JUN 23 2003

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		Cog. Eng.									
1	1	Cog. Mgr. C. Defigh-Price	[signature]	6-19-03	R2-58						
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		Safety									
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To	From	Page 1 of 1
Distribution	Design Engineering	Date 6/17/03
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Sample AOR Calculation using ANSYS Axisymmetric Parametric Model for Tank SST-AX

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

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

6/19/03

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Revision 0

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

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

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

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Revision 0

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

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

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JLR The Engineering Solutions Company

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May 2003

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

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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-13998, Rev. 0, Sample AOR Calculation using ANSYS Axisymmetric Parametric Model for Tank SST-AX

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

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

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

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

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

Reviewer/Approver (signature) [signature] 6/17/03
Date

CHECKLIST FOR INDEPENDENT REVIEW

Document Reviewed: RPP-13998, Rev. 0, Sample AOR Calculation using ANSYS Axisymmetric Parametric Model for Tank SST-AX

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

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

* Sample Calculation / Model Development

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

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

ERRATA

ANSYS Macro	Tracking #	Issue Description	Recommended Action
Parm_ax.mac	1	Material properties are set at default values that may or may not be appropriate for specific analysis.	Verify material input values appropriate for specific analysis.
	2	Concrete creep coefficients not listed.	See RPP-13990 for proper creep coefficient specification and usage.

ANSYS is a registered trademark of SAS IP, Inc.

ANALYTICAL CALCULATIONS

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Originator	Xianghong Li X. Li	Date	3/11/03
Checker	Jim Radochia JR	Date	3/11/03

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Checker	Jim Radochia JDR	Date	3/11/03

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Checker	Jim Radochia JR	Date	3/11/03

1.0 OBJECTIVE/PURPOSE

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

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

2.0 METHODS OF ANALYSIS

1. A simplified linear, axisymmetric shell model of the SST-AX tanks was first developed using the ANSYS Parametric Design Language (APDL) in ANSYS 7.0, a general purpose finite element analysis program [Ref 1]. Assumptions derived from RPP-14249 [Ref 2] are applied to the model, including a) no liner or waste present in the tank, b) no friction/contact at the soil/tank interface, c) no rebar, d) elastic soil modulus, and e) Poisson's ratio of 0.27 for soil.

2. The parametric model of the SST-AX tank was then analyzed based on AOR loads. Contour plots showing stress and displacement are provided, as are tables summarizing force/moment resultants.

3.0 INPUT DATA

The geometry of the SST-AX tank is provided in drawing H-2-44562 [Ref 4], and is shown in Figure 1. The parametric model includes material properties for the tank, and nominal soil material properties. For purposes of this calculation, the soil overburden (at the top of the tank dome) is 13.84 feet [Ref 3], with a unit weight of 125 pcf, Poisson ratio of 0.27. The soil is divided into three layers, shown in Figure 2. Each layer has different elastic moduli. Material properties for structural concrete and soil are the same as those in document RPP-14249 [Ref 2], and are listed in Table 1. The concrete reinforcing bar properties are also specified in the drawing, but are not needed for this simplified analysis.

Table 1. Material Properties [Ref_2]

Material	Elastic Modulus (psi)	Poisson's Ratio	Density (lb/ft^3)
Structural Concrete	3,100,000	0.2	150
Top Soil	7,000	0.27	125
Mid-Soil	13,000	0.27	125
Bottom Soil	20,000	0.27	125

Both the concrete tank and soil are modeled with 2D solid elements PLANE42, with axisymmetric characteristics turned on. Figures 3 and 4 show the finite element mesh used for this calculation.

The AOR loads for the SST-AX tank include a uniform pressure load of 40 lbf/ft^2 on the soil surface and a concentrated load of 200 kip over a circular region with a radius of 10 ft. The concentrated load is applied to the soil surface as a pressure load in this calculation. A vacuum load of -6 in. water gage was also applied to the inside surface of the tank. Boundary conditions for the axisymmetric model are shown in Figure 5. Figure 6 shows the uniform and vacuum pressure loads, and Figure 7 depicts the concentrated load for the SST-AX tank. Gravity is also included in the calculation.

The parametric inputs used in this calculation are summarized in the attachments. The files and their functions are listed in Table 2.

