO material model
tbdele,BISO,mat_rebar

!remove soil DP material model
!!!!!!!!!!tbdele,DP,mat_soil
```

Attachment 9.18. Listing of ANSYS input macro SET_PARMS.MAC

```
! Material properties:

![1]          steel (for liner, jbolts, studs, anchors, bearing plates)
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_yield=36000 !yield strength [psi]
steel_tan=2       !rebar tangent modulus [% of elastic modulus]

![2]              structural concrete
conc_ex=3.8e6     !elastic modulus [psi]
conc_prxy=0.15    !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_open=0.1     !shear transfer coefficient for open crack
conc_closed=0.98  !shear transfer coefficient for closed crack
conc_crush=-1     !uniaxial crushing stress [psi] (-1 turns off
feature)
conc_crack=-1     !tensile cracking stress [psi](-1 turns off feature)

tb,creep,mat_conc  !creep coefficients per Table 11 of RPP-13990
tbdata,1,.2545e-6,1,-.838,320,,1

![3]              rebar
rebar_ex=27.7e6   !elastic modulus [psi]
rebar_prxy=0.3    !Poisson ratio
rebar_alpx=6.38   !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]

![4]              insulating concrete
insul_ex=0.2e6    !elastic modulus [psi]
insul_prxy=0.15   !Poisson ratio
insul_alpx=6.38   !thermal expansion coefficient [me/F]
insul_gamma=30    !unit weight [lbf/ft^3]
insul_kx=1        !thermal conductivity [BTU/hr/ft/F]
insul_c=1         !specific heat [BTU/R/(lbf-sec^2/in)]

insul_open=0.1    !shear transfer coefficient for open crack
```

```
insul_closed=0.98 !shear transfer coefficient for closed crack
insul_crush=-1    !uniaxial crushing stress [psi](-1 turns off feature)
insul_crack=-1    !tensile cracking stress [psi] (-1 turns off feature)

tb,creep,mat_insul  !creep coefficients per Table 11 of RPP-13990
tbdata,1,.2545e-6,1,-.838,320,,1

![6]              slab rebar
srebar_ex=27.7e6  !elastic modulus [psi]
srebar_prxy=0.3   !Poisson ratio
srebar_alpx=6.38  !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]


! These were originally defined in define_loads.mac:
! [5]              backfill soil
backfill_gamma=125              !unit weight of backfill above dome pcf
backfill_pr=0.27                !backfill Poisson ratio
backfill_e=7000                 !backfill elastic modulus psi (per RPP-14249)
backfill_kx=1                   !thermal conductivity BTU/hr/ft/F
backfill_c=1                    !specific heat BTU/R/(lbf-sec^2/in)
backfill_phi=35.4               !soil friction angle deg
backfill_dil=35.4               !backfill dilatancy angle deg
backfill_cte=0                  !thermal expansion coef me/f


! Loads
pres_surf=40                    !ground surface uniform pressure psf
point_cent=200000               !point load at center lb
point_rad=120             !radius over which point load is applied inches
pres_annulus=1                  !annulus pressure inches h2o
pres_int=-6                     !annulus internal pressure inches h2o
height_waste1=(381.5-18)*1/3    !height of waste 1 inches
gamma_waste1=1.7                !specific gravity of waste 1
height_waste2=(381.5-18)*1/3    !height of waste 2 inches
gamma_waste2=1.7                !specific gravity of waste 2
height_waste3=(381.5-18)*1/3    !height of waste 3 inches
gamma_waste3=1.7                !specific gravity of waste 3


! These were originally defined in set_slice.mac
!Only 3 layers (not 18 as used here) are now used.
!However, these are still needed to build the model
!define soil layers
*dim,soil_emod,,20
*dim,soil_pr,,20
*dim,soil_gam,,20
```

```
*dim,soil_z0,,20
*dim,soil_z1,,20
soil_z0(1)=60,144,240,336,432,510,588,672,756,879    !vertical distance from surface
soil_z0(11)=1001,1124,1247,1369,1492,1615,1737,1860  !vertical distance from surface
soil_z1(1)=0,60,144,240,336,432,510,588,672,756      !vertical distance from surface
soil_z1(11)=879,1001,1124,1247,1369,1492,1615,1737   !vertical distance from surface

e_surf=7000   !psi - E of soil (excluding backfill) above haunch region
e_tank=13000  !psi - E of soil alongside tank
e_below=20000 !psi - E of soil below tank
soil_emod(1)=e_surf,e_surf,e_surf,e_tank,e_tank,e_tank,e_tank,e_tank,e_below,e_below
soil_emod(11)=e_below,e_below,e_below,e_below,e_below,e_below,e_below,e_below

s_pr=0.27     !poisson's ratio of soil layers (excluding backfill)
soil_pr(1)=s_pr,s_pr,s_pr,s_pr,s_pr,s_pr,s_pr,s_pr,s_pr,s_pr
soil_pr(11)=s_pr,s_pr,s_pr,s_pr,s_pr,s_pr,s_pr,s_pr

s_gam=125   !lbf/ft^3 density of soil layers (excluding backfill)
soil_gam(1)=s_gam,s_gam,s_gam,s_gam,s_gam,s_gam,s_gam,s_gam,s_gam,s_gam
soil_gam(11)=s_gam,s_gam,s_gam,s_gam,s_gam,s_gam,s_gam,s_gam

! Nonlinear material options
creep_ID=0        !turn off/on (0/1) creep in structural concrete
creep_ID_ins=0    !turn off/on (0/1) creep in insulating concrete

!Liner thicknesses (corrosion reduction is later subtracted from these reals)
corrosion=0  !corrosion reduction as a positive number (in)
r50=1    !shell thickness (in) (R1 of Figure 11 in RPP-13990)
r51=3/8  !shell thickness (in) (R2,R6,R7,R9 of Figure 11 in RPP-13990)
r52=7/8  !shell thickness (in) (R3 of Figure 11 in RPP-13990)
r53=3/4  !shell thickness (in) (R4 of Figure 11 in RPP-13990)
r54=1/2  !shell thickness (in) (R5,R8 of Figure 11 in RPP-13990)
r55=1/4  !shell thickness (in) (R10 of Figure 11 in RPP-13990)
r56=3/8  !shell thickness (in) of secondary liner above 357.5 in
```

Attachment 9.19. Listing of ANSYS input macro SET_SLAYER.MAC

```
max_mat=max_mat+1

/prep7

cmsel,s,soil_elem
nsle,,1

csys,0
nsel,r,loc,y,top_elev-arg1,top_elev-arg2
esln,
esel,r,mat,,5
emodif,all,mat,max_mat
emodif,all,real,7


soil_ex=arg3       !elastic modulus [psi]
soil_prxy=arg4     !Poisson ratio
soil_alpx=0        !thermal expansion coefficient [me/F]
soil_gamma=arg5    !unit weight [lbf/ft^3]
soil_kx=1          !thermal conductivity [BTU/hr/ft/F]
soil_c=1           !specific heat [BTU/R/(lbf-sec^2/in)]
soil_cohesion=0    !drucker-prager constant (assume small number) [psi]
soil_friction=arg6!internal friction angle [deg]
soil_dilat=arg6    !dilatancy angle [deg]

soil_alpx=soil_alpx*1e-6       !in/in/F
soil_dens=soil_gamma/1728/386 !lb-sec^2/in^4
soil_kx=soil_kx/3600/12        !BTU/sec-in-degreeF

mp,ex,max_mat,soil_ex
mp,dens,max_mat,soil_dens
mp,prxy,max_mat,soil_prxy
mp,alpx,max_mat,soil_alpx
mp,kxx,max_mat,soil_kx
mp,c,max_mat,soil_c
tb,dp,max_mat
tbdata,1,soil_cohesion,soil_friction,soil_dilat
```

Attachment 9.20. Listing of ANSYS input macro SET_SOIL.MAC

