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1	1	Cog. Mgr. C. Defigh-Price	C. Defigh-Price	R2-58	6-19-03						
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Sample AOR Calculation using ANSYS Parametric Model for Tank DST-AY

L.J. Julyk/T.C. Mackey
CH2M HILL Hanford Group, Inc.
Richland, WA 99352
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Abstract: This document documents the ANSYS parametric model for double-shell tank AY and provides sample calculation for analysis-of-record mechanical load conditions.

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Sample AOR Calculation using ANSYS Parametric Model for Tank DST-AY

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

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

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Sample AOR Calculation using ANSYS 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

Date Published
May 2003

CH2MHILL
Hanford Group, Inc.
P. O. Box 1500
Richland, Washington

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

Document Reviewed: RPP-14001, Rev. 0, Sample AOR Calculation using ANSYS Parametric Model for Tank DST-AY

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

Document Reviewed: RPP-14001, Rev. 0, Sample AOR Calculation using ANSYS Parametric Model for Tank DST-AY

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) B. V. Winkel 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.
	2	Concrete creep coefficients listed are incorrectly specified for implicit user-defined creep. Solid65 elements can only use explicit creep.	See RPP-13990 for proper creep coefficient specification and usage.
Submodel.mac	3	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 provide a sample analysis of the DST-AY tanks based on AOR loads, plus loads identified in the Statement of Work (SOW) for CHG contract 92879. This is not an analysis. Instead, the present calculation utilizes the parametric model generated for 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, and evaluates stresses and deformations throughout the tank and surrounding soil mass.

The sample calculation in this document is 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. A parametric model of the DST-AY tanks [Ref_1] was analyzed using ANSYS (7.0), a general-purpose finite element analysis program [Ref_3]. Contour plots showing stress and displacement are provided, as are the force/moment resultants. A 2.862-degree slice of the full 360-degree model was analyzed. Since all loads and boundary conditions are symmetric with respect to the tank center axis, the stress analysis results are also axisymmetric.

2. Miscellaneous hand calculations are performed using Excel [Ref_4] spreadsheets and MathCad 7.0 [Ref_5] documents. All calculations are confirmed using either a handheld calculator or an alternate form of calculation.

4.0 INPUT DATA

Reference 1 documents the parametric finite element analysis model developed for the DST-AY tanks. The basic geometry for this tank is shown in Figure 1. The parametric model includes material properties for the tank and slab reinforced concrete and reinforcing steel, the primary and secondary liner steel, the steel used for j-bolts, stiffeners, anchors and studs, and the insulating concrete. It also provides nominal soil material properties. For purposes of this calculation, the soil overburden (at the top of the tank dome) is 8.3 feet [Ref_2], with a unit weight of 125 pcf, Poisson ratio of 0.27, and friction angle of 35.4 degrees. The soil material properties are unique to three layers – above the haunch, alongside the tank, and below the tank. (See [Ref_9].) These layers are shown in Figure 6.

The SOW [Ref_2] identifies loads and material properties that may or may not be the same as those used as default values in [Ref_1]. They are summarized in Table 1. The tank is assumed to contain no liquid waste material.

Figures 2 through 6 show the finite element mesh used for this calculation, with the colors representing different materials.

The internal pressure loads on the primary liner are shown in Figures 7 and 8, and the distributed and point loads at the ground surface are shown in Figure 9.

The parametric inputs used in this calculation are summarized in the attachments. They are included in the following file (see Attachment 9.01):

- **set_parms.mac**

Other than the parametric values specified in set_parms.mac, the standard parametric model and the associated files as specified in RPP-13990 [Ref_1] are used. The model is run by placing all the macro files (set_parms.mac from this calculation and the rest from RPP-13990) in an ANSYS 7.0 working directory, and type "set_slice" at the ANSYS command line.

Table 1. Summary of Loads/Material Properties Specified in SOW.

Description	Value
Concentrated load at grade above dome center	200,000 lbf
Uniformly distributed surface load at grade	40 psf
Pressure inside tank	-6 inches water column
Unit weight of soil above dome	125 pcf
Poisson ratio of soil above dome	0.27
Internal friction angle of soil above dome	35.4 degrees
Compressive strength of structural concrete	3000 psi
Compressive strength of insulating concrete	200 psi
Poisson ratio for structural concrete	0.15
Poisson ratio for insulating concrete	0.15
Poisson ratio for steel liners	0.3
Poisson ratio for reinforcing steel	0.3
Unit weight of liner steel	490 pcf
Unit weight of structural concrete	150 pcf
Unit weight of insulating concrete	30 pcf

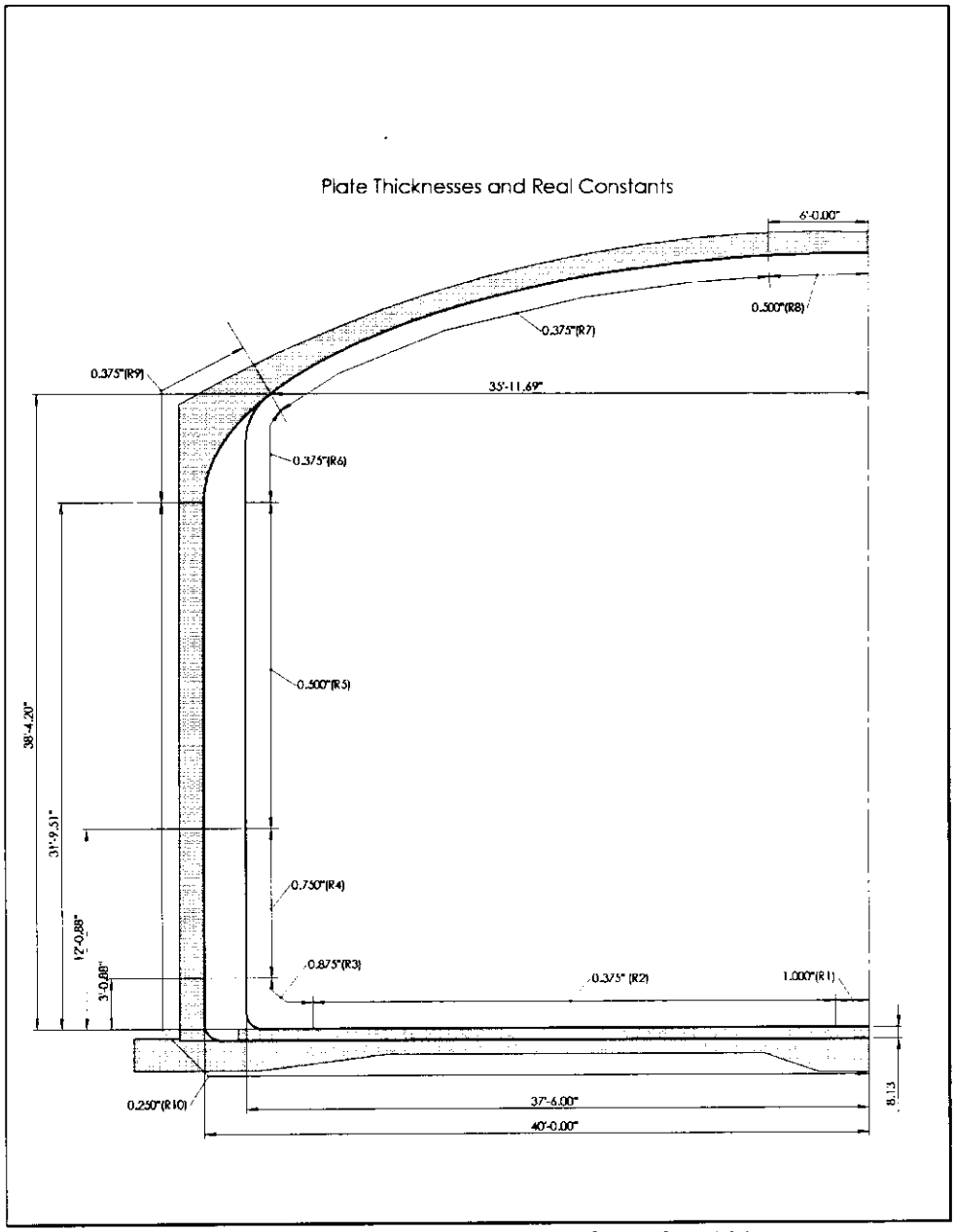

Figure 1. Liner thicknesses for DST-AY.

Table 2. Soil Material Properties.

Soil Depth (ft)	Layer	Modulus (psi)	Poisson Ratio	Density (pcf)
0-18.6	Above the haunch	7,000	0.27	125
18.6-58.9	Alongside the tank	13,000	0.27	125
58.9-155.0	Below the tank	20,000	0.27	125

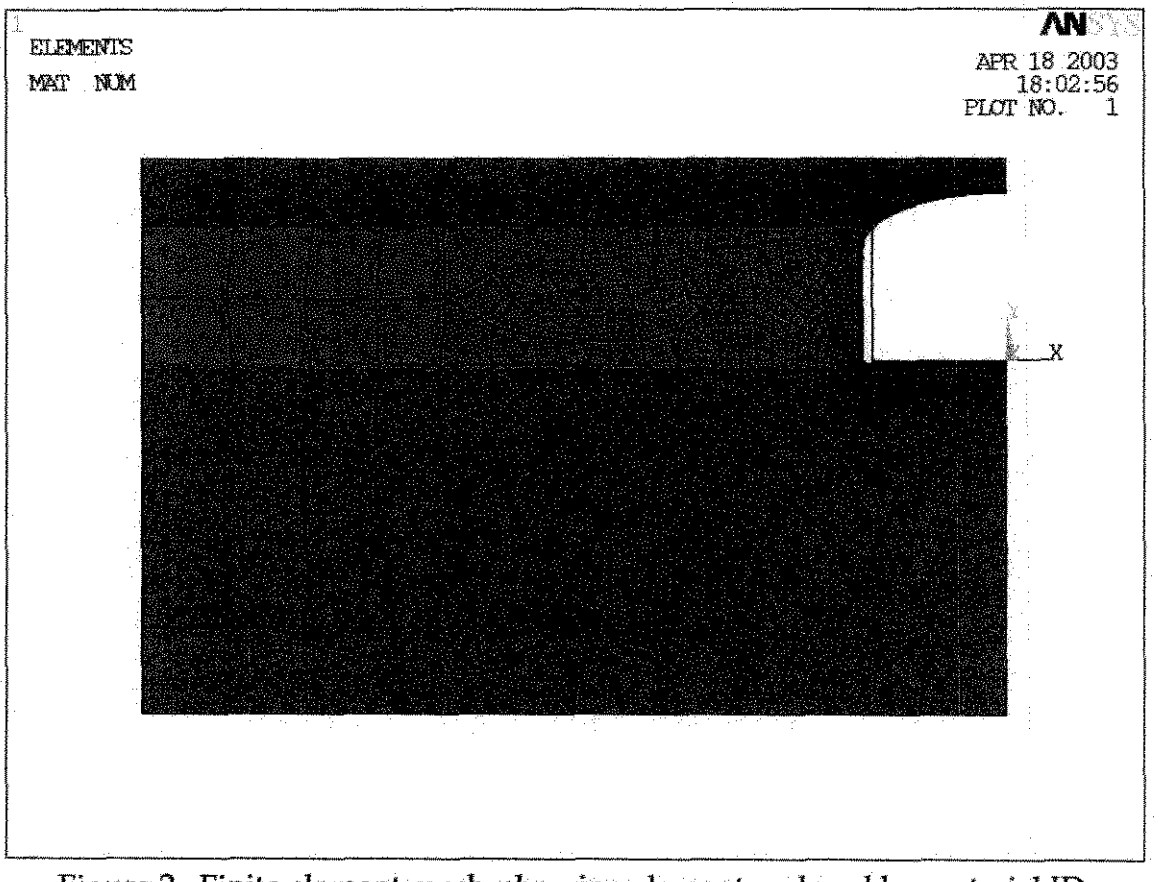

Figure 2. Finite element mesh, showing elements colored by material ID.

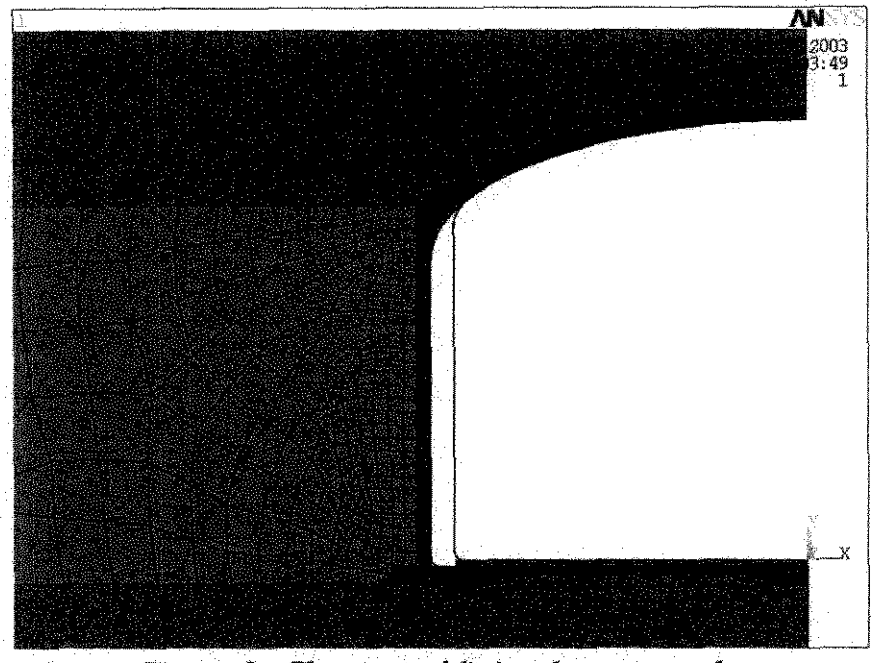

Figure 3. Close-up of finite element mesh.

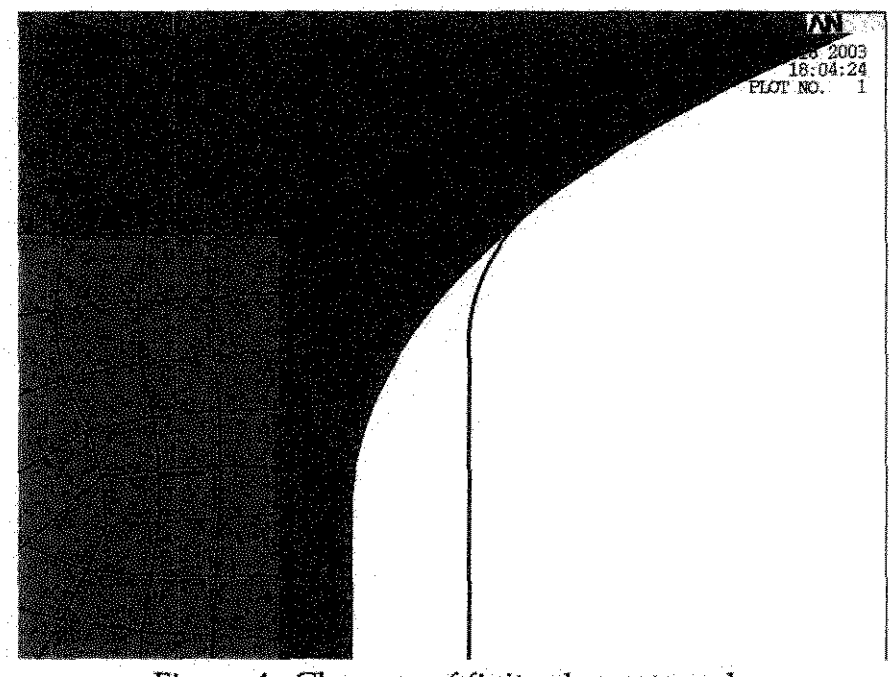

Figure 4. Close-up of finite element mesh.

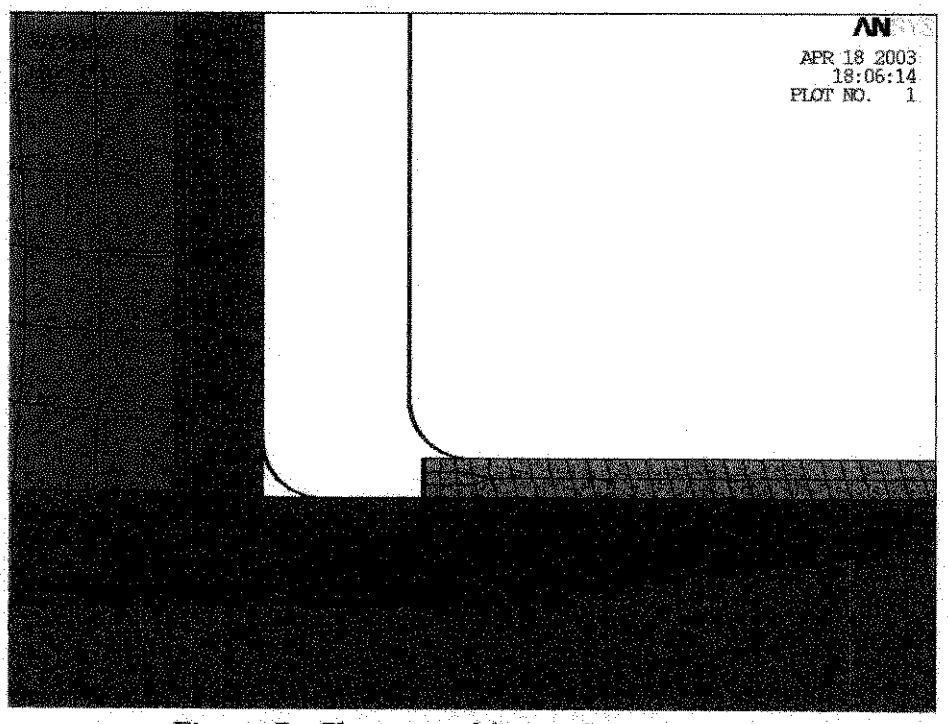

Figure 5. Close-up of finite element mesh.

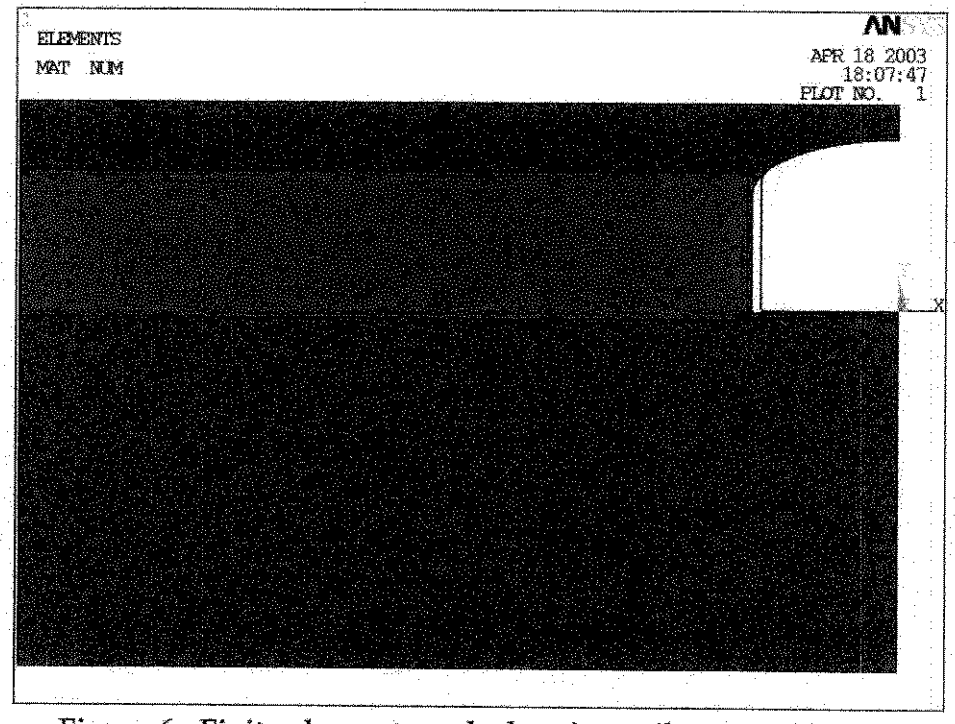

Figure 6. Finite element mesh showing soil material layers.

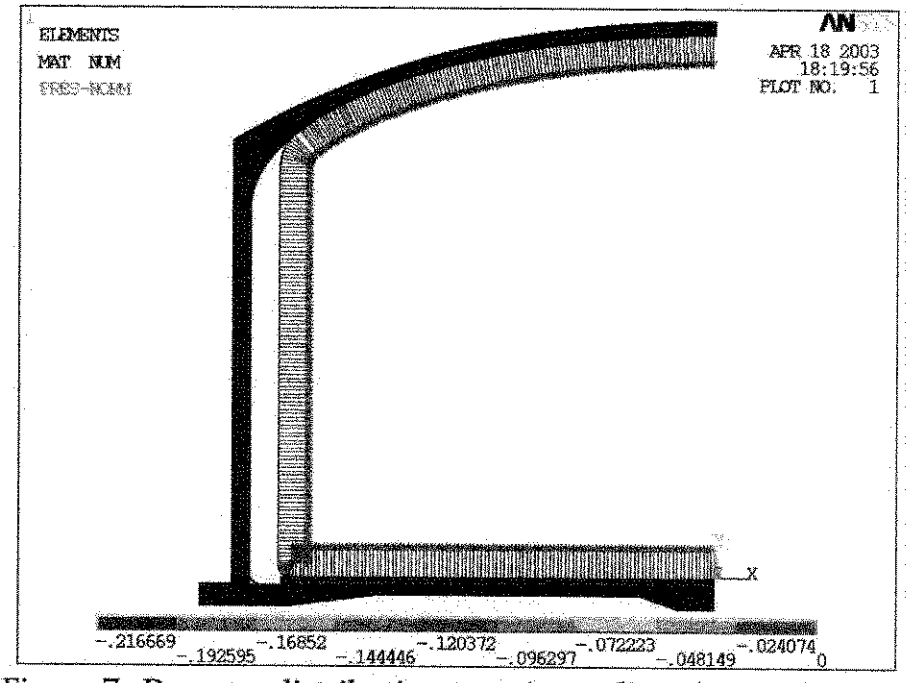

Figure 7. Pressure distribution on primary liner (vector format).

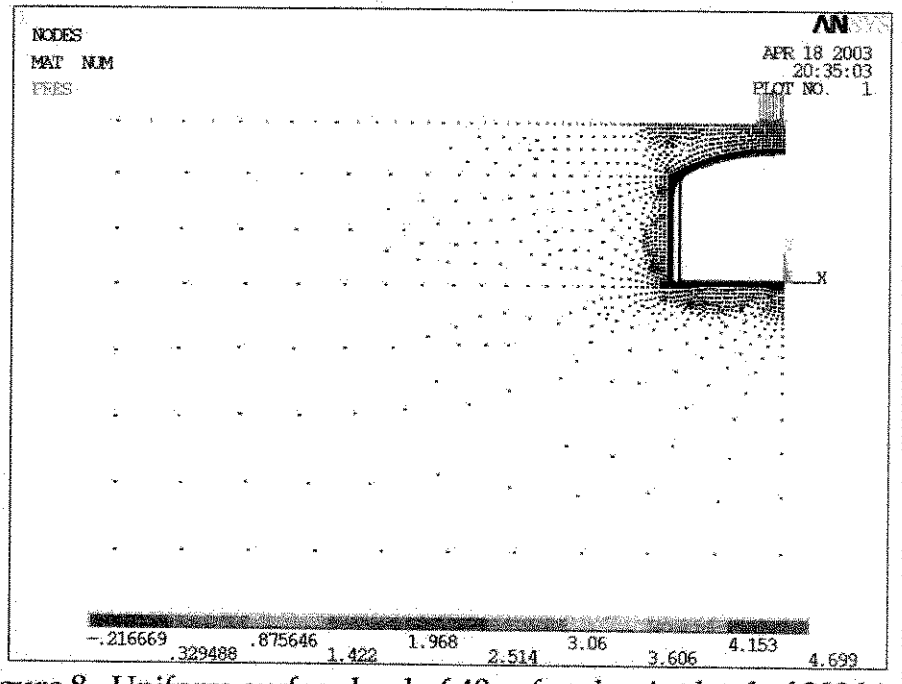

Figure 8. Uniform surface load of 40 psf and point load of 200 kips.

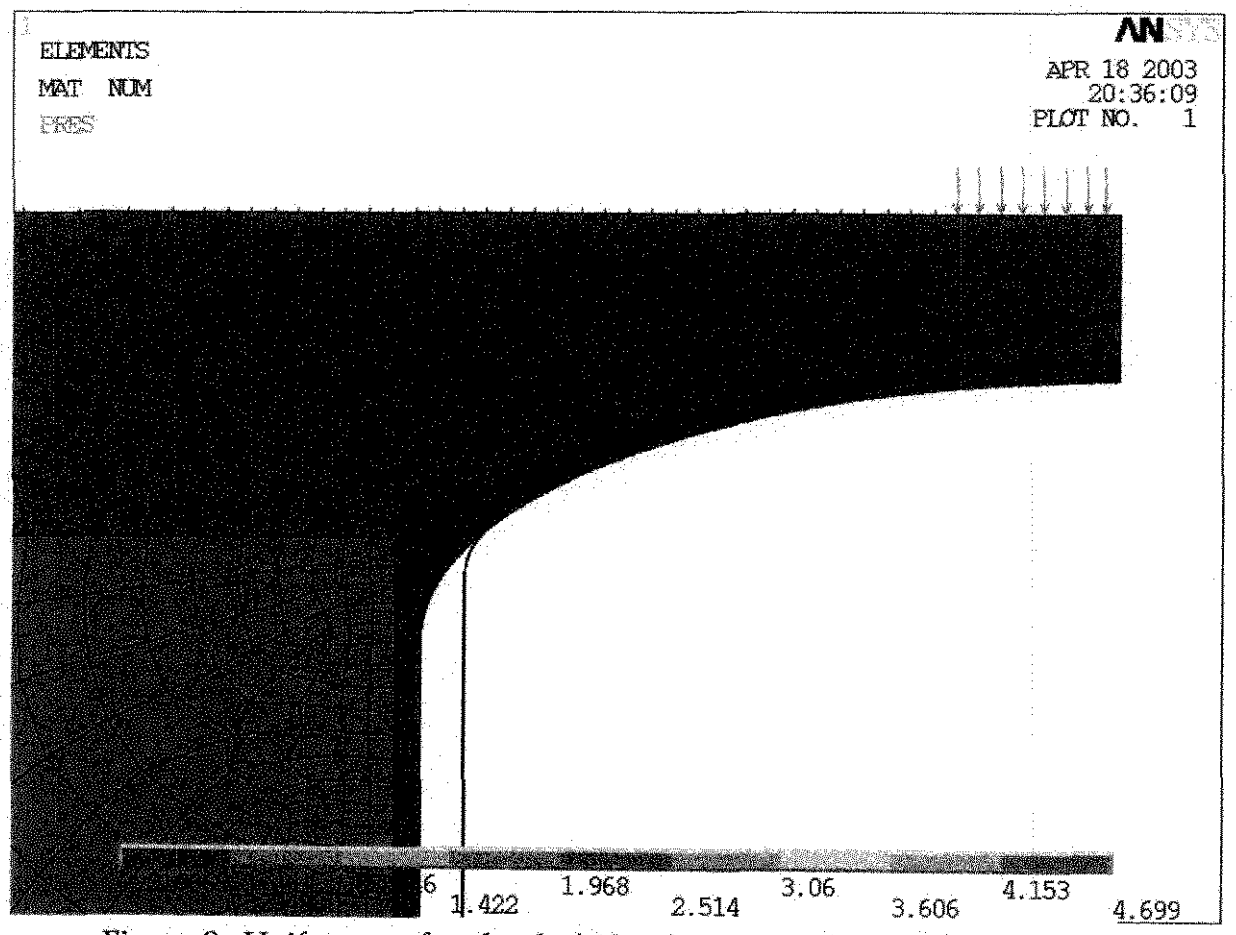

Figure 9. Uniform surface load of 40 psf and point load of 200 kips.