```
!resume,run_dstay_1,db
/prep7

csys,0
vsel,s,mat,,1
aslv
asel,u,loc,z,0
cm,aold,area
aslv
asel,r,loc,z,0
cm,anew,area
eslv
nsle
cpdele,all,all
vclear,all
vdele,all
cmsel,s,aold
adele,all,,,1
cmsel,s,anew
lsla
lesize,all,,,-1,,1
esize,16

adrag,2163,,,,,,2166
aovlap,all
cm,asoil,area
asel,s,,,160
adele,all,,,1
cmsel,s,asoil
lcomb,12,2160
aatt,mat_soil,,type_soil
amesh,all

!/input,define_soil_layers,mac

!overburden=8.25*12
!totaldepth=155*12
!totalwidth=240*12

allsel
*get,km,kp,,num,max
dy=overburden-12

k,km+1,kx(1208)-dy,ky(1206)+dy
k,km+2,kx(1173)-dy,ky(1173)-dy
k,km+3,0,ky(km+2)
k,km+4,kx(km+2),ky(km+1)-totaldepth
k,km+5,0,ky(km+4)
```

```
k,km+6,0,ky(km+1)
k,km+7,-totalwidth,ky(km+1)
k,km+8,kx(km+7),ky(km+2)
k,km+9,kx(km+8),ky(km+4)
asel,none
a,1208,1206,km+6,km+1
a,km+1,km+2,1173,1208
a,km+2,km+3,1175,1173
a,km+2,km+4,km+5,km+3
a,km+1,km+7,km+8,km+2
a,km+2,km+8,km+9,km+4
lsla
lsel,r,loc,x,kx(km+7)+1,kx(km+1)-1
lesize,all,,,20,1/10
lsel,r,loc,y,ky(km+1)
lesize,all,,,20,10,1
lsla
lsel,r,loc,y,ky(km+9)+1,ky(km+8)-1
lesize,all,,,10,10
lsel,r,loc,x,0
lesize,all,,,10,.1,1
aatt,mat_soil,,type_soil
mshkey,1
amesh,all

asel,s,mat,,mat_soil
type,type_soil+10
mat,mat_soil
ksel,all
vsel,none
vrotat,all,,,,,,ikbot,iktop,2.862,1
aclear,all

csys,22
nrotate,all

!couple to concrete DOFs
asel,s,,,491,492
asel,a,,,499,500
asel,a,,,510
asel,a,,,512
asel,a,,,524,525
asel,a,,,529
cm,avert,area
asel,s,,,511
asel,a,,,519
asel,a,,,521,522
cm,ahorz,area

esel,s,mat,,2
```

```
nsle
nsel,r,ext
cm,nconc,node

cmsel,s,avert
nsla,,1
cm,nsoil,node
*get,nnode,node,,count
*do,i,1,nnode
      *get,inode,node,,num,min
      cmsel,s,nconc
      incoup=node(nx(inode),ny(inode),nz(inode))
      nsel,s,,,incoup
      nsel,a,,,inode
      cp,next,uz,all
      cmsel,s,nsoil
      nsel,u,,,inode
      cm,nsoil,node
*enddo

cmsel,s,ahorz
nsla,,1
cm,nsoil,node
*get,nnode,node,,count
*do,i,1,nnode
      *get,inode,node,,num,min
      cmsel,s,nconc
      incoup=node(nx(inode),ny(inode),nz(inode))
      nsel,s,,,incoup
      nsel,a,,,inode
      cp,next,ux,all
      cmsel,s,nsoil
      nsel,u,,,inode
      cm,nsoil,node
*enddo

/eof
csys,22
nsel,s,loc,y,180-.01,180+.01
nsel,a,loc,y,180+2.862-.01,180+2.862+.01
nrotate,all
d,all,uy,0
allsel
```

Attachment 9.21. Listing of ANSYS input for miscellaneous macros

set_type.mac

```
*get,ia,area,,num,min
*get,iareal,area,ia,attr,real
*get,iamat,area,ia,attr,mat
*get,iacsys,area,ia,attr,esys
aatt,iamat,iareal,arg1,iacsys
```

set_real.mac

```
*get,ia,area,,num,min
*get,iamat,area,ia,attr,mat
*get,iatype,area,ia,attr,type
*get,iacsys,area,ia,attr,esys
aatt,iamat,arg1,iatype,iacsys
```

set_mat.mac

```
*get,ia,area,,num,min
*get,iareal,area,ia,attr,real
*get,iatype,area,ia,attr,type
*get,iacsys,area,ia,attr,esys
aatt,arg1,iareal,iatype,iacsys
```

set_csys.mac

```
*get,ia,area,,num,min
*get,iareal,area,ia,attr,real
*get,iamat,area,ia,attr,mat
*get,iatype,area,ia,attr,type
aatt,iamat,iareal,iatype,arg1
```

set_rx.mac

```
cmsel,s,arg4
csys,0
asel,r,loc,x,arg1,arg2
set_real,arg3
```

set_ry.mac

```
cmsel,s,arg4
csys,0
asel,r,loc,y,arg1,arg2
set_real,arg3
```

Attachment 9.22. Listing Of Ansys Input Macro CC3.MAC.

```
finish
/clear
/prep7

et,1,65
keyopt,1,7,1            !allow stress relaxation after cracking

et,2,45

!steel material properties
mp,ex,1,27.7e6
mp,prxy,1,.3

r,100,0

tb,biso,1
tbdata,1,25000,0

!concrete material properties (no rebar)
mp,ex,2,3.8e6
mp,prxy,2,.15
tb,concr,2
tbdata,1,.1,1,300,3000

!concrete material properties (rebar)
mp,ex,3,3.8e6
mp,prxy,3,.15

len=24

block,0,len,-10,-8,-.25,.25
block,0,len,-8,-7,-.25,.25
block,0,len,-7,7,-.25,.25
block,0,len,7,8,-.25,.25
block,0,len,8,10,-.25,.25
nummrg,kp

!length
lsel,s,length,,len
lesize,all,,,10
lsel,s,,,4,5
lesize,all,,,10

!cover
lsel,s,length,,2
lesize,all,,,4

!width
```

```
lsel,s,length,,.5
lesize,all,,,1

!rebar
lsel,s,length,,1
lesize,all,,,4

!core
lsel,s,length,,14
lesize,all,,,12

vsel,s,,,1,5,2
vatt,2,100,1,0
vsel,invert
vatt,1,,2,0

allsel
vsweep,all

asel,s,loc,x,len
et,10,63
r,10,1
mp,ex,10,10e6
mp,prxy,10,.3
aatt,10,10,10
amesh,all
nsla,,1
nsel,r,loc,y,0
*get,inc,node,,num,min
f,inc,mz,250000*.85
nsla,,1
cerig,inc,all,all

nsel,s,loc,x,0
d,all,ux,0
d,all,uy,0
allsel
d,all,uz,0
asel,s,loc,y,10
asel,a,loc,y,-10
nsla,,1
!d,all,uy,0

allsel
eplo

finish
/config,nproc,2
/filnam,cc3
```

```
allsel
/sol
time,1
nsubst,200,10000,25
outres,all,all
save
solve

/post1
!plcrack

/post26
ESOL,2,275,246,S,X,
ESOL,3,17,532,S,X
ESOL,4,224,257,S,X,
ESOL,5,57,488,S,X,
plvar,2,3
```

Attachment 9.23. Listing Of Ansys Input Macro BUILD_360.MAC

```
/sys,del *.db

dstay
dstay2
dstay3
dstay4_360
dstay5
dstay6
dstay7
dstay8
dstay9
dstay10
dstay11

/sys,del
```

Attachment 9.24. Listing Of Ansys Input Macro DSTAY10.MAC

```
finish
resume,dstay9,db
/prep7

/nerr,,-1
SHPP,MODIF,1,1000,
/input,mesh_size_360,mac
!num_div=6

allsel
ddele,all,all
sfdele,all,all
cpdele,all,all
fdele,all,all
aslv
cm,a_vol,area  !areas contained within volumes
asel,invert
cm,a_area,area !areas not contained within volumes
allsel
cm,v_old,volu
cm,a_old,area
cm,e_old,elem
cm,n_old,node
cm,l_old,line

!note - esys later respecified in set_esys_3d.mac

!slab elements with rebar
*do,i,100,108
*do,j,100,130
esel,s,real,,i
esel,r,esys,,j
vsle
aslv
csys,0
asel,r,loc,z,-.01,0.01
allsel,below,area
type,15
mat,2
real,i
esys,j
extopt,esize,num_div
ksel,a,,,1
ksel,a,,,2
*get,a_num,area,,count
*if,a_num,ne,0,then
vrotat,all,,,,,,1,2
nsle
```

```
nummrg,node
*endif
*enddo
*enddo

!wall elements with rebar
*do,i,200,213
*do,j,112,187
esel,s,real,,i
esel,r,esys,,j
vsle
aslv
csys,0
asel,r,loc,z,-.01,0.01
allsel,below,area
type,15
mat,2
real,i
esys,j
extopt,esize,num_div
ksel,a,,,1
ksel,a,,,2
*get,a_num,area,,count
*if,a_num,ne,0,then
vrotat,all,,,,,,1,2
nsle
nummrg,node
*endif
*enddo
*enddo

!dome elements with rebar
*do,i,300,313
*do,j,114,177
esel,s,real,,i
esel,r,esys,,j
vsle
aslv
csys,0
asel,r,loc,z,-.01,0.01
allsel,below,area
type,15
mat,2
real,i
esys,j
extopt,esize,num_div
ksel,a,,,1
ksel,a,,,2
*get,a_num,area,,count
*if,a_num,ne,0,then
```

```
vrotat,all,,,,,,1,2
nsle
nummrg,node
*endif
*enddo
*enddo

!haunch internal/external elements with rebar
*do,i,400,406
*do,j,111,168
esel,s,real,,i
esel,r,esys,,j
vsle
aslv
csys,0
asel,r,loc,z,-.01,0.01
allsel,below,area
type,15
mat,2
real,i
esys,j
extopt,esize,num_div
ksel,a,,,1
ksel,a,,,2
*get,a_num,area,,count
*if,a_num,ne,0,then
vrotat,all,,,,,,1,2
nsle
nummrg,node
*endif
*enddo
*enddo

!haunch middle vertical/radial elements with rebar
*do,i,500,502
*do,j,107,108
esel,s,real,,i
esel,r,esys,,j
vsle
aslv
csys,0
asel,r,loc,z,-.01,0.01
allsel,below,area
type,15
mat,2
real,i
esys,j
extopt,esize,num_div
ksel,a,,,1
ksel,a,,,2
```

```
*get,a_num,area,,count
*if,a_num,ne,0,then
vrotat,all,,,,,,1,2
nsle
nummrg,node
*endif
*enddo
*enddo

!haunch middle diagonal elements with rebar
*do,i,503,503
*do,j,107,108
esel,s,real,,i
esel,r,esys,,j
vsle
aslv
csys,0
asel,r,loc,z,-.01,0.01
allsel,below,area
type,13
mat,2
real,i
esys,j
extopt,esize,num_div
ksel,a,,,1
ksel,a,,,2
*get,a_num,area,,count
*if,a_num,ne,0,then
vrotat,all,,,,,,1,2
nsle
nummrg,node
*endif
*enddo
*enddo

!soil elements
esel,s,type,,17
vsle
aslv
csys,0
asel,r,loc,z,-.01,0.01
allsel,below,area
type,17
real,44
mat,5
esys,0
extopt,esize,num_div
vrotat,all,,,,,,1213,1214
nsle
nummrg,node
```

```
!unreinforced tank elements
esel,none
esel,s,type,,12
vsle
aslv
csys,0
asel,r,loc,z,-.01,0.01
allsel,below,area
type,12
real,700
esys,0
mat,2
asel,u,,,17
asel,u,,,142
extopt,esize,num_div
vrotat,all,,,,,,1,2
nsle
nummrg,node,0.1,0.1
allsel,below,volu
nummrg,kp,0.1,0.1
!
asel,s,,,142
vrotat,all,,,,,,1,2
!
asel,s,,,17
vrotat,all,,,,,,1,2
!
allsel,below,volu
nummrg,node
nummrg,kp

!unreinforced slab elements
esel,s,type,,14
vsle
aslv
csys,0
asel,r,loc,z,-.01,0.01
allsel,below,area
type,14
real,700
mat,2
esys,0
extopt,esize,num_div
ksel,a,,,1
ksel,a,,,2
vrotat,all,,,,,,1,2
nsle
nummrg,node
```

```
!insulating concrete elements
esel,s,type,,16
vsle
aslv
csys,0
asel,r,loc,z,-.01,0.01
allsel,below,area
type,16
real,600
mat,4
esys,0
extopt,esize,num_div
ksel,a,,,1
ksel,a,,,2
vrotat,all,,,,,,1,2
nsle
nummrg,node

allsel
numcmp,node

!j-bolt and anchor elements
*get,maxnd,node,,num,max
csys,22
esel,s,type,,20,21
nsle
egen,num_div*4,maxnd,all,,,,,,,,,90/num_div,
nsle

allsel
numcmp,node
nrotat,all

!merge j-bolt, tank, haunch, and rebar elements
esel,s,type,,20
esel,a,type,,12,13
esel,a,type,,15
nsle
nummrg,node

!merge anchor, tank, and rebar elements
esel,s,type,,21
esel,a,type,,12
esel,a,type,,15
nsle
nummrg,node

!---360 deg liners

esel,s,type,,1
```

```
asle
allsel,below,area
csys,0
lsel,r,loc,z,-.01,0.01
type,1
mat,1
esys,0
*get,l_num,line,,count
ll=0
*do,i,1,l_num
lnxt=lsnext(ll)
extopt,esize,num_div
ksel,a,,,1
ksel,a,,,2
arotat,lnxt,,,,,,1,2 !elements not generated for arot
ll=lnxt
•enddo
ksll
nummrg,kp
csys,22
lsel,r,loc,x,kx(313)
lesize,all,,,num_div
cmsel,u,a_old
asel,u,,,4299,4302
asel,u,,,4255,4258
asel,u,,,4323,4326
cm,atemp,area !liner areas

*do,j,1,40
asll
cmsel,r,atemp
amesh,all !mesh liners
lsla
*enddo
cm,atemp1,area



allsel
numcmp,node
*get,maxnd,node,,num,max
asel,s,,,3002
asel,a,,,3303
asel,a,,,3604
asel,a,,,3867
vsla
cm,vtemp,volu
vgen,2,all
cmsel,u,vtemp
cm,vtemp2,volu
```