5.0 RESULTS

The model parameters for this calculation are specified in the following file (see attachment 9.01):

- **set_parms.mac**

This file, as well as the rest of the files required to build and run this model, are accessed by the macro **set_slice.mac** (see [Ref_1]). This macro loads the basic parametric model, creates the finite element mesh, applies loads, and defines the material properties.

Figures 10 and 11 summarize the displacement response due to loads identified in Section 4. The peak downward displacement of the soil mass is 5.5 inches, and this occurs at grade. The peak downward tank displacement is 4.7 inches; the peak upward displacement of the primary liner is 3.6 inches. The relative displacement between the dome top and slab bottom (along the centerline) is 1.17 inches. Figures 12 and 13 show true and exaggerated views respectively of the tank/slab displacement. Note the separation in Figure 13 between the bottom of the tank wall and top of the slab towards the outer radius of these mating surfaces. Also note in Figure 12 that the primary liner separates from the insulating concrete away from the outer radial region.

The von Mises equivalent stress contours are presented in Figures 14 through 16. The peak equivalent stress in the liner is approximately 12,600 psi, and this occurs at the lower bend of the primary liner (see Figure 15).

Rebar stresses are shown in Figures 17 through 26. In these figures, the stresses are shown for the various rebar directions; Table 3 identifies the local element orientations for the slab, wall, haunch, and dome steel. Figure 27 shows the local element orientation near the haunch. Note that the element "x" direction remains continuous throughout all regions. However, at the transition of the top of the vertical tank wall into the haunch region, the element "z" direction abruptly becomes the element "-y" direction. This then remains continuous through the rest of the haunch region and the dome.

Table 3. Local Rebar Element Orientations.

Region	X-direction	Y-direction	Z-direction
Slab	Radial	Circumferential	Vertical
Wall	Radial	Circumferential	Vertical
Haunch Vertical Steel	Radial	Circumferential	Vertical
Haunch Inclined Steel	Normal to surface	Tangent to surface	Circumferential
Dome	Normal to surface	Tangent to surface	Circumferential

Component stresses in the concrete are plotted in Figures 28 through 30, and the principal stresses are shown in Figures 31 to 33. The peak (tensile) principal stress is approximately 1,400 psi. High stresses occur at the base of the slab below the wall and at the top of the slab where it becomes thinner. This suggests cracking will occur in these regions (although this sample AOR calculation assumes that the concrete material is behaving linearly without any cracking). The peak compressive principal stress is approximately 2,800 psi, and it occurs at the top of the slab where the ID of the wall bears on the slab.

Section Force/Moment Path Plots using Submodeling - To address the difficulty of obtaining a smooth and reasonably accurate section force/moment path plots for the free meshed DST-AY tank, a brick meshed submodel of the tank was created and analyzed using the macro **submodel.mac**. (See attachment 9.02 for a listing of this macro plus others required for this operation.) This postprocessing step is run after the analysis is completed, and requires a consistent jobname. (Otherwise, the database file and results file needed for this step will not be found.) Besides plots, a tabular data output file called path_ay.dat is also created. The cut boundary for the submodel consists of all external areas of the tank, except the contact region at the wall/slab interface. The tank material is construction concrete without rebar; this assumes that the rebar will not affect the global section force/moment significantly.

The flow of **submodel.mac** is:

- Take in the global data base, write out CDB and IGES file for the tank, then read back in the tank geometry
- Map mesh the tank, define contact between wall/slab interface
- Get the cut boundary nodes on all external surfaces other than symmetry planes and wall/slab contact surfaces
- Read in global results, get displacement on cut boundary nodes
- Apply the cut boundary condition and symmetry BCs
- Solve for submodel results
- Get the section force/moment the same way as for SST tanks

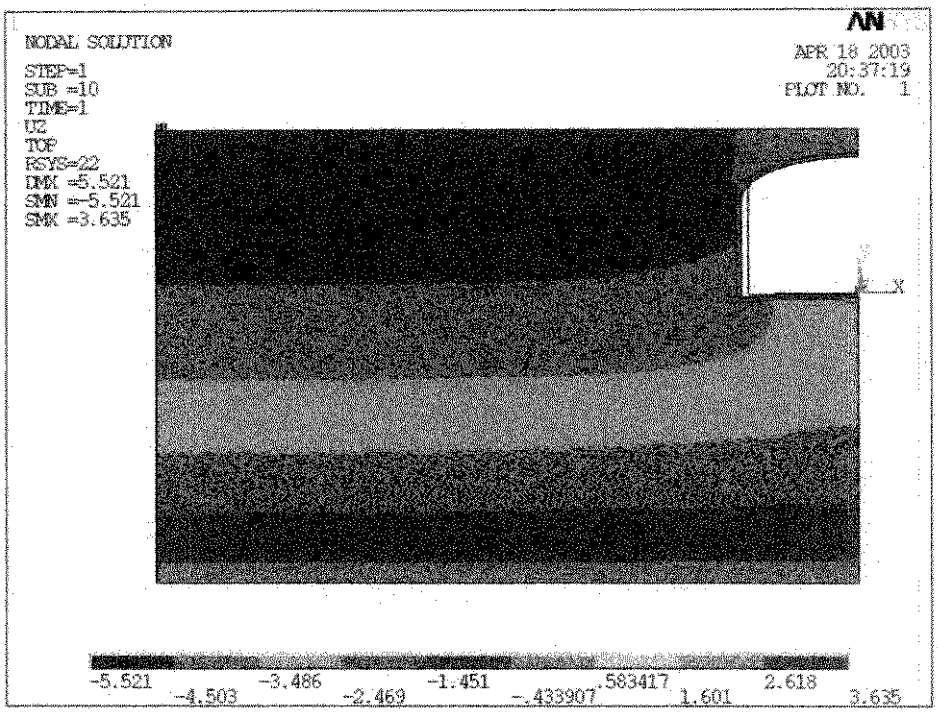

Figure 10. Displacement contours (inches).

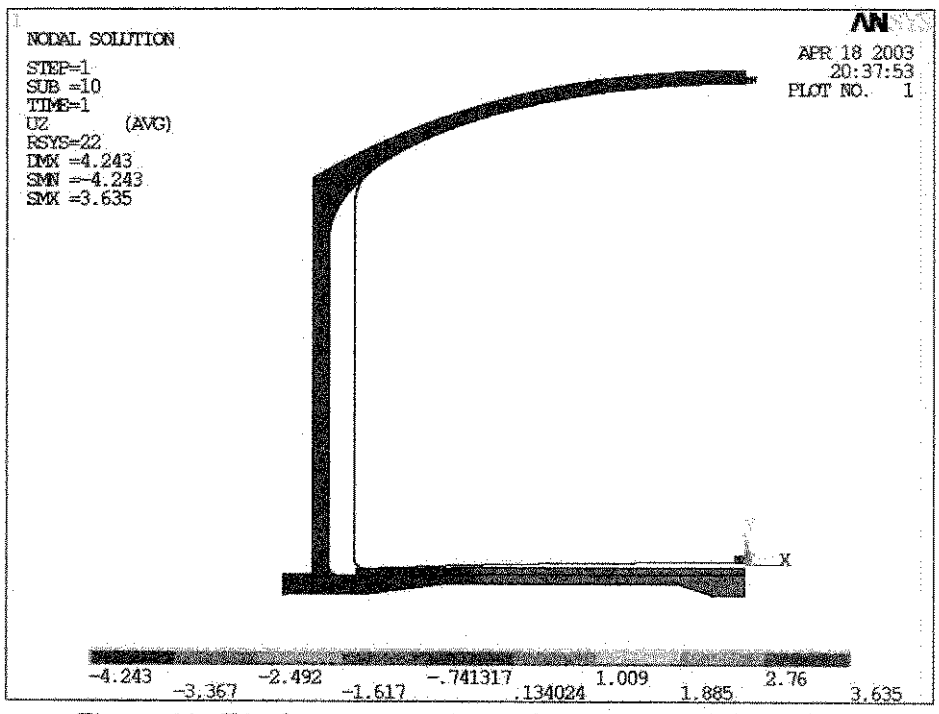

Figure 11. Displacement contours for tank and slab (inches).

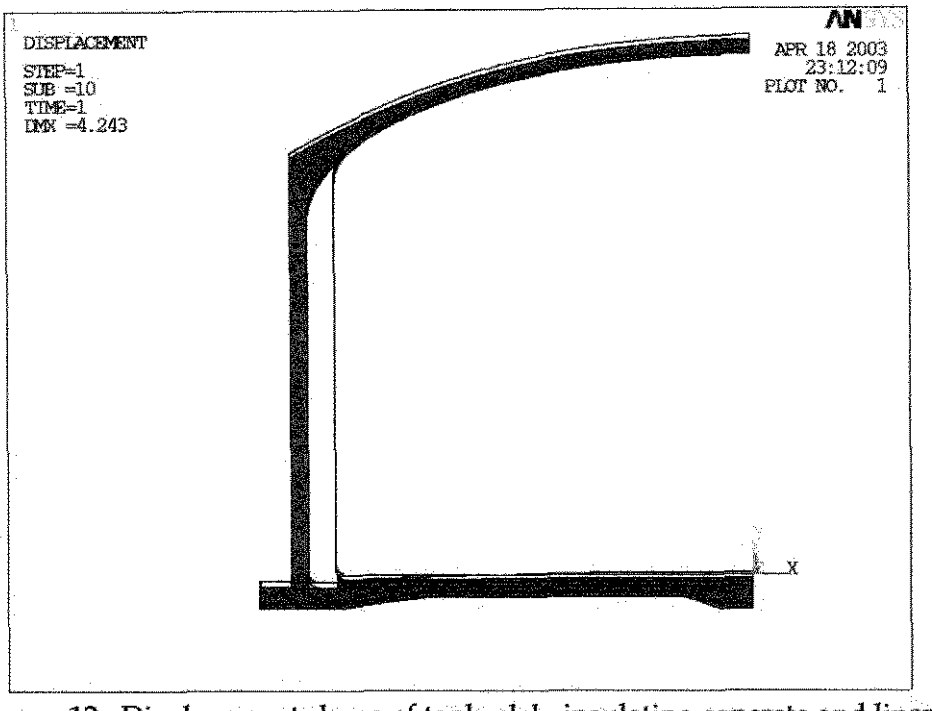

Figure 12. Displacement shape of tank, slab, insulating concrete and liners (displacement magnitude is true scale in this figure).

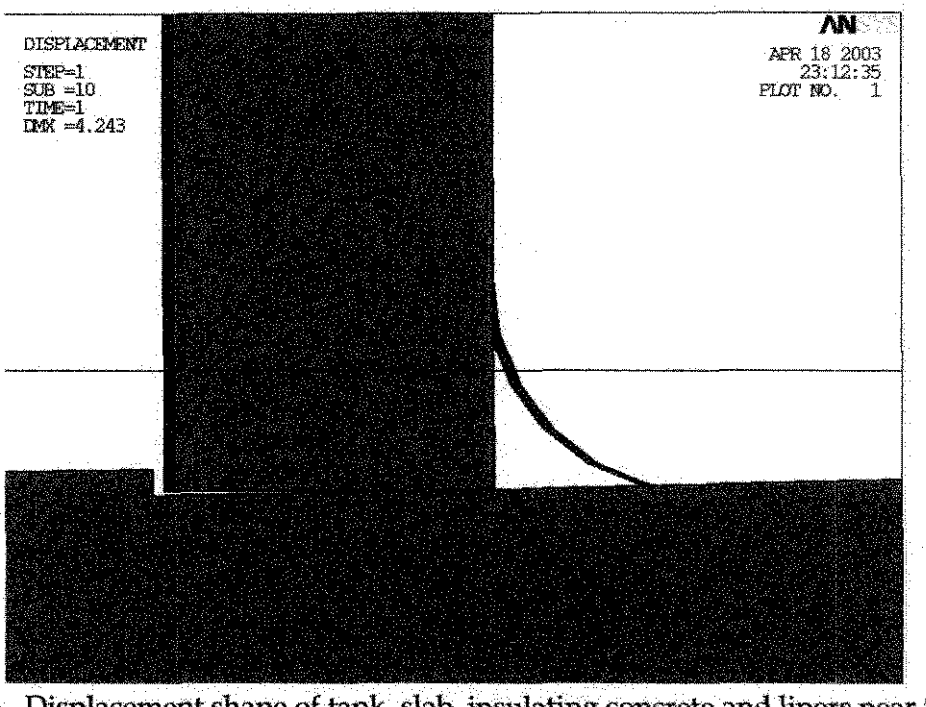

Figure 13. Displacement shape of tank, slab, insulating concrete and liners near the base of the tank wall (displacement magnitude is exaggerated in this figure).