```
allsel,below,volu
nummrg,node
nummrg,kp

asel,s,,,4459
asel,a,,,4464
asel,a,,,4468
asel,a,,,4472
asel,a,,,3982
asel,a,,,4047
asel,a,,,4112
asel,a,,,4177
asel,a,,,4229
asel,a,,,4236
asel,a,,,4243
asel,a,,,4250
cm,liner_end,area
type,1
mat,1
real,50
esys,0
amesh,all

agen,2,all
cmsel,u,liner_end
cm,liner_end,area
cmsel,s,vtemp2
allsel,below,volu
aclear,all
vclear,all
vdele,all,,,1

allsel
cmsel,u,a_old
aslv,u
asle,u
adele,all,,,1



esel,s,type,,1
cmsel,u,e_old
asle
allsel,below,area
nummrg,node
nummrg,kp
cm,atemp,area
agen,2,all
cmsel,u,atemp
cm,liner,area
```

```
cmsel,s,atemp
aclear,all
aslv,u
adele,all,,,1

allsel
csys,22
nrotat,all



!---- Assign real constants to liner elements
cmsel,s,liner
allsel,below,area
nummrg,node !changed from 0.4,0.4
nummrg,kp   !changed from 0.4,0.4
esla
nsle
lsla
ksll
csys,22
ksel,r,loc,x,0,kx(2676)
ksel,r,loc,z,kx(2676),99999
lslk,,1
asll,,1
cmsel,r,liner
esla
emodif,all,real,51
cm,r_51,area

asel,s,,,4619,4622
cm,r_55_end,area
ksel,s,,,2627
lslk
asll
*do,i,1,40
lsla
asll
cmsel,u,r_55_end
*enddo
cmsel,a,r_55_end
cm,r_55,area
esla
emodif,all,real,55

cmsel,s,liner
cmsel,u,r_51
cmsel,u,r_55
allsel,below,area
csys,22
```

```
nsel,r,loc,z,376,9999
esln,,1
esel,r,type,,1
emodif,all,real,51

cmsel,s,liner
cmsel,u,r_51
cmsel,u,r_55
allsel,below,area
csys,22
nsel,r,loc,z,141,376+.01
esln
esel,r,type,,1
emodif,all,real,54

cmsel,s,liner
cmsel,u,r_51
cmsel,u,r_55
allsel,below,area
csys,22
nsel,r,loc,z,33.89,141.1
esln,,1
esel,r,type,,1
emodif,all,real,53

cmsel,s,liner
cmsel,u,r_51
cmsel,u,r_55
allsel,below,area
csys,22
nsel,r,loc,x,23.9,398.19
esln,,1
esel,r,type,,1
emodif,all,real,51

cmsel,s,liner
cmsel,u,r_51
cmsel,u,r_55
allsel,below,area
csys,22
nsel,r,loc,x,0,24
esln,,1
esel,r,type,,1
emodif,all,real,50

cmsel,s,liner
cmsel,u,r_51
cmsel,u,r_55
allsel,below,area
csys,22
```

```
nsel,u,loc,z,35.79,9999
nsel,u,loc,x,0,398.17
esln,,1
emodif,all,real,52

cmsel,s,r_51
allsel,below,area
nsel,u,loc,x,76.83,9999
esln,,1
emodif,all,real,54 !last save


!---create baseplate
allsel
csys,22
esel,s,type,,12
esel,a,type,,15
esel,u,real,,100,130
cmsel,u,e_old
vsle
allsel,below,volu
cm,a_tank,area
nummrg,node
nummrg,kp

ksel,s,loc,z,kz(11)
ksel,r,loc,x,kx(12),9999
lslk,,1
asll,,1
cmsel,u,a_old
allsel,below,area
cmsel,r,a_tank
cm,baseplate,area
cmsel,u,a_old
lsla
nsla,,1
type,22
mat,1
real,40
esys,0
amesh,all

!---create confining ring
ksel,all
csys,22
ksel,s,loc,x,kx(18)
ksel,r,loc,z,kz(27),kz(18)
lslk,,1
asll,,1
cmsel,u,a_old
```

```
cm,conf_ring,area

ksel,all
ksel,s,loc,x,kx(12)-.1,kx(12)+.1
ksel,r,loc,z,kz(12),kz(15)
lslk,,1
asll,,1
cmsel,u,a_old
cmsel,a,conf_ring
type,23
mat,1
real,41
esys,0
vsla
allsel,below,volu
nummrg,node
nummrg,kp
cmsel,s,conf_ring
amesh,all


!---stiffner
ksel,all
ksel,s,loc,x,kx(456)-.1,kx(456)+.1
ksel,r,loc,z,kz(456),kz(459)
lslk,,1
asll,,1
cmsel,u,a_old
cm,a_stiff,area

ksel,all
ksel,s,loc,z,kz(459)-.1,kz(459)+.1
ksel,r,loc,x,kx(459),kx(1008)
lslk,,1
asll,,1
cmsel,u,a_old
cmsel,a,a_stiff
cm,a_stiff,area

ksel,all
ksel,s,loc,z,kz(566)-.1,kz(566)+.1
ksel,r,loc,x,kx(566),kx(1016)
lslk,,1
asll,,1
cmsel,u,a_old
cmsel,a,a_stiff
cm,a_stiff,area

ksel,all
ksel,s,loc,x,kx(566)-.1,kx(566)+.1
```

```
ksel,r,loc,z,kz(566),kz(567)
lslk,,1
asll,,1
cmsel,u,a_old
cmsel,a,a_stiff
cm,a_stiff,area

ksel,all
ksel,s,loc,z,kz(791)-.1,kz(791)+.1
ksel,r,loc,x,kx(791),kx(1024)
lslk,,1
asll,,1
cmsel,u,a_old
cmsel,a,a_stiff
cm,a_stiff,area

ksel,all
ksel,s,loc,x,kx(573)-.1,kx(573)+.1
ksel,r,loc,z,kz(573),kz(791)
lslk,,1
asll,,1
cmsel,u,a_old
cmsel,a,a_stiff
cm,a_stiff,area

ksel,all
ksel,s,loc,x,kx(741)-.1,kx(741)+.1
ksel,r,loc,z,kz(741),kz(740)
lslk,,1
asll,,1
cmsel,u,a_old
cmsel,a,a_stiff
cm,a_stiff,area

ksel,all
ksel,s,loc,z,kz(741)-.1,kz(741)+.1
ksel,r,loc,x,kx(741),kx(798)
lslk,,1
asll,,1
cmsel,u,a_old
cmsel,a,a_stiff
cm,a_stiff,area

type,24
mat,1
real,42
esys,0
lsla
nsla,,1
esln
```

```
cmsel,u,e_old
cmsel,s,a_stiff
vsla
allsel,below,volu
nummrg,node
nummrg,kp
cmsel,s,a_stiff
amesh,all

!---type 25 (detail 9 anchor)
ksel,all
csys,22
ksel,s,loc,x,kx(909),kx(536)
lslk,,1
asll,,1
cmsel,u,a_old
cm,type_25,area

ksel,all
ksel,s,loc,x,kx(535),kx(536)
ksel,r,loc,z,kz(535),kz(536)
lslk,,1
asll,,1
cmsel,a,type_25
cmsel,u,a_old
cm,type_25,area
vsla
allsel,below,volu
nummrg,node
nummrg,kp
cmsel,s,type_25
type,25
mat,1
real,43
esys,0
amesh,all


!---type 26 (anchors 2 and 3)
ksel,all
ksel,s,loc,x,kx(474),kx(472)
ksel,r,loc,z,kz(474),kz(472)
lslk,,1
asll,,1
cmsel,u,a_old
cm,type_26,area

ksel,all
ksel,s,loc,x,kx(474)
ksel,r,loc,z,kz(474),kz(473)
```

```
lslk,,1
asll,,1
cmsel,a,type_26
cmsel,u,a_old
cm,type_26,area

ksel,all
ksel,s,loc,x,kx(880)-.1,kx(882)+.1
ksel,r,loc,z,kz(882)
lslk,,1
asll,,1
cmsel,a,type_26
cmsel,u,a_old
cm,type_26,area

ksel,all
ksel,s,loc,x,kx(881)-.1,kx(881)+.1
ksel,r,loc,z,kz(881),kz(882)
lslk,,1
asll,,1
cmsel,a,type_26
cmsel,u,a_old
cm,type_26,area

vsla
allsel,below,volu
nummrg,node
nummrg,kp
cmsel,s,type_26
type,26
mat,1
real,44
esys,0
amesh,all

cmsel,s,liner
esla
cm,etemp,elem
esel,s,type,,1
cmsel,u,etemp
cmsel,u,e_old
nsle
edele,all
ndele,all
allsel
save,dstay10,db
```

Attachment 9.25. Listing Of Ansys Input Macro DSTAY11.MAC

```
finish
resume,dstay10,db
/nerr,,1000000
/prep7

max_mat=100
max_real=1000

cont_id_slab=1
cont_id_liner=1

! make normals of primary liner self-consistent
esel,s,real,,50,54
cmsel,u,e_old
nsle
*get,e_min,elem,,num,min
enorm,e_min
*get,e_max,elem,,num,max
enorm,e_max
ensym,,,,all

! make normals of secondary liner self-consistent
esel,s,real,,55,56
cmsel,u,e_old
nsle
*get,e_min,elem,,num,min
enorm,e_min
ensym,,,,all


!-------define area components for contacts
allsel
cmsel,s,a_tank
asel,r,ext
cm,a_tank,area

esel,s,type,,17
vsle
aslv
asel,r,ext
cmsel,u,a_old
cm,a_soil,area
allsel,below,area

csys,22
cmsel,s,a_soil
lsla
ksll
```

```
asel,u,loc,z,kz(1214)
asel,u,loc,x,kx(1783)
asel,u,loc,z,kz(1213)
cm,soil_cont,area

cmsel,s,baseplate
cm,tank_bot_cont,area !wall, not slab

ksel,s,,,1
lslk
asll
cmsel,r,a_tank
*do,i,1,10
lsla
asll
cmsel,r,a_tank
cmsel,u,tank_bot_cont
*enddo
cm,tank_cont,area !tank areas in contact with soil

esel,s,type,,14
esel,a,real,,100,120
vsle
allsel,below,volu
nummrg,node
nummrg,kp
cm,slab,volu
aslv
asel,r,ext
lsla
ksll
cmsel,u,a_old
cm,a_slab,area !external slab areas
cm,k_slab,kp

cmsel,s,k_slab
ksel,r,loc,x,kx(2503)-5,kx(2498)
lslk,,1
asll,,1
cmsel,u,a_old
cm,slab_top_cont,area !wall interface

cmsel,s,a_slab
ksel,s,,,323
lslk
asll
cmsel,r,a_slab
*do,i,1,10
lsla
asll
```

```
cmsel,r,a_slab
cmsel,u,slab_top_cont
*enddo
cm,slab_cont,area !soil interface

et,60,170
et,61,173
mp,mu,61,.3
KEYOPT,61,1,0
KEYOPT,61,2,0
KEYOPT,61,4,0
KEYOPT,61,5,0
KEYOPT,61,7,0
KEYOPT,61,8,0
KEYOPT,61,9,0
KEYOPT,61,10,0
KEYOPT,61,11,0
!KEYOPT,61,12,4
!KEYOPT,61,12,5
KEYOPT,61,12,0

!et,62,170
!et,63,173
!mp,mu,63,.3
!KEYOPT,63,12,5

cmsel,s,tank_bot_cont
cmsel,a,slab_top_cont
lsla
nsla,,1
cm,tk_slab_cp,node

*if,cont_id_slab,eq,1,then

!---contact between bottom of wall and top of slab
cmsel,s,tank_bot_cont
lsla
nsla,,1
esln
esel,u,type,,21,22
cmsel,u,e_old
type,60
r,66
real,66
mat,66
esurf
cmsel,s,slab_top_cont
lsla
nsla,,1
esln
```

```
cmsel,u,e_old
type,61
esurf

*else
cmsel,s,tank_bot_cont
cmsel,a,slab_top_cont
lsla
nsla,,1
nsel,u,cp,,all
cpintf,uz
*endif

*if,cont_id_liner,eq,1,then

esel,s,type,,1
asle
cm,a_liner,area

esel,s,type,,16
vsle
cm,insl_concr,volu

esel,s,type,,1,16,15
cmsel,u,e_old
nsle
ksel,all
csys,22
nsel,r,loc,z,kz(359)-.1,kz(359)+.1
!nummrg,node

cmsel,s,insl_concr
allsel,below,volu
cmsel,a,a_liner
lsla
ksll
ksel,r,loc,z,kz(359)-.1,kz(359)+.1
!nummrg,kp


!---contact between secondary liner and wall
esel,s,type,,1
esel,r,real,,55,56
asle
aslv,u
asel,u,,,4459,4470
!asel,u,,,4523,4530
ksel,all
asel,u,loc,x,0,400
cmsel,u,a_old
```

```
nsla,,1
esln
cmsel,u,e_old
esel,r,type,,1
esel,r,real,,55,56
type,60
mat,62
real,62
!secondary liner is target
esurf
ksel,s,,,2149
lslk
asll
cmsel,u,baseplate
*do,i,1,50
lsla
asll
cmsel,r,a_tank
cmsel,u,a_old
cmsel,u,baseplate
*enddo
cm,tk_cont_in,area
lsla
ksll
ksel,u,loc,z,465,9999
lslk,,1
asll,,1
cmsel,r,a_tank
cmsel,u,a_old
cmsel,u,baseplate
nsla,,1
esln
esel,r,type,,12,15,3
cmsel,u,e_old
type,61
esurf

!---contact between primary liner and dome
real,63
type,60
mat,63
esel,s,type,,1
esel,r,real,,51,54,3
asle
aslv,u
ksel,all
asel,u,loc,z,-999,440
cmsel,u,a_old
nsla,,1
esln
```

```
cmsel,u,e_old
esel,r,type,,1
esel,r,real,,51,54,3
!primary liner is target
esurf
ksel,s,,,2149
lslk
asll
cmsel,u,baseplate
*do,i,1,50
lsla
asll
cmsel,r,a_tank
cmsel,u,a_old
cmsel,u,baseplate
*enddo
cm,tk_cont_in,area
lsla
ksll
ksel,u,loc,z,-999,440
lslk,,1
asll,,1
cmsel,r,a_tank
cmsel,u,a_old
cmsel,u,baseplate
nsla,,1
esln
cmsel,u,e_old
esel,r,type,,12,15,3
type,61
esurf

!---contact between slab top/insulating concrete bot
cmsel,s,slab
allsel,below,volu
lsla
ksll
csys,22
ksel,r,loc,x,0,kx(2444)
ksel,r,loc,z,kz(2444)-.1,kz(2444)+.1
lslk,,1
asll,,1
cmsel,u,a_old
cm,slab_top_cont2,area
lsla
nsla,,1
esln
cmsel,u,e_old
type,60
mat,65
```