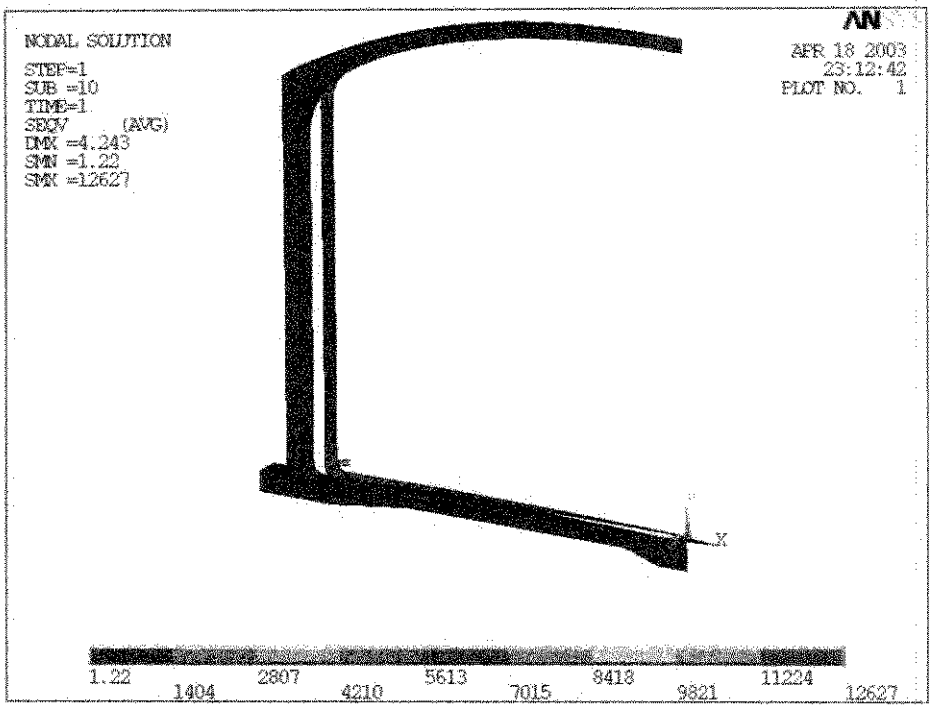

Figure 14. von Mises equivalent stress contours (psi).

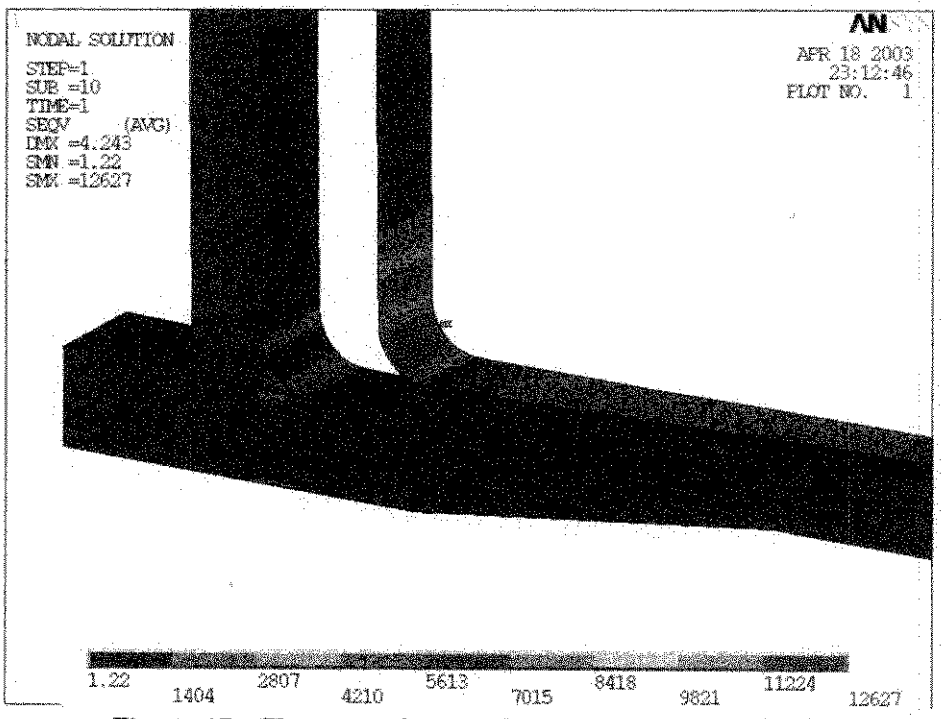

Figure 15. Close-up of equivalent stress contours (psi).

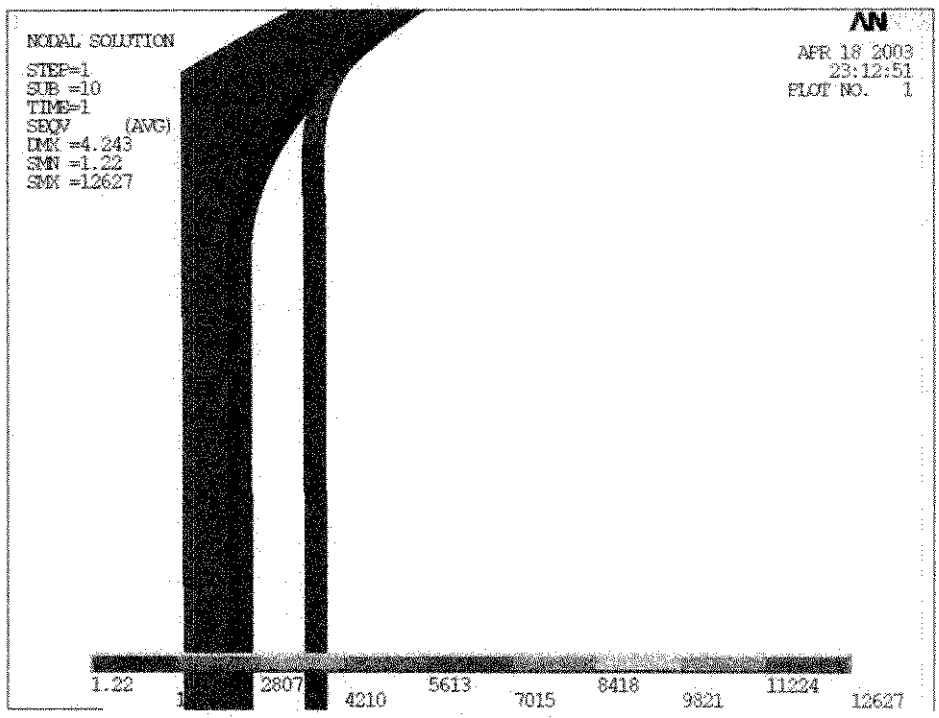

Figure 16. Close-up of equivalent stress contours (psi).

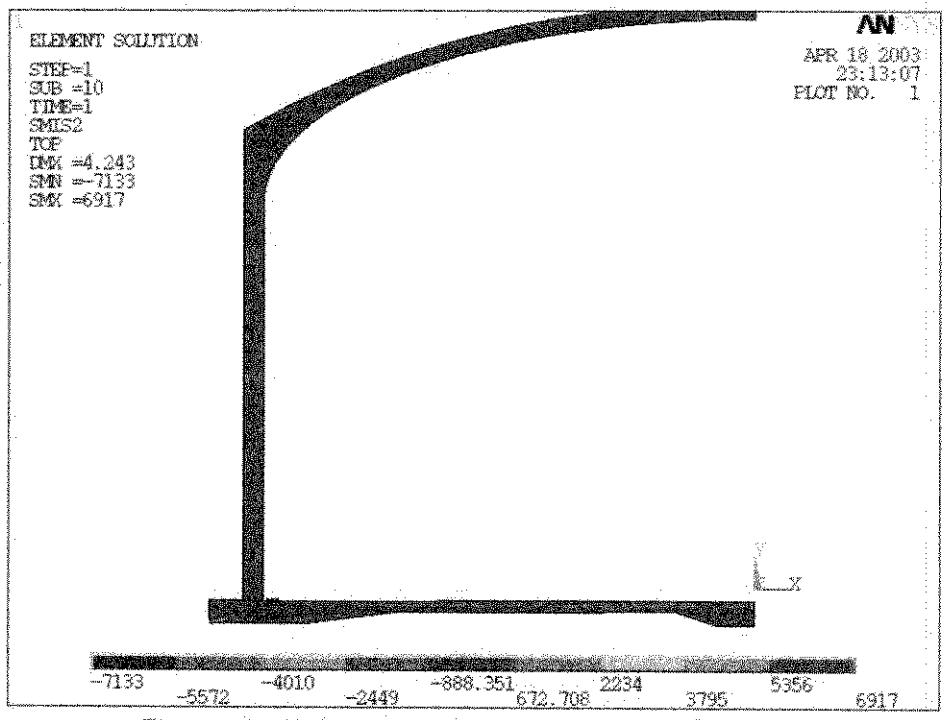

Figure 17. Rebar stress (psi) in element x-direction.

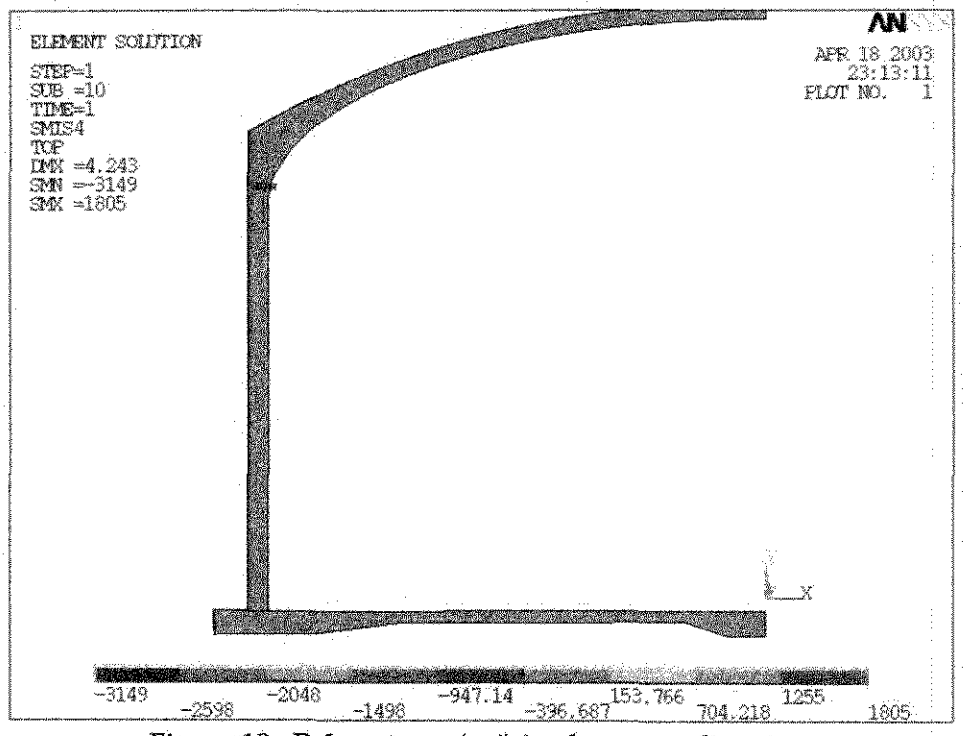

Figure 18. Rebar stress (psi) in element y-direction.

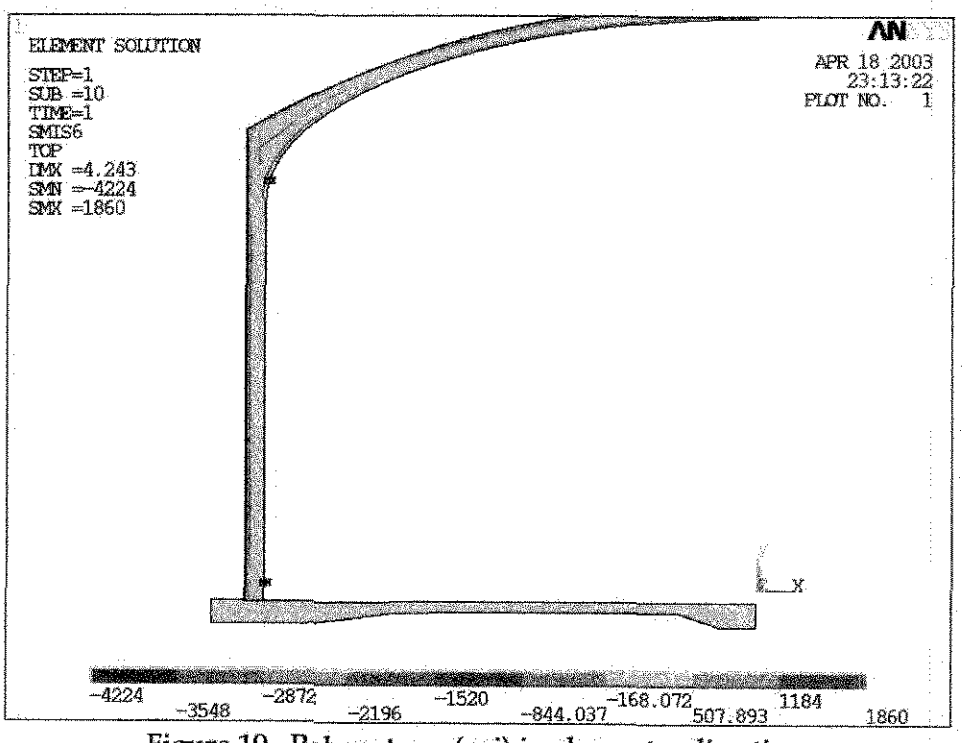

Figure 19. Rebar stress (psi) in element z-direction.