```
real,65
esurf
cmsel,s,insl_concr
cmsel,u,v_old
allsel,below,volu
asel,r,loc,z,kz(2625)-.1,kz(2625)+.1
lsla
nsla,,1
esln
esel,r,type,,16
cmsel,u,e_old
type,61
esurf

!--contact between insulating concrete/primary liner

asel,s,,,4299,4302
asel,a,,,4459,4462
lsla
nsla,,1
esln
type,60
mat,64
real,64
esurf
cmsel,s,insl_concr
cmsel,u,v_old
allsel,below,volu
asel,r,loc,z,kz(302)-.1,kz(302)+.1
lsla
nsla,,1
esln
esel,u,type,,23
cmsel,u,e_old
type,61
esurf


*else

!---coupling between liner and tank
ksel,all
esel,s,type,,1
esel,a,mat,,2
cmsel,u,e_old
nsle
csys,22
nsel,r,loc,z,kz(1977),9999
nsel,u,cp,,all
cpintf,uz,0.02
```

```
nsle
nsel,r,loc,z,kz(1977),kz(2812)
cpintf,ux,0.02

nsle
nsel,r,loc,z,kz(302)
nsel,u,cp,,all
cmsel,u,tk_slab_cp
cpintf,uz,0.02

nsle
nsel,r,loc,z,kz(301)
nsel,u,cp,,all
cmsel,u,tk_slab_cp
cpintf,uz,0.02

*endif

!---delete old components
allsel
cmsel,s,v_old
vclear,all
vdele,all,,,1

cmsel,s,a_old
aclear,all
allsel
aslv,u
cmsel,r,a_old
adele,all,,,1

cmsel,s,l_old
!lclear,all

!cmsel,s,e_old
!nsle
!edele,all
!ndele,all
allsel

csys,22
nsel,s,loc,y,0,90
esln,,1
cm,qtr_model,elem

allsel
/input,set_esys_3d,mac
allsel
```

```
!add steel plate below wall (on slab)
r,45,1/4
csys,22
vsel,s,mat,,2
vsel,r,real,,700
allsel,below,volu
asel,r,loc,z,-8,-8.2
lsla,s
ksll,s
ksel,r,loc,x,480,498
lslk,s,1
asll,s,1
asel,u,real,,40
mat,1
real,45
type,22
amesh,all
allsel

!use separate nodes for insulating concrete/outer ring
allsel
mat,1
type,23
real,41
asel,s,real,,41
cm,a_ins_outer,area
aclear,all
agen,2,all
asel,r,,,1,1000
amesh,all
nrot,all
esel,s,real,,41
nsle
ensym,,,,all
cm,a_ring,area
allsel

!couple ring and secondary liner nodes
!  in vertical direction
esel,s,real,,55
asle
cmsel,a,a_ring
csys,0
asel,u,loc,y,20,9999
nsla,,1
nsel,r,loc,y,-8.2,-8.0
cpintf,uz,.1

!--contact between top of slab and secondary liner
cmsel,s,slab
```

```
allsel,below,volu
lsla
ksll
csys,22
ksel,r,loc,x,0,480
ksel,r,loc,z,kz(2444)-.1,kz(2444)+.1
lslk,,1
asll,,1
cm,slab_top_cont2,area
lsla
nsla,,1
esln
esel,r,type,,14
real,67
type,60
mat,67
esurf
type,61
esel,s,type,,1
esel,r,real,,55
asle
aslv,u
asel,u,,,4459,4470
!asel,u,,,4523,4530
ksel,all
asel,r,loc,z,-99,20
nsla,,1
esln
esel,r,type,,1
esel,r,real,,55
esurf

!--contact between outer perimeter of insulating concrete/ring
real,68
type,60
mat,68
cmsel,s,a_ins_outer
nsla,,1
esln
esel,r,type,,16
esurf
type,61
cmsel,s,a_ring
nsla,,1
esln
esurf

allsel

!----modify contact setting
```

```
r,61,,,50,50 !make 500x higher due to TB
r,62,,,.1,.1
r,63,,,.1,.1
r,64,,,.1,.1
r,65,,,.1,.1
r,66,,,.1,.1
r,67,,,.1,.1
r,68,,,.1,.1
mp,mu,61,.3
mp,mu,62,.3
mp,mu,63,.3
mp,mu,64,.3
mp,mu,65,.3
mp,mu,66,.1
mp,mu,67,.3
mp,mu,68,.3

r,41,3/16          !insulating concrete confining ring thickness

!merge primary liner/concrete nodes at dome centerline
csys,22
ksel,s,loc,z,561.4,561.6
ksel,r,loc,x,0
nslk
nummrg,node
nummrg,kp
allsel

!couple nodes at primary/secondary liner intersection
csys,22
ksel,s,loc,x,431,433
ksel,r,loc,z,459,461
lslk,s,1
nsll,,1
cpintf,all,0.5
allsel

!merge liner and j-bolt nodes
esel,s,type,,1
esel,a,type,,20
nsle
nummrg,node
allsel

!make sure anchors/jbolts/studs etc are merged with concrete
esel,s,mat,,2
esel,a,type,,20,26
esel,u,type,,14  !exclude slab concrete
esel,u,type,,1
esel,u,real,,45   !added to prevent coincident nodes at tank/slab from merging
```

```
nsle,,1
nummrg,node

!---define soil layers (redefined later)
!*dim,soil_emod,,20
!*dim,soil_pr,,20
!*dim,soil_gam,,20
!*dim,soil_z0,,20
!*dim,soil_z1,,20

soil_z0(1)=60,144,240,336,432,510,588,672,756,879
soil_z0(11)=1001,1124,1247,1369,1492,1615,1737,1860
soil_z1(1)=0,60,144,240,336,432,510,588,672,756
soil_z1(11)=879,1001,1124,1247,1369,1492,1615,1737
soil_emod(1)=4561,4880,8527,12000,4755,5192,8890,12510,13348,13776
soil_emod(11)=14976,14040,14170,14573,14760,15091,15264,15478
soil_pr(1)=.2,.2,.2,.2,.23,.18,.27,.39,.42,.435
soil_pr(11)=.44,.44,.44,.44,.44,.44,.44,.42
soil_gam(1)=120,120,120,120,114,118,108,127,115,108
soil_gam(11)=108,108,108,108,108,108,108,108

esel,s,mat,,5
nsle,,1
csys,0
*get,top_elev,node,,mxloc,y
cm,soil_elem,elem

*do,i,1,18
      set_slayer,soil_z0(i),soil_z1(i),soil_emod(i),soil_pr(i),soil_gam(i),34.5,34.5
*enddo
!set backfill material above dome
/input,set_backfill,mac
allsel

!modify soil elements so there are 3 horizontal layers
!  modify 2D geometry and mesh
esel,s,mat,,5
esel,a,mat,,101,120
nsle
vsln
aslv
lsla
ksll
vclear,all
aclear,all
vdel,all
cm,a_soil,area
csys,22
asel,u,loc,y,180
asel,u,loc,y,-180
```

```
adel,all,,,1

cmsel,s,a_soil
csys,0
aadd,all
kwpave,1200
wprot,0,0,90
asbw,all
kwpave,1186
asbw,all
aadd,154,159
lcomb,452,956
lcomb,19,947
lcomb,9,2190
lcomb,2183,2181,2178
lcomb,2175,2172,21
lcomb,126,130
lcomb,2189,915,918
lcomb,917,962
lcomb,2178,2181
lcomb,21,2172
lcomb,918,915

kwpave,1205
wpoff,0,point_rad
wprot,0,90
lsbw,19
type,type_soil
real,7
kesize,all,300
ksel,r,loc,x,-700,1
ksel,r,loc,y,-200,999
kesize,all,16
ksll
mshkey,0
smrt,off
mat,101
amesh,155
mat,104
amesh,157
mat,109
amesh,156
!rotate 2D soil geometry/mesh to create 3D
type,type_soil+10
esize,,num_div
mat,101
ksel,a,,,iktop
ksel,a,,,ikbot
vrot,155,,,,,,ikbot,iktop,swp_th,swp_th/90
mat,104
```

```
vrot,157,,,,,,ikbot,iktop,swp_th,swp_th/90
mat,109
vrot,156,,,,,,ikbot,iktop,swp_th,swp_th/90
nummrg,node
nummrg,kp
aclear,all
cm,a_soil_3d,area
csys,22
nrot,all
csys,0

!soil_concrete contact
csys,22
asel,r,ext
asel,u,loc,x,totalwidth-100,99999
asel,r,loc,z,kz(ikbot),kz(iktop)
cm,asoil,area !soil areas of contact with tank
allsel
real,61
type,61
mat,61
cmsel,s,tank_cont
cmsel,a,slab_cont
nsla,,1
esln
esel,r,type,,12,14,2
esurf
type,60
cmsel,s,asoil
nsla,,1
esln
esurf
allsel

!modify reals of rebar elements in wall
!  to correct for vertical offset error in wall
!  elements of 8.125 inches
csys,0
!
esel,s,real,,200,205 !external wall rebar elements
mat,2
type,15
esys,22
y_cor=8.125
*get,e_tot,elem,,count
  *do,i,1,e_tot
    *get,e_number,elem,,num,min
     *if,centry(e_number),ge,0-y_cor,and,centry(e_number),lt,123-y_cor,then
         real,200
         emod,e_number
     *endif
```

```
      *if,centry(e_number),ge,123-y_cor,and,centry(e_number),lt,155-y_cor,then
          real,201
          emod,e_number
      *endif
      *if,centry(e_number),ge,155-y_cor,and,centry(e_number),lt,204-y_cor,then
          real,202
          emod,e_number
      *endif
      *if,centry(e_number),ge,204-y_cor,and,centry(e_number),lt,279-y_cor,then
          real,203
          emod,e_number
      *endif
      *if,centry(e_number),ge,279-y_cor,and,centry(e_number),lt,311-y_cor,then
          real,213
          emod,e_number
      *endif
      *if,centry(e_number),ge,311-y_cor,and,centry(e_number),lt,348-y_cor,then
          real,204
          emod,e_number
      *endif
      *if,centry(e_number),ge,348-y_cor,and,centry(e_number),lt,382-y_cor,then
           real,205
           emod,e_number
       *endif
    esel,u,,,e_number
  *enddo
allsel
!
esel,s,real,,206,212 !internal wall rebar elements
mat,2
type,15
esys,22
y_cor=8.125
*get,e_tot,elem,,count
  *do,i,1,e_tot
    *get,e_number,elem,,num,min
      *if,centry(e_number),ge,0-y_cor,and,centry(e_number),lt,123-y_cor,then
          real,206
          emod,e_number
      *endif
      *if,centry(e_number),ge,123-y_cor,and,centry(e_number),lt,155-y_cor,then
          real,207
          emod,e_number
      *endif
      *if,centry(e_number),ge,155-y_cor,and,centry(e_number),lt,204-y_cor,then
          real,208
          emod,e_number
      *endif
      *if,centry(e_number),ge,204-y_cor,and,centry(e_number),lt,279-y_cor,then
          real,209
          emod,e_number
      *endif
      *if,centry(e_number),ge,279-y_cor,and,centry(e_number),lt,311-y_cor,then
          real,210
```

```
        emod,e_number
      *endif
      *if,centry(e_number),ge,311-y_cor,and,centry(e_number),lt,348-y_cor,then
        real,211
        emod,e_number
      *endif
      *if,centry(e_number),ge,348-y_cor,and,centry(e_number),lt,382-y_cor,then
         real,212
         emod,e_number
      *endif
    esel,u,,,e_number
  *enddo
allsel

!modify reals of elements in haunch to
!  correct from 12" to 30" above dome tangent error
mat,2
type,15
esel,s,real,,400,401
nsle
nsel,r,loc,y,381.5,413.6
esln,r,1
esys,22
real,400
emod,all
!
esel,s,real,,405,406
nsle
nsel,r,loc,y,381.5,413.6
esln,r,1
esys,202
real,405
emod,all
allsel

!modify reals of elements in haunch to
!  correct from 44" to 12" in corner
csys,22
mat,2
type,15
esys,201
esel,s,real,,403
nsle
nsel,r,loc,x,0,487
esln,r,1
real,404
emod,all
csys,0
allsel

! Create and assign new ESYS for rebar elements in dome and haunch
```

```
! (Otherwise ESYS away from theta=0 or 180 is not correctly aligned.)
csys,22
mesh_ang=90/num_div
tot_cs=4*num_div

!modify esys200 elements
esel,s,esys,,200
cm,esys200,elem
*do,i,1,tot_cs
   cmsel,s,esys200
   nsle
   csys,22
   nsel,r,loc,y,(i-1)*mesh_ang-.1,i*mesh_ang+.1
   nsel,a,loc,x,0
   local,300+i,2,0,-683.5,0,0,0,(((i-1+i)*mesh_ang)/2)
   csys,22
   esln,r,1
   cmsel,r,esys200
   emodif,all,esys,300+i
*enddo

!modify esys201 elements
esel,s,esys,,201
cm,esys201,elem
*do,i,1,tot_cs
   cmsel,s,esys201
   nsle
   csys,22
   nsel,r,loc,y,(i-1)*mesh_ang-.1,i*mesh_ang+.1
   nsel,a,loc,x,0
   local,500+i,2,0,-315.5,0,0,0,(((i-1+i)*mesh_ang)/2)
   csys,22
   esln,r,1
   cmsel,r,esys201
   emodif,all,esys,500+i
*enddo

!modify esys202 elements
esel,s,esys,,202
cm,esys202,elem
*do,i,1,tot_cs
   cmsel,s,esys202
   nsle
   csys,22
   nsel,r,loc,y,(i-1)*mesh_ang-.1,i*mesh_ang+.1
   nsel,a,loc,x,0
   local,700+i,2,0,381.5,0,90,(((i-1+i)*mesh_ang)/2),0,80/30,80/30
   csys,22
   esln,r,1
   cmsel,r,esys202
```

```
   emodif,all,esys,700+i
*enddo

allsel

!merge coincident contact nodes
  *do,i,61,68,1
    esel,s,real,,i
    esel,r,type,,60
    nsle
    nummrg,node
    esel,s,real,,i
    esel,r,type,,61
    nsle
    nummrg,node
  *enddo

allsel
finish

/sol
!--set BCs and Loads
/input,apply_loads_360,mac

csys,0
allsel

eqslv,sparse
neqit,50
nlgeom,on
cnvtol,f,,.001,2
!cnvtol,m,,.001,2
nsubst,10,100,10
allsel

save,final,db
solve,,,,,noch
```

Attachment 9.26. Listing Of Ansys Input Macro BERM_DIMS.MAC