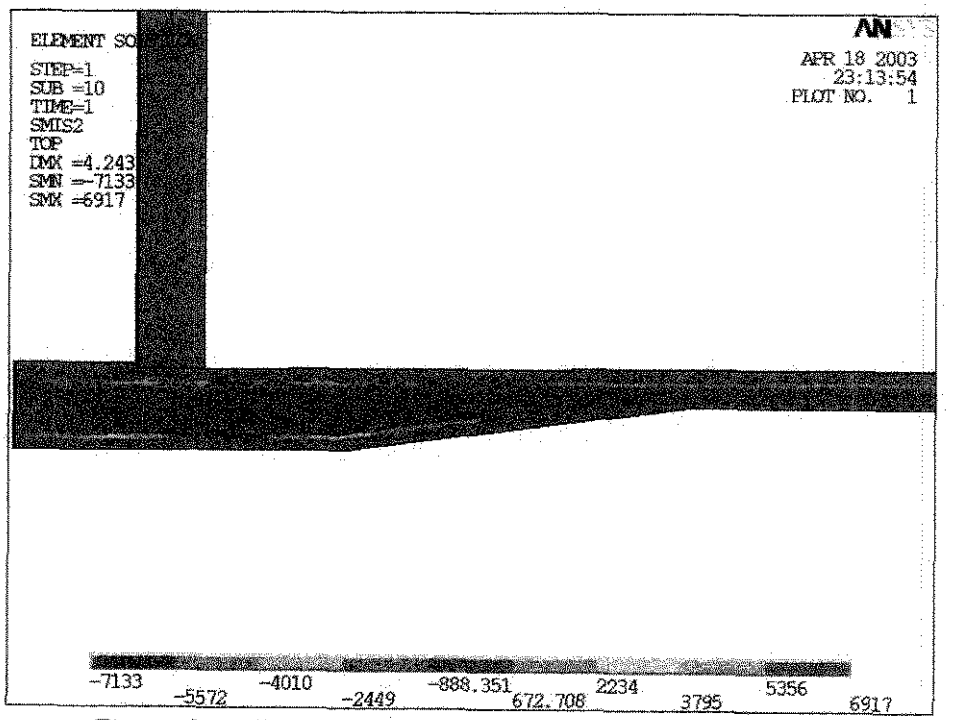

Figure 20. Close-up of rebar stress in element x-direction.

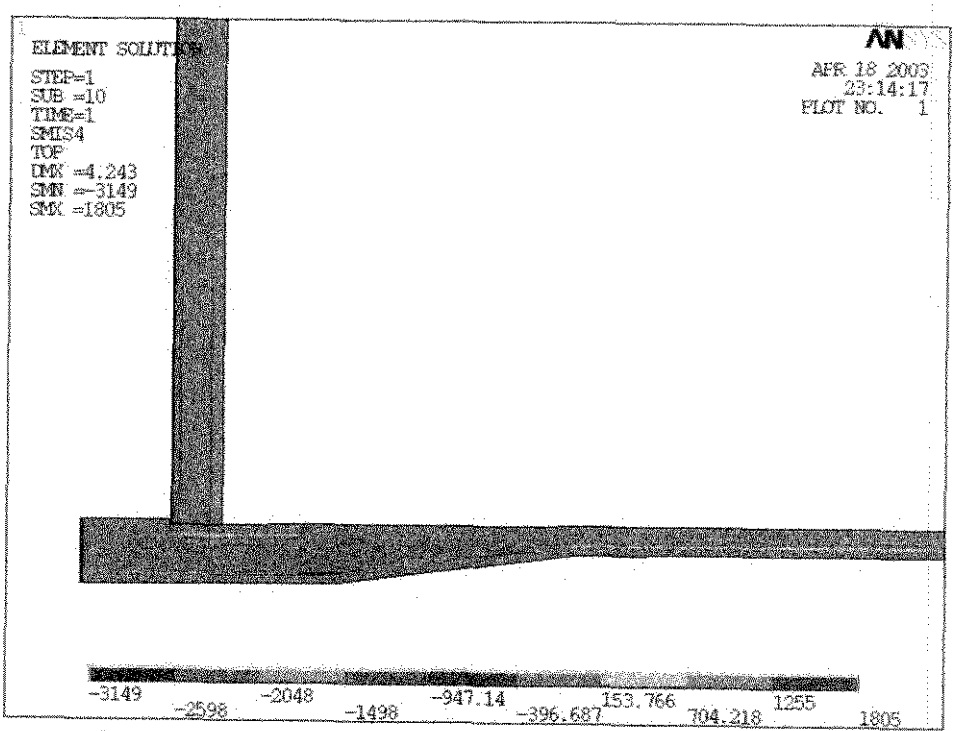

Figure 21. Close-up of rebar stress in element y-direction.

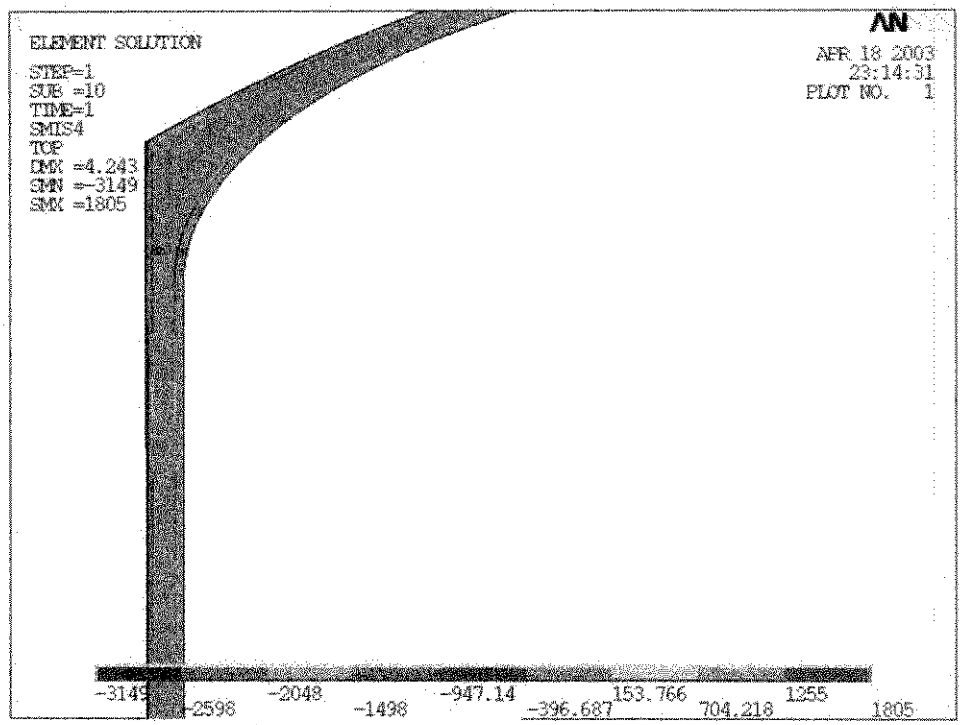

Figure 22. Close-up of rebar stress in element y-direction.

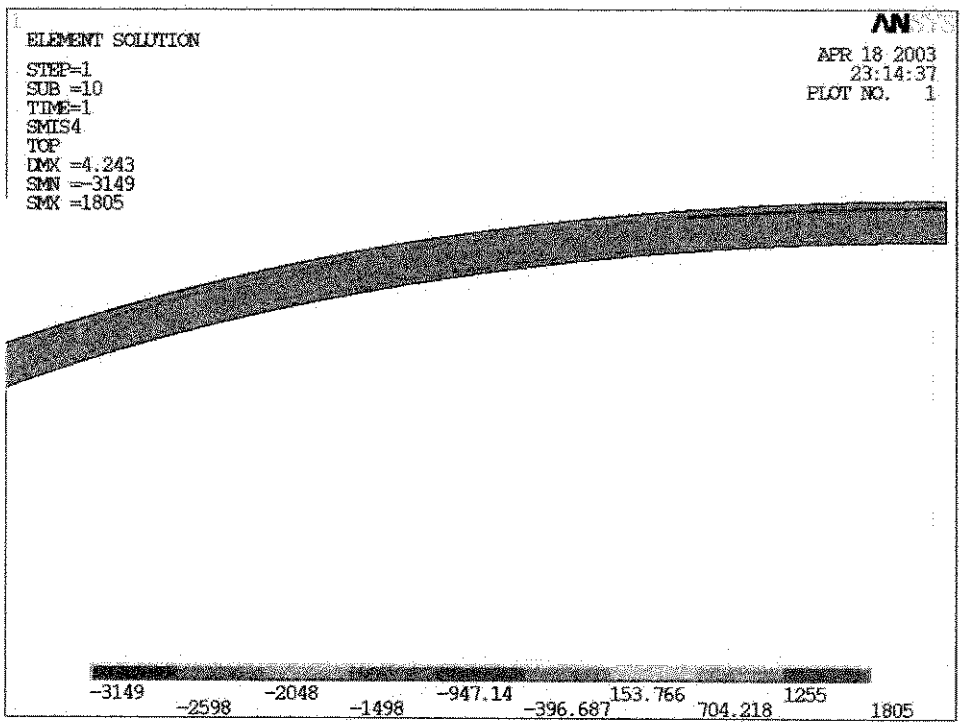

Figure 23. Close-up of rebar stress in element y-direction.

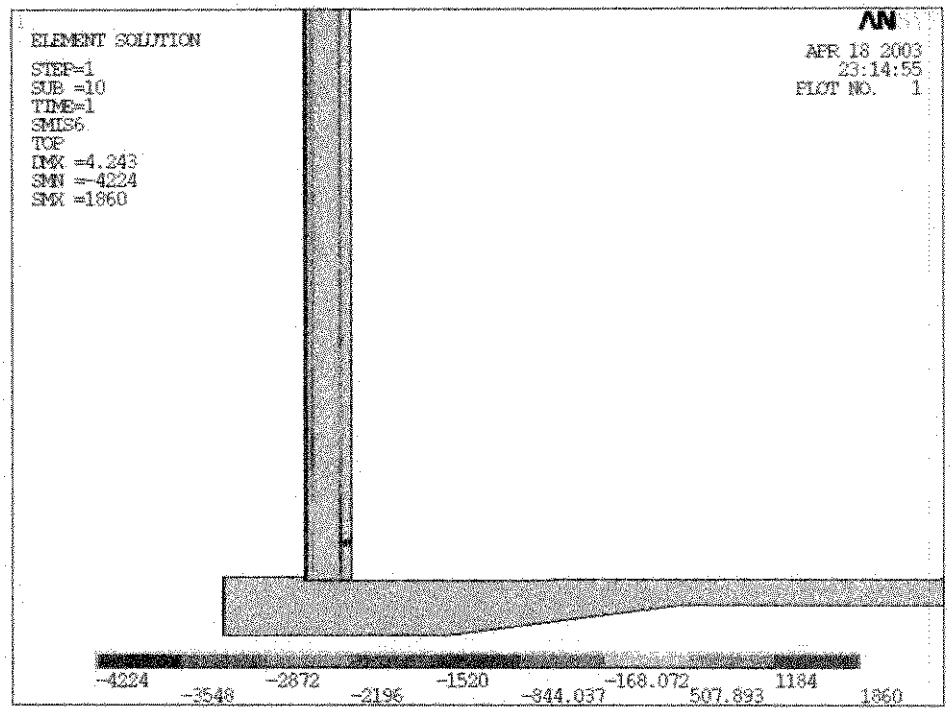

Figure 24. Close-up of rebar stress in element z-direction.

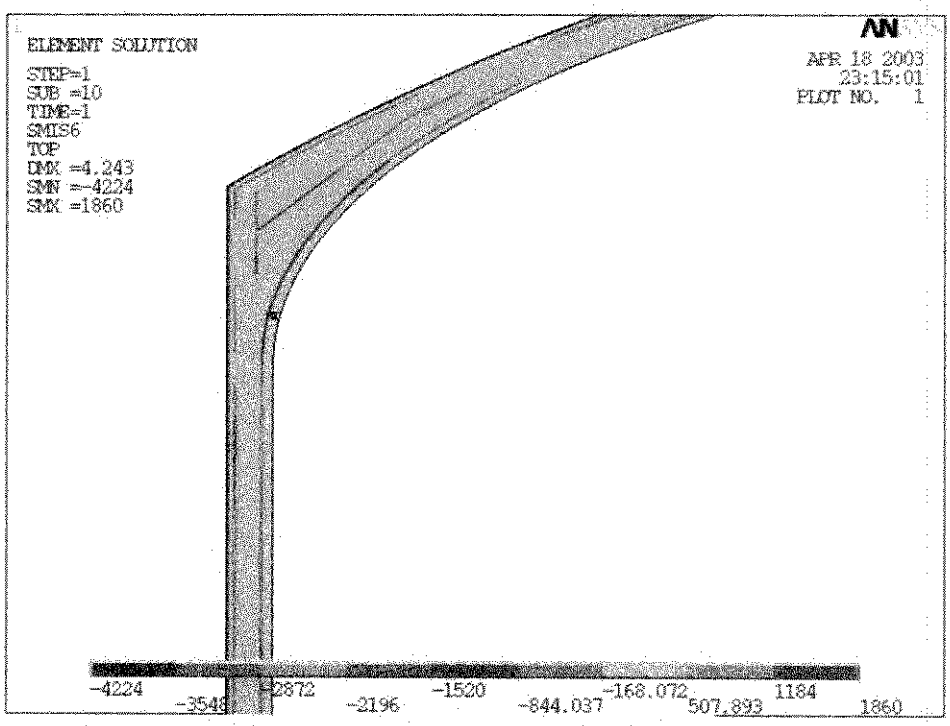

Figure 25. Close-up of element stress in element z-direction.

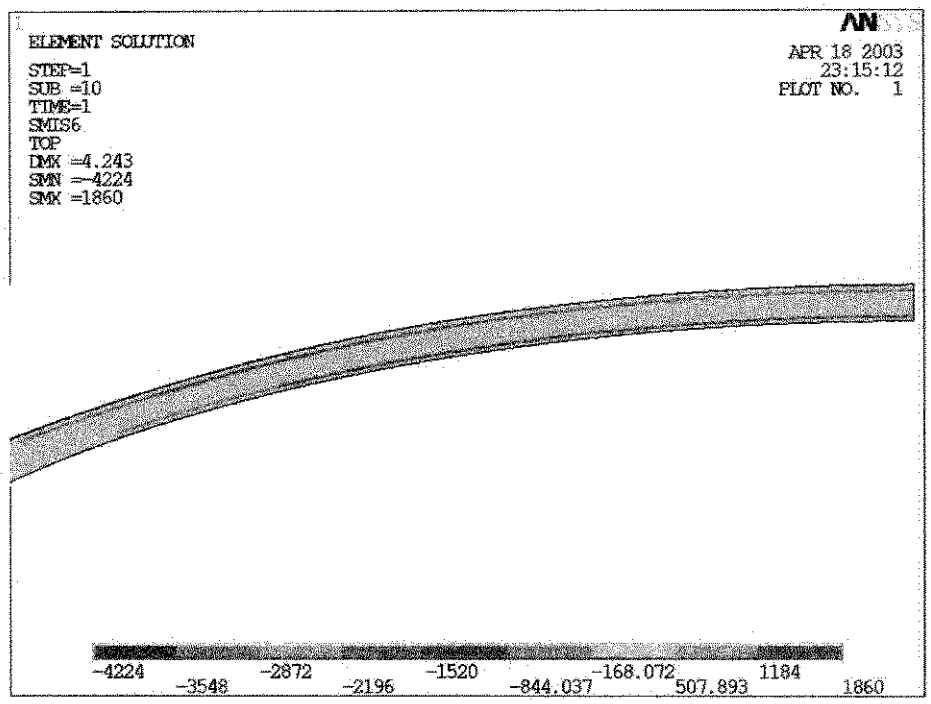

Figure 26. Close-up of element stress in element z-direction.

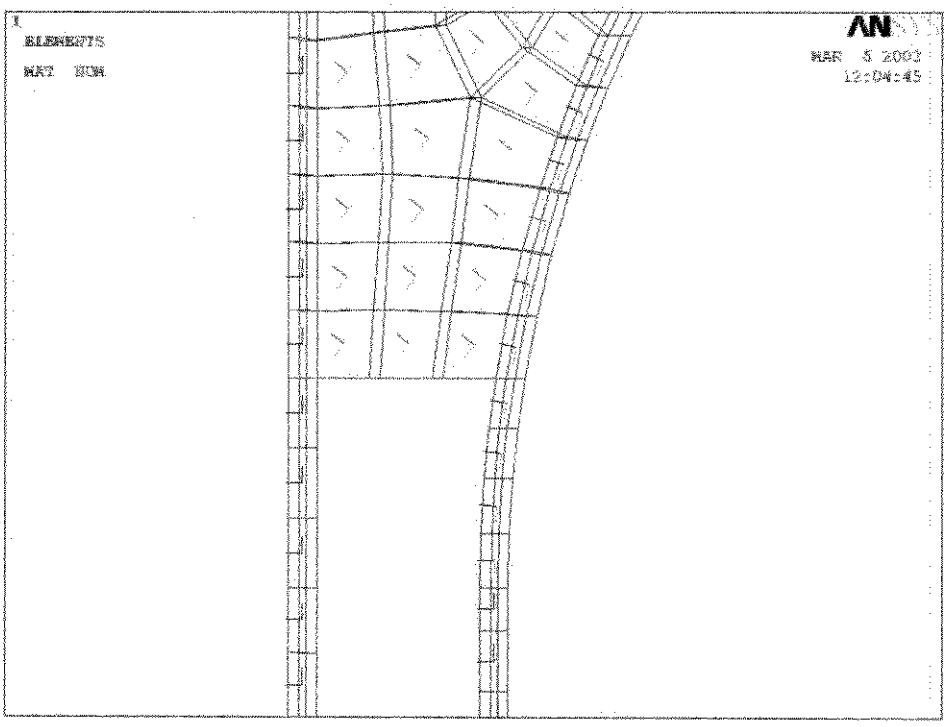

Figure 27. Element orientations in haunch region.

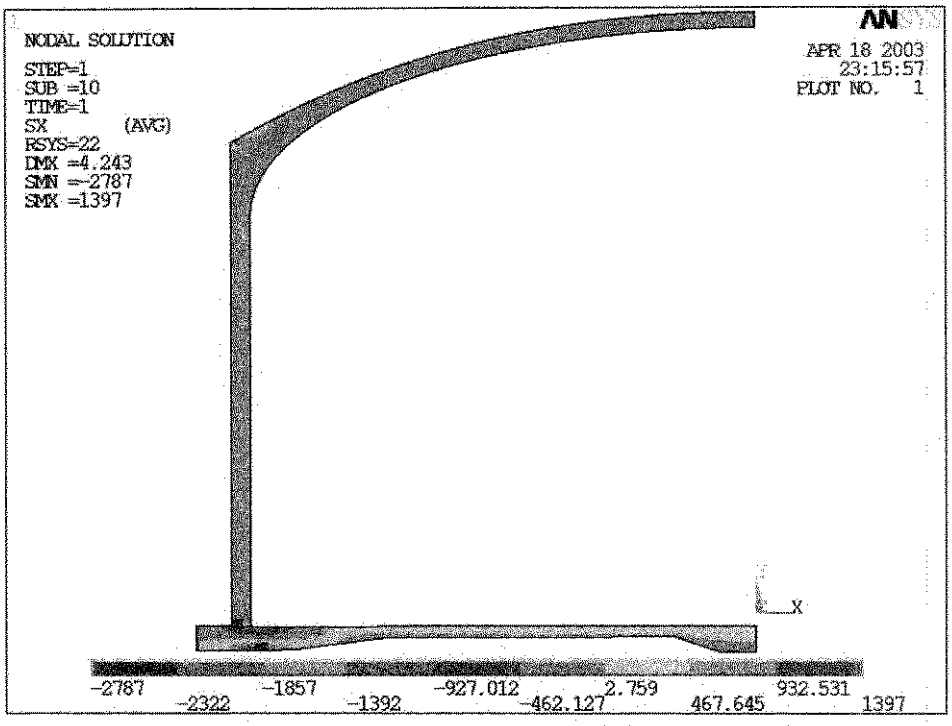

Figure 28. Concrete stress in radial direction (psi).

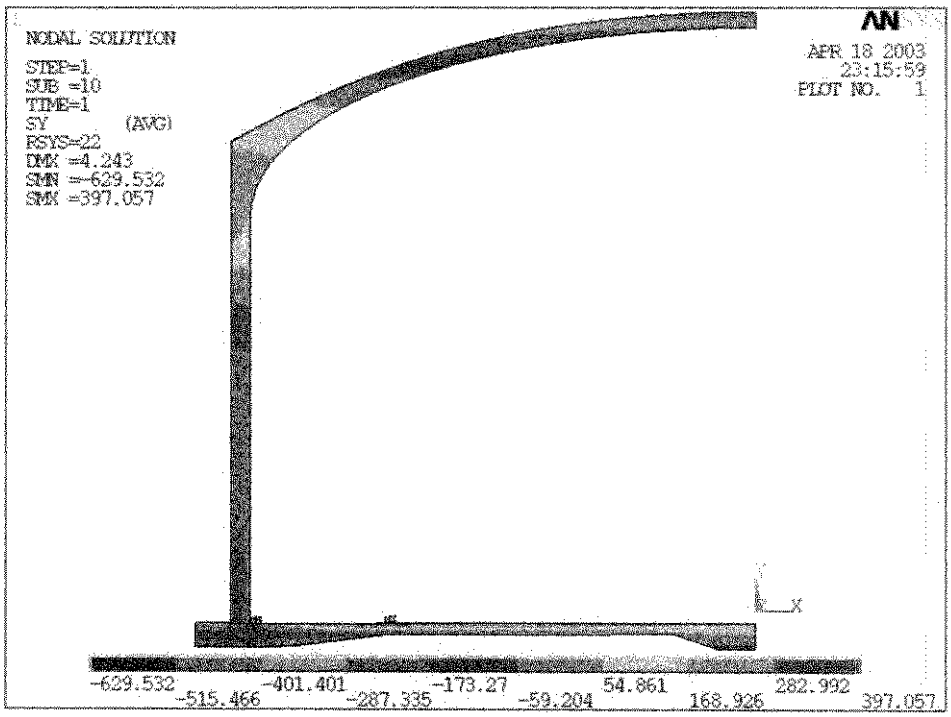

Figure 29. Concrete stress (psi) in circumferential direction.

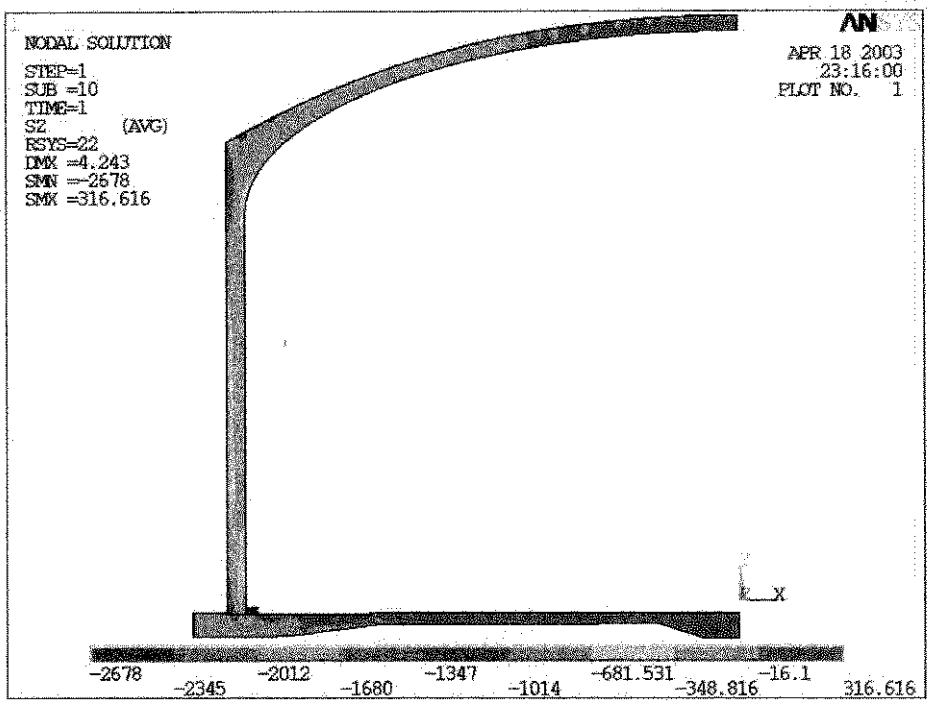

Figure 30. Concrete stress (psi) in vertical direction.

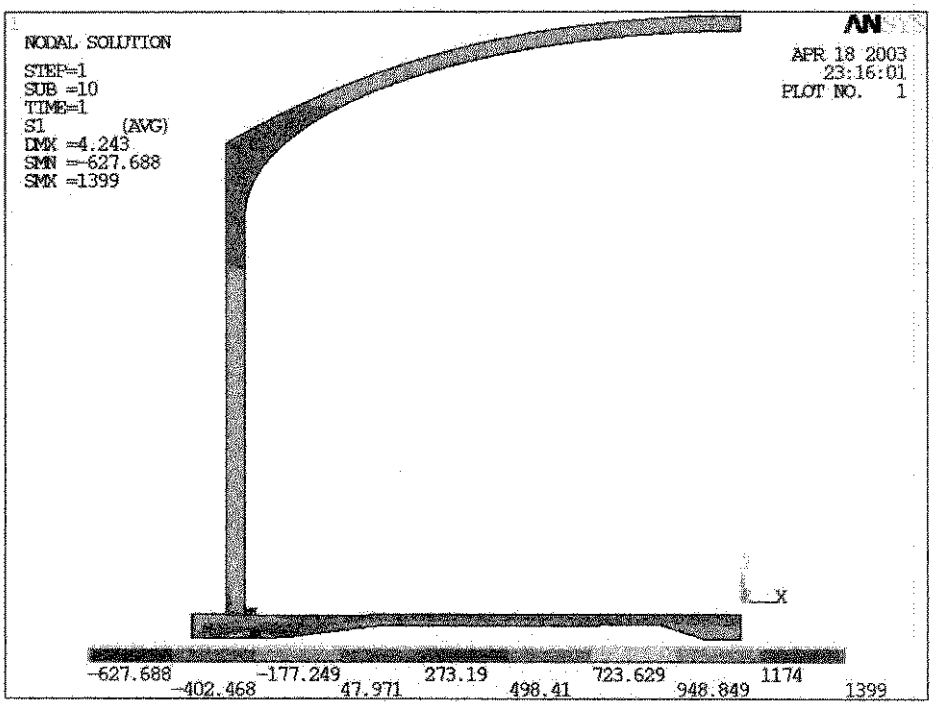

Figure 31. Concrete 1st principal stress (psi).

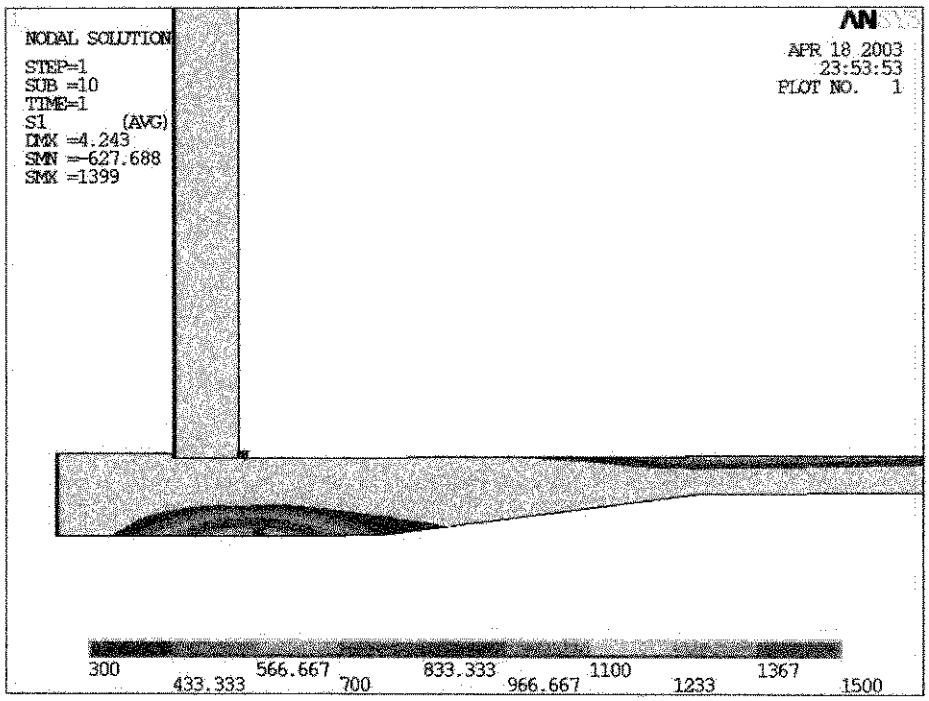

Figure 32. Concrete 1st principal stress (psi); gray region has principal stress less than 300 psi, the concrete tensile strength.