```
berm_type=2        !=1 straight berm; =2 circular berm
h=6*12             !height
w_top=6*12         !top width
w_bot=18*12        !bottom width
berm_dens=-125     ![pcf], input negative if hole
berm_esize=40      !default element size inches
r_strt=2000        !start radius for linear berm inches
theta_strt=-45     !start theta for linear berm degrees
r_end=2000         !end radius for linear berm inches
theta_end=45       !end theta for linear berm degrees
r_berm=1000        !mean radius of circular berm inches
```

Attachment 9.27. Listing Of Ansys Input Macro SET_BERM.MAC

```
finish
/clear
resume,final,db  !final db file from 360 degree model
/prep7
allsel

/input,berm_dims,mac

csys,22
h_top=kz(1214)

*if,berm_type,eq,1,then

ksel,none
k,,r_strt,theta_strt,h_top
k,,r_end,theta_end,h_top
*get,k1,kp,,num,min
*get,k2,kp,,num,max
lsel,none
lstr,k1,k2

l_berm=sqrt((kx(k1)-kx(k2))**2+(kz(k1)-kz(k2))**2)
v_berm=l_berm*h*(.5*(w_top+w_bot))
a_top=l_berm*w_top

*else
wpcsys,-1,0
kwpave,1214
wprot,,-90
lsel,none
circle,1214,r_berm,1213
v_berm=2*3.14159*r_berm*h*(.5*(w_top+w_bot))
a_top=2*3.14159*r_berm*w_top
*endif
cm,drag_line,line
*get,l_num,line,,num,min
lwpla,-1,l_num
wprot,180
csys,4
ksel,none
k,,-w_bot/2,,,
*get,k1,kp,,num,min
ksel,none
k,,w_bot/2,,,
*get,k2,kp,,num,min
ksel,none
k,,w_top/2,h,,
*get,k3,kp,,num,min
```

```
ksel,none
k,,-w_top/2,h,,
*get,k4,kp,,num,min
ksel,s,,,k1,k4
lsel,none
lstr,k1,k2
lstr,k2,k3
lstr,k3,k4
lstr,k4,k1
asel,none
al,all
cmsel,s,drag_line
*get,num_l,line,,count
*dim,ln,,num_l

ll=0
*do,i,1,num_l
ln(i)=lsnext(ll)
ll=ln(i)
*enddo

vsel,none
*if,num_l,eq,1,then
vdrag,all,,,,,,ln(1)
*else
vdrag,all,,,,,,ln(1),ln(2),ln(3),ln(4)
*endif

cm,v_berm,volu
allsel,below,volu
nummrg,kp

et,70,45
et,71,170
et,72,173
keyopt,72,12,5
r,72,,.1,.1
mp,ex,70,1e5/10
mp,prxy,70,.3

cmsel,s,v_berm
type,70
mat,70
esize,berm_esize
vsweep,all

allsel,below,volu
asel,r,loc,y,0
cm,atemp,area
lsla
```

```
nsla,,1
esln
type,71
real,72
esurf

csys,22
asel,s,loc,z,h_top
cmsel,u,atemp
lsla
nsla,,1
esln
type,72
esurf

*if,berm_dens,gt,0,then
      mp,dens,70,berm_dens/1728/386
*else
      mp,dens,70,0
      vsel,s,mat,,70
      aslv
      lsla
      ksll
      csys,0
      *get,kbmax,kp,,mxloc,y
      asel,r,loc,y,kbmax-.5,kbmax+.5
      fberm=v_berm*abs(berm_dens)/1728
      nsla,,1
      esln
      sf,all,pres,-fberm/a_top
*endif

allsel
fini

/solu
solve
fini
```

Attachment 9.28. Listing Of Ansys Input Macro APPLY_LOADS_360.MAC

```
!nodes around soil perimeter
csys,22
nsel,s,loc,x,totalwidth-1,totalwidth+1
d,all,uy,0
d,all,ux,0

!nodes at bottom of soil
allsel
*get,mnz,node,,mnloc,z
nsel,s,loc,z,mnz-1,mnz+1
d,all,uz,0

!nodes along centerline
nsel,s,loc,x,-.1,.1
d,all,ux,0
d,all,uy,0
d,all,rotz,0

!pressure at grade
allsel
*get,mxz,node,,mxloc,z
nsel,s,loc,z,mxz-.1,mxz+.1
sf,all,pres,pres_surf/144

!10-foot concentrated load
p_cload=point_cent/(3.14159*point_rad**2)
nsel,s,loc,z,mxz-.1,mxz+.1
nsel,r,loc,x,0,point_rad+.1
sf,all,pres,p_cload+pres_surf/144
allsel

!gravity
acel,,386

!liner pressure loads
p_annulus=pres_annulus/12*62.4/144
p_internal=pres_int/12*62.4/144

!waste depth and unit weight
hw1=height_waste1
gammaw1=gamma_waste1
hw2=height_waste2
gammaw2=gamma_waste2
hw3=height_waste3
gammaw3=gamma_waste3

*if,abs(gammaw1),lt,1e-3,then
      gammaw1=1e-6
```

```
*else
      gammaw1=gammaw1*62.4/1728
*endif
*if,abs(gammaw2),lt,1e-3,then
      gammaw2=1e-6
*else
      gammaw2=gammaw2*62.4/1728
*endif
*if,abs(gammaw3),lt,1e-3,then
      gammaw3=1e-6
*else
      gammaw3=gammaw3*62.4/1728
*endif

zz4=0
zz3=hw1
zz2=zz3+hw2
zz1=zz2+hw3
zz0=460
pp0=p_internal
pp1=p_internal-p_annulus
pp2=pp1+hw3*gammaw3
pp3=pp2+hw2*gammaw2
pp4=pp3+hw1*gammaw1

/pbc,all,0
/psf,pres,,2
/psym,esys,0
allsel

!primary liner
esel,s,real,,50,54
nsle
cm,nliner,node

!top reaches of dome
allsel
csys,0
cmsel,s,nliner
nsel,r,loc,y,zz0,9999
sfgrad,pres
sf,all,pres,pp0

!space between top of fluid and prim/secon liner intersection
cmsel,s,nliner
nsel,r,loc,y,zz1,zz0
sf,all,pres,pp1

!waste region 3
cmsel,s,nliner
```

```
nsel,r,loc,y,zz2,zz1
esln
esel,r,type,,1
nsle,,1
sfgrad,pres,0,y,zz1,-(pp1-pp2)/hw3
sf,all,pres,pp1

!waste region 2
cmsel,s,nliner
nsel,r,loc,y,zz3,zz2
esln
esel,r,type,,1
nsle,,1
sfgrad,pres,0,y,zz2,-(pp2-pp3)/hw2
sf,all,pres,pp2

!waste region 1
cmsel,s,nliner
nsel,r,loc,y,zz4,zz3
esln
esel,r,type,,1
nsle,,1
sfgrad,pres,0,y,zz3,-(pp3-pp4)/hw1
sf,all,pres,pp3

!annulus
esel,s,type,,1
nsle,,1
cmsel,u,nliner
nsel,u,loc,y,-9999,-8.124
esln
esel,r,type,,1
nsle,,1
cm,nsecon,node
esln
esel,r,type,,1
sfgrad,pres
sf,all,pres,p_annulus

cmsel,s,nliner
cmsel,a,nsecon
esln
/psf,pres,,2
nplot
```

Attachment 9.29. Listing Of Ansys Input Macro MESH_SIZE_360.MAC

```
eesize=4            !default element size for rebar [in]
soil_size=20        !default element size for soil elements [in]
swp_th=360          !sweep angle [deg]
swp_sl=2.862        !slice model sweep angle [deg]
num_div=6           !number of elements per quadrant
```