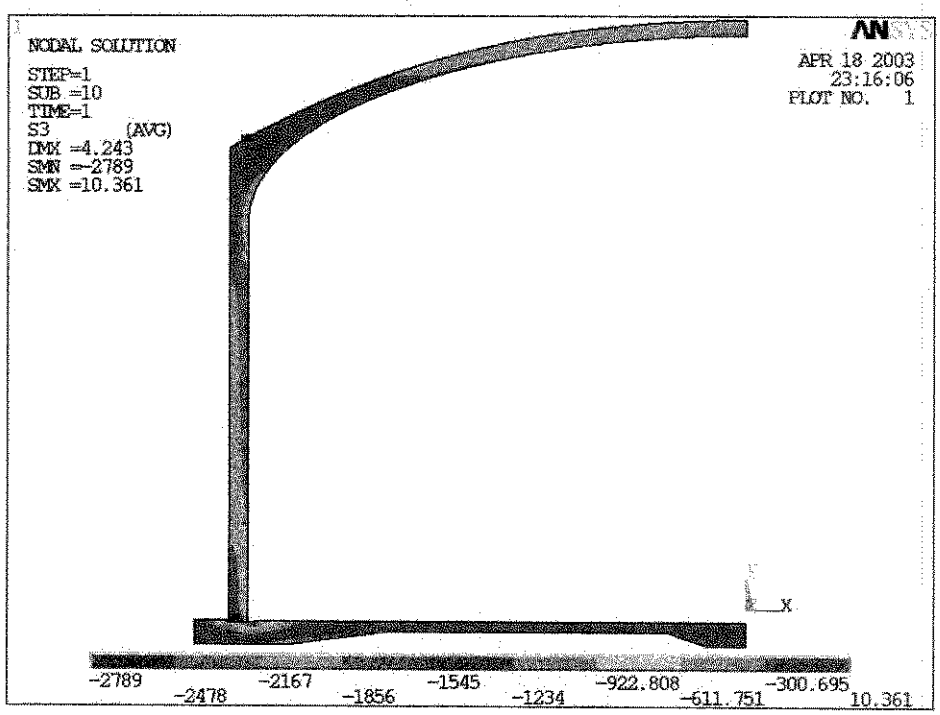

Figure 33. Concrete 3rd principal stress (psi).

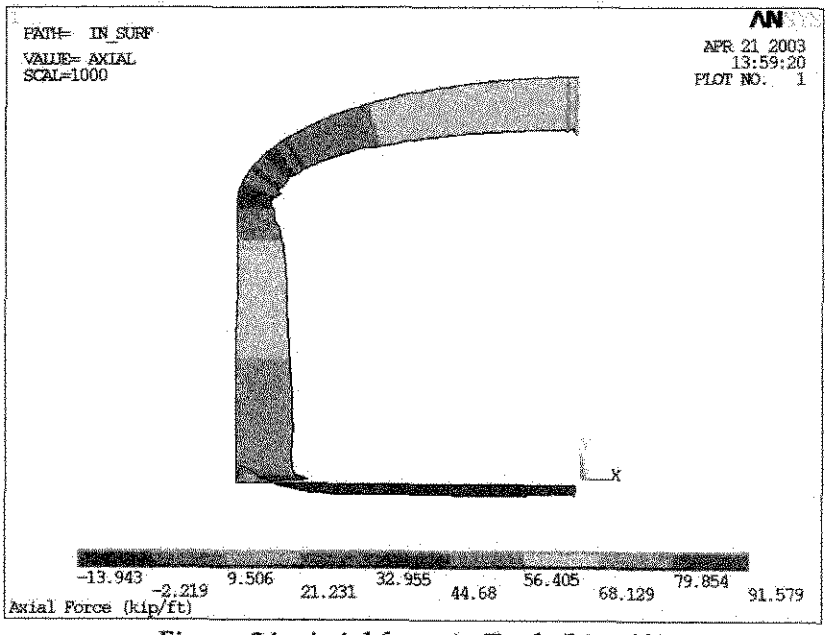

Figure 34. Axial force in Tank (kips/ft)

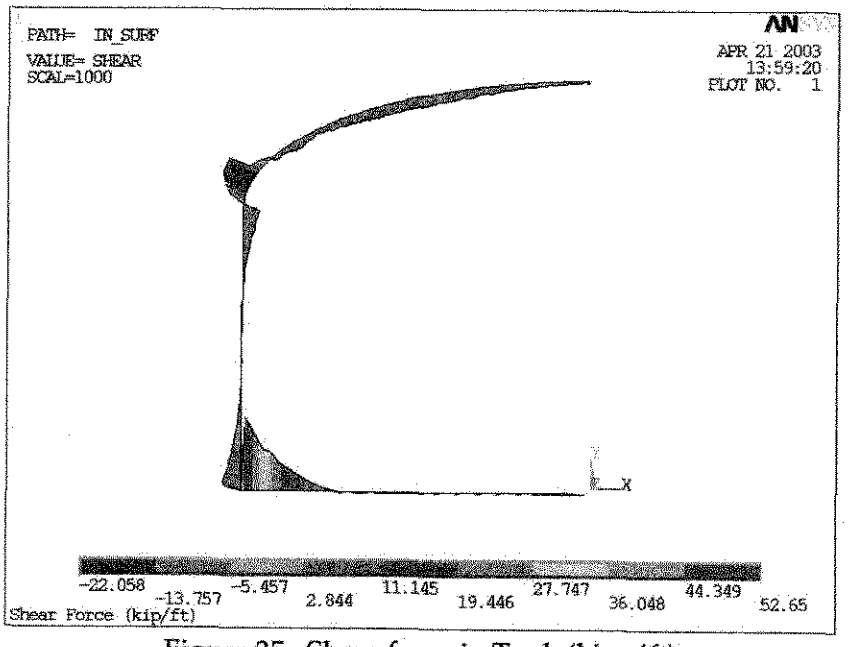

Figure 35. Shear force in Tank (kips/ft)

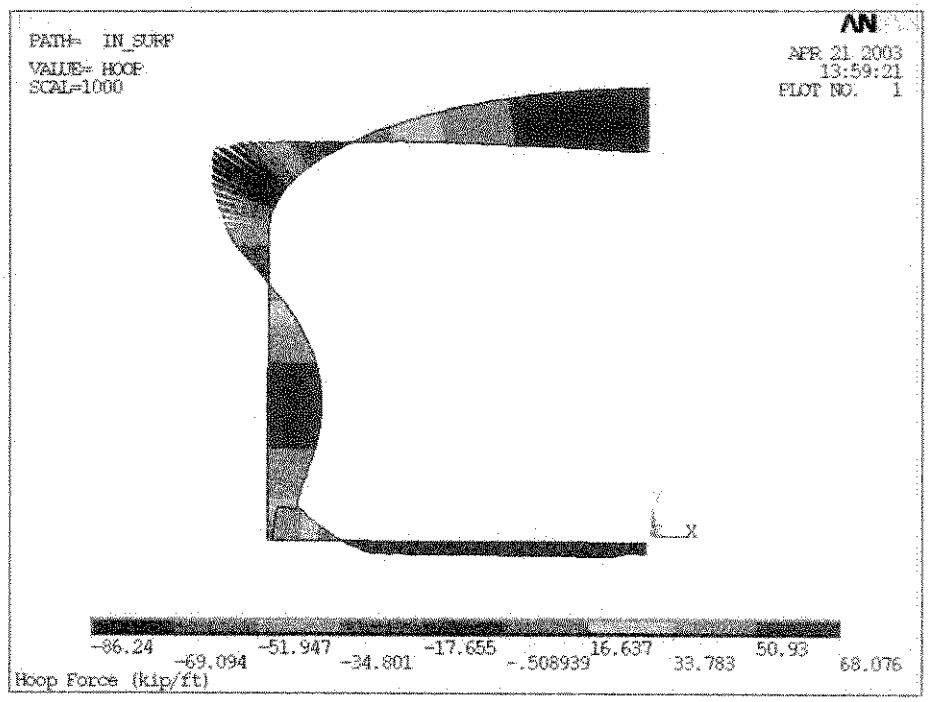

Figure 36. Hoop force in Tank (kips/ft)

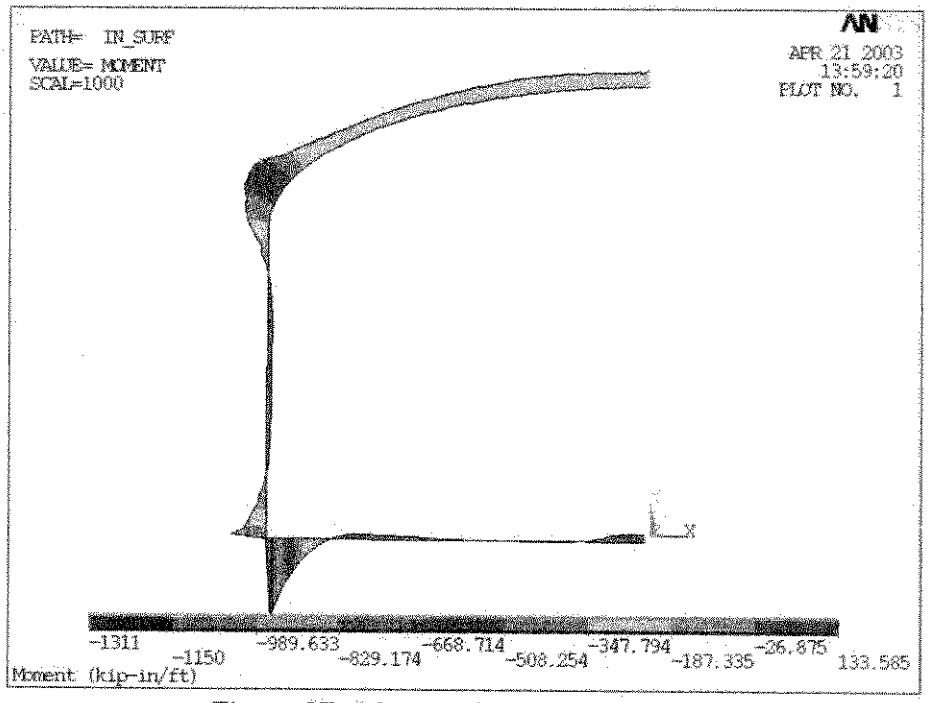

Figure 37. Moment in Tank (kip-in/ft)

6.0 CONCLUSIONS

The calculation results suggest that the base slab will sustain cracking below the tank wall and where it thins down when subjected to gravity loads, a 40 psf uniform load at the ground surface, and the 200 kip point load at grade above the dome center. The concrete compressive strength is not exceeded anywhere, and the peak equivalent stresses in the liner steel is less than 12.6 ksi. The peak axial and bending moment resultants were approximately 92 kip/ft and 1,311 kip-in/ft respectively.

The sample calculation demonstrates the use of the parametric model for tank DST-AY, and provides examples of the types of inputs that can be defined and the types of outputs that can be obtained. It is concluded that the parametric model can be used effectively to evaluate the tank response to a broad range of loading conditions and material properties.

7.0 RECOMMENDATIONS

None

8.0 REFERENCES

[Ref_1] RPP-13990, Rev. 0, "ANSYS Parametric Model for Tank DST-AY,", February, 2003.

[Ref_2] Statement of Work, Requisition #92879, "Development of ANSYS Finite Element Models for SST and DST Tanks," Revision 1, February 24, 2003.

[Ref_3] ANSYS 7.0 General-Purpose Finite Element Analysis Program, ANSYS Inc.

[Ref_4] Excel 2002 v10.2614.3311, Microsoft Corp.

[Ref_5] MathCad Standard 7.0. MathSoft, Inc.

[Ref_6] ARH-R-172, "Analysis of Underground Waste Storage Tanks 241-SY at Hanford WA," URS/Blume, 1974.

[Ref_7] Drawing H-2-64449, Rev. 6, 6/11/70.

[Ref_8] SD-WM-ANAL-034, "241AY and 241AZ Waste Storage Tanks Supplemental Gravity Load Analysis, Vols 1 & 2", Advent Engineering Services, Inc., August 26, 1994.

[Ref_9] M&D Professional Services, "Dome Load Evaluation for Hanford 241-C Farm 100-Series Tanks", Document Number RPP-14249, January 14, 2003.

9.0 ATTACHMENTS AND APPENDICES

ATTACHMENT 9.01. Listing of macro used to define parameters in slice model

SET_PARMS.MAC

```
! This file sets the values of all parameters that may be changed


! These were originally defined in define_soil_layers.mac:

overburden=8.3*12  !overburden height above dome apex (ft)
totaldepth=155*12  !total soil depth from surface to bottom of model (ft)
totalwidth=240*12  !total soil width (radius) from tank centerline to edge (ft)


! These were originally defined in dstay7.mac:

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)


! This was originally defined in set_esys_3d.mac:

r56=3/8    !shell thickness (in) of secondary liner above 357.5 in


! These were originally defined in set_materials.mac:

![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=3000        !uniaxial crushing stress [psi]
conc_crack=0.1*conc_crush     !tensile cracking stress [psi]

tb,creep,mat_conc,,,100  !creep coefficients per Table 11 of RPP-13990
tbdata,1,.1936,.28,.375,.348,.069
```

```
tbdata,6,226.09,-.00429,147.52,-.367,-309.26,-.044

![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=200        !uniaxial crushing stress [psi]
insul_crack=200        !tensile cracking stress [psi] - assumed

tb,creep,mat_insul,,,100  !creep coefficients per Table 11 of RPP-13990
tbdata,1,.1936,.28,.375,.348,.069
tbdata,6,226.09,-.00429,147.52,-.367,-309.26,-.044

![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

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=0                        !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=0.0                      !specific gravity of waste 1 is 0 for AOR loading
height_waste2=(381.5-18)*1/3          !height of waste 2 inches
gamma_waste2=0.0                      !specific gravity of waste 2 is 0 for AOR loading
height_waste3=(381.5-18)*1/3          !height of waste 3 inches
gamma_waste3=0.0                      !specific gravity of waste 3 is 0 for AOR loading
```

```
! 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
```

ATTACHMENT 9.02. Listing of macros used to run Section Force/Moment Path Plots using Submodeling

SUBMODEL.MAC

```
finish
/clear
/prep7

rebld_id=1
cdb_id=1
*if,rebld_id,eq,1,then

*if,cdb_id,eq,1,then   !rewrite CDB file
resume
esel,s,mat,,2
vsle
vsel,a,,,153
aslv
eslv
nsle
lsla
ksll
esln,,1
/sys,del tank.cdb
/sys,del tank.iges
cdwrite,all,submodel,cdb
*endif

finish
/clear
/filname,brk_submodel
/prep7
cdread,all,submodel,cdb
allsel

esel,s,mat,,2
nsle
esln,,1
edele,all
ndele,all

allsel
vsel,u,,,153
aslv
vclear,all
vdele,all
cm,atemp,area

csys,0
```

```
asel,r,loc,z,-.1,.1
cm,akeep,area
cmsel,s,atemp
cmsel,u,akeep
adele,all,,,1
cmsel,s,akeep

wpcsys,-1,0
kwpave,12
csys,4
asel,s,loc,y,-.1,-9999
cmsel,r,akeep
aadd,all
asel,invert
cmsel,r,akeep
aadd,all

lstr,34,51
asbl,1,2
lstr,17,223
asbl,4,3
kwpave,215
wprot,,90
asbw,all

FLST,2,10,4,ORDE,10
FITEM,2,351
FITEM,2,358
FITEM,2,363
FITEM,2,368
FITEM,2,375
FITEM,2,378
FITEM,2,385
FITEM,2,390
FITEM,2,-391
FITEM,2,395
LCOMB,P51X, ,0

FLST,2,8,4,ORDE,8
FITEM,2,338
FITEM,2,340
FITEM,2,345
FITEM,2,-346
FITEM,2,350
FITEM,2,438
FITEM,2,447
FITEM,2,451
LCOMB,P51X, ,0

FLST,2,7,4,ORDE,7
FITEM,2,53
```

```
FITEM,2,183
FITEM,2,199
FITEM,2,331
FITEM,2,433
FITEM,2,441
FITEM,2,448
LCOMB,P51X, ,0

FLST,2,3,4,ORDE,3
FITEM,2,4
FITEM,2,85
FITEM,2,87
LCOMB,P51X, ,0

lcomb,1,81

lsel,s,,,10
lsel,a,,,42
lsel,a,,,50
lsel,a,,,96
lsel,a,,,110
lcomb,all

lsel,s,,,44
lsel,a,,,52
lsel,a,,,101
lsel,a,,,112
lsel,a,,,114
lcomb,all

lsla
FLST,2,21,4,ORDE,21
FITEM,2,20
FITEM,2,243
FITEM,2,248
FITEM,2,253
FITEM,2,263
FITEM,2,268
FITEM,2,273
FITEM,2,281
FITEM,2,283
FITEM,2,288
FITEM,2,293
FITEM,2,303
FITEM,2,310
FITEM,2,315
FITEM,2,398
FITEM,2,400
FITEM,2,403
FITEM,2,405
FITEM,2,408
```

```
FITEM,2,410
FITEM,2,-411
LCOMB,P51X, ,0

asel,s,,,2
lsla
lwpla,-1,496
asbw,all
lwpla,-1,494
asbw,all
lwpla,-1,494,1
asbw,all
lwpla,-1,492,1
asbw,all
kwpave,331
asbw,all
wprot,,,90
asbw,all

FLST,2,10,4,ORDE,4
FITEM,2,9
FITEM,2,488
FITEM,2,500
FITEM,2,-507
LCOMB,P51X, ,0

FLST,2,5,4,ORDE,5
FITEM,2,60
FITEM,2,67
FITEM,2,508
FITEM,2,528
FITEM,2,556
LCOMB,P51X, ,0

asel,a,,,6
allsel,below,area

lwpla,-1,9
kwpave,12
asbw,11
asle,u
wpoff,,,-12
asbw,all

wprot,,,90
wpoff,,,12
asbw,all

asel,a,,,1
asel,a,,,3,4
```

```
type,3
mat,2
esize,7
mshkey,1
amesh,all

allsel
aslv,u
extopt,esize,1
type,12
mat,2
real,700
vrotat,all,,,,,,321,2,2.862

allsel
aclear,all

allsel
csys,22
nrotat,all

!--define contact on tank
asel,s,,,17
asel,a,,,20
asel,a,,,26,32,3
asel,a,,,37,38
asel,a,,,43,52,3
asel,a,,,56,57
asel,a,,,60,68,4
!asel,a,,,69
cm,tk_cnt,area
lsla
nsla,,1
esln
type,61
real,61
mat,61
esurf

!--define boundary nodes
keep_id=0
*if,keep_id,eq,1,then
csys,22
nsel,s,loc,x,550-.1,550+.1
cm,bc_nd,node

allsel
*get,mxz,node,,mxloc,z
nsel,s,loc,z,mxz-.1,mxz+.1
cmsel,a,bc_nd
cm,bc_nd,node
```

```
allsel
*get,mnz,node,,mnloc,z
nsel,s,loc,z,mnz-.1,mnz+.1
cmsel,a,bc_nd
cm,bc_nd,node
*endif

asel,s,,,6
asel,a,,,22
asel,a,,,25,28,3
asel,a,,,34
asel,a,,,42
asel,a,,,47,50,3
asel,a,,,54
asel,a,,,65
asel,a,,,67
cmsel,a,tk_cnt
asel,a,,,58
lsla
nsla,,1
lsel,s,,,75
lsel,a,,,99
lsel,a,,,105,106
nsll,u,1
cm,bc_nd,node

nwrite,cut,node

!==========just keep the tank in model
esel,s,mat,,2
vsle
vsel,invert
vclear,all
vdele,all,,,1
esel,invert
nsle
edele,all
ndele,all
allsel

asel,s,,,61
lsla
nsla,,1
esln
type,60
real,61
mat,61
esurf

asel,s,,,69
```

```
lsla
nsla,,1
esln
type,61
esurf


allsel
save

finish
/clear
/prep7
resume
/post1
set,last
esel,s,mat,,2
nsle
CBDOF,'cut','node',' ','cut','cbdo',' ',0, ,0

finish
/clear
/filname,brk_submodel
/prep7
resume
allsel
/input,cut,cbdo

csys,22
nsel,s,loc,y,180-.1,180+.1
d,all,uy,0
nsel,s,loc,y,180+2.862-.1,180+2.862+.1
d,all,uy,0

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

allsel

acel,,386

/solu
nsubst,5,100,1
nlgeom,on
allsel
nsle
save
solve
/post1
set,last
```

```
*else

resume,brk_submodel,db
/post1
file,brk_submodel
set,last

*endif


allsel
*afun,deg

/VIEW, 1 ,,,1

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

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

csys,22
pstart=0  !starting point of consequent path points

!=========================dome region
lsel,s,,,1
lsel,a,,,11
nsll,,1
cm,nd_out,node

lsel,s,,,338
lsel,a,,,351
nsll,,1
cm,nd_in,node

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

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


!--reorder nodes according x-coord.
cmsel,s,nd_out
```

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

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

asel,s,,,1,3,2
lsla
nsla,,1
cm,dome_nd,node

wpcsys,-1,0
csys,0
!--for line equation for each pair of in/out nodes
*do,ii,1,in_num
    nsel,s,,,nodeout(ii)
    nsel,a,,,nodein(ii)
    path_nd(pstart+ii)=nodein(ii)
    *get,x_out,node,nodeout(ii),loc,x
    *get,y_out,node,nodeout(ii),loc,y
    *get,x_in,node,nodein(ii),loc,x
    *get,y_in,node,nodein(ii),loc,y
    nwpla,-1,nodeout(ii),nodein(ii)
    csys,4
    cmsel,s,dome_nd
    nsel,r,loc,y,-2,2
    cm,ntemp,node
    esln
    esel,r,mat,,2
    nsle
```

```
    nsel,r,loc,y,-1,99999
    esln,,1
    cm,etemp,elem
    cmsel,s,ntemp
    cmsel,s,etemp
    csys,0
    get_res_slice

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

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

*enddo

pstart=pstart+in_num

!==============haunch and wall
lsel,s,,,4,
lsel,a,,,25
lsel,a,,,34
nsll,,1
cm,nd_out,node

lsel,s,,,26
lsel,a,,,35
lsel,a,,,53
nsll,,1
cm,nd_in,node

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

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

!--reorder nodes according y-coord.
cmsel,s,nd_out
*get,out_num,node,,count
*dim,nodeout,,out_num
*do,i,1,out_num
```

```
cmsel,s,nd_out
*get,y_max,node,,mxloc,y
nsel,r,loc,y,y_max-.1,y_max+.1
*get,ndnum,node,,num,min
nodeout(i)=ndnum
cmsel,s,nd_out
nsel,u,,,ndnum
cm,nd_out,node
*enddo

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

asel,s,,,4,8,4
asel,a,,,15
lsla
nsla,,1
cm,hnch_nd,node

!--for line equation for each pair of in/out nodes
*do,ii,1,in_num
    nsel,s,,,nodeout(ii)
    nsel,a,,,nodein(ii)
    path_nd(pstart+ii)=nodein(ii)
    *get,x_out,node,nodeout(ii),loc,x
    *get,y_out,node,nodeout(ii),loc,y
    *get,x_in,node,nodein(ii),loc,x
    *get,y_in,node,nodein(ii),loc,y
    nwpla,-1,nodeout(ii),nodein(ii)
    csys,4
    cmsel,s,hnch_nd
    nsel,r,loc,y,-1,1
    cm,ntemp,node
    esln
    esel,r,mat,,2
    nsle
    nsel,r,loc,y,-1,99999
    esln,,1
    cm,etemp,elem
    cmsel,s,ntemp
```

```
    cmsel,s,etemp
    csys,0
    get_res_slice

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

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

*enddo

pstart=pstart+in_num

!==========================slab region
lsel,s,,,21
lsel,a,,,32
lsel,a,,,492,495
nsll,,1
cm,nd_out,node

lsel,s,,,7,9,2
lsel,a,,,12
lsel,a,,,16
lsel,a,,,18
lsel,a,,,31
nsll,,1
cm,nd_in,node

csys,22
!--unselect end nodes
cmsel,s,nd_out
*get,x_max,node,,mxloc,x
nsel,u,loc,x,x_max-.1,x_max+.1
cm,nd_out,node

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

!--reorder nodes according x-coord.
cmsel,s,nd_out
*get,out_num,node,,count
*dim,nodeout,,out_num
*do,i,1,out_num
    cmsel,s,nd_out
    *get,x_max,node,,mxloc,x
```

```
    nsel,r,loc,x,x_max-.1,x_max+.1
    *get,ndnum,node,,num,min
    nodeout(i)=ndnum
    cmsel,s,nd_out
    nsel,u,,,ndnum
    cm,nd_out,node
*enddo

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

asel,s,,,13,14
asel,a,,,5
asel,a,,,2
asel,a,,,9,11
lsla
nsla,,1
cm,slab_nd,node

!--for line equation for each pair of in/out nodes
*do,ii,1,in_num-1
    nsel,s,,,nodeout(ii)
    nsel,a,,,nodein(ii)
    path_nd(pstart+ii)=nodein(ii)
    *get,x_out,node,nodeout(ii),loc,x
    *get,y_out,node,nodeout(ii),loc,y
    *get,x_in,node,nodein(ii),loc,x
    *get,y_in,node,nodein(ii),loc,y
    nwpla,-1,nodeout(ii),nodein(ii)
    csys,4
    cmsel,s,slab_nd
    nsel,r,loc,y,-1,1
    cm,ntemp,node
    esln
    esel,r,mat,,2
    nsle
    nsel,r,loc,y,-1,99999
    esln,,1
    cm,etemp,elem
    cmsel,s,ntemp
```

```
    cmsel,s,etemp
    csys,0
    get_res_slice

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

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

*enddo

pstart=pstart+in_num-1

rsys,0
/gresume,path_ay,plt
axial_path
plpng
shear_path
plpng
moment_path
plpng
hoop_path
plpng

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

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

AXIAL_PATH.MAC

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

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


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

GET_HPFRC.MAC

```
*get,nnode,node,,count

csys,0

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

sz_sum=sz_sum/nnode

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

GET_RES_SLICE.MAC

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

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

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

xmean=0
ymean=0
zmean=0

fsumx=0
fsumy=0
fsumz=0

cm,nn0,node
csys,0
*do,i,1,nnode
      *get,inode,node,,num,min
      nsel,s,,,inode
      xx(i)=nx(inode)
      yy(i)=ny(inode)
      zz(i)=nz(inode)
      xmean=xmean+xx(i)
      ymean=ymean+yy(i)
      zmean=zmean+zz(i)
      cmsel,s,nn0
      nsel,u,,,inode
      cm,nn0,node
*enddo

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

cmsel,s,ntemp
cmsel,s,etemp
```

```
spoint,,xmean,ymean,zmean

rsys,4
fsum,rsys

*get,fsumx,fsum,fx
*get,fsumy,fsum,fy
*get,fsumz,fsum,fz
*get,mmzz,fsum,mz


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

fct=2.862/360

arc_length=abs(3.14159*xmean*2)*fct

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

HOOP_PATH.MAC

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

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


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

MOMENT_PATH.MAC

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

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


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

PLPNG.MAC

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

SHEAR_PATH.MAC

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

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


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