Table 2. Input File List

Input File Name	Function	Calling For
sst_ax.mac	Master input creating parametric model for SST-AX tank and getting solutions	Parm_ax.mac set_load_ax.mac
parm_ax.mac	Set all parametric variables used to create the parametric model	NONE
set_load_ax.mac	Apply boundary conditions and AOR loads	NONE
pst_proc_ax.mac	Calculate section force/moment, generate results pictures in png fomat, and output path data to path_ax.dat file	get_res.mac get_hpfrc.mac plpng.mac path_ax.plt
get_res.mac	Calculate total forces and moments at individual section	NONE
plpng.mac	Create image hard copy in png format	NONE
path_ax.plt	View setting for path plot	NONE
get_hpfrc.mac	Calculate section hoop force	NONE

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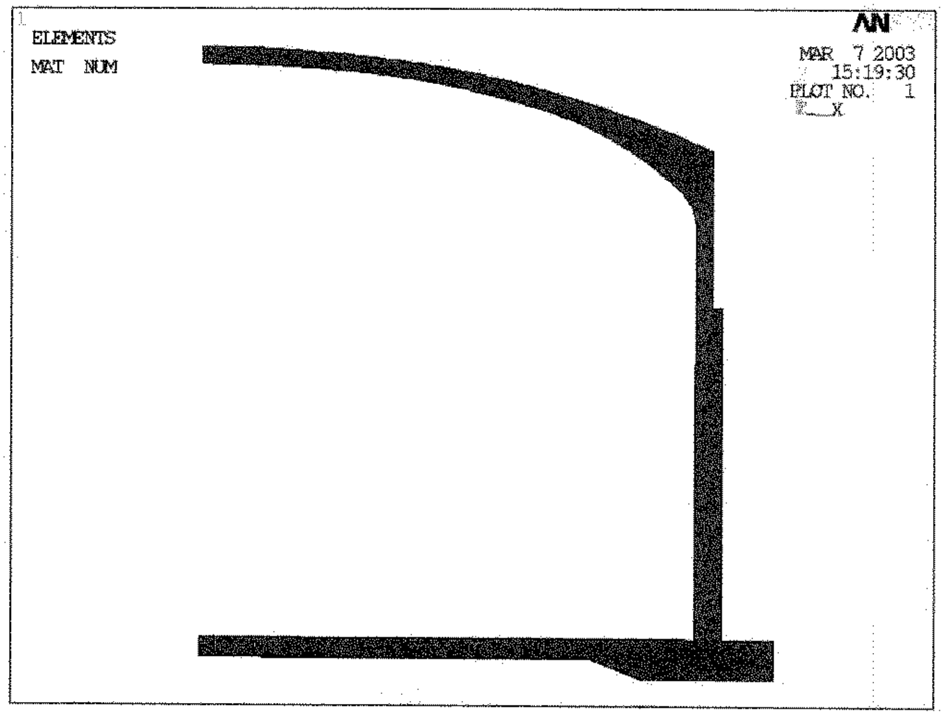

Figure 1. Geometry of SST-AX Tank

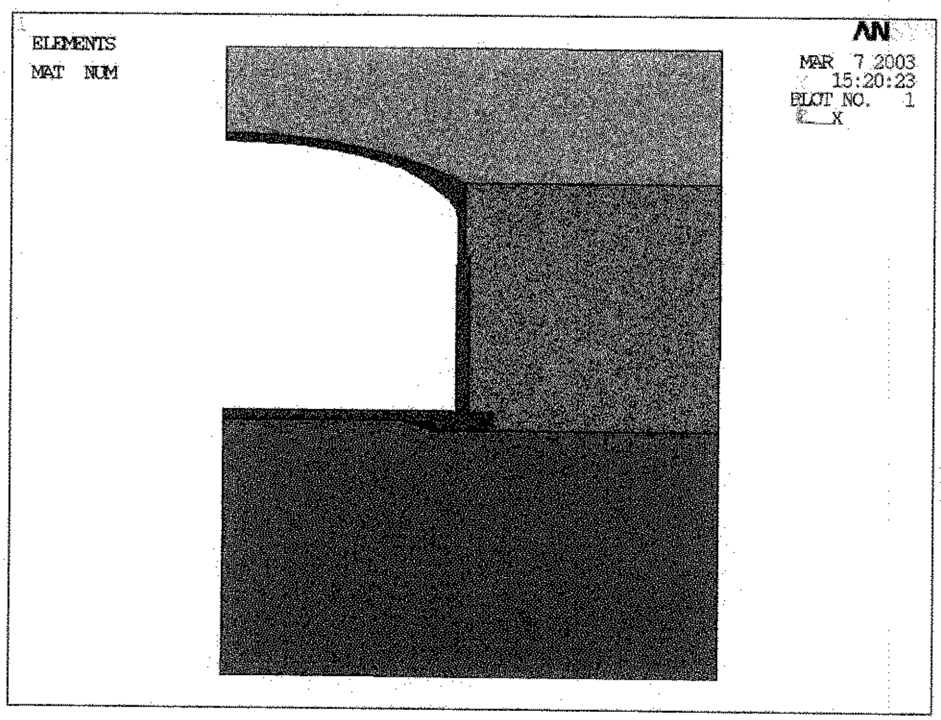

Figure 2. Soil Layers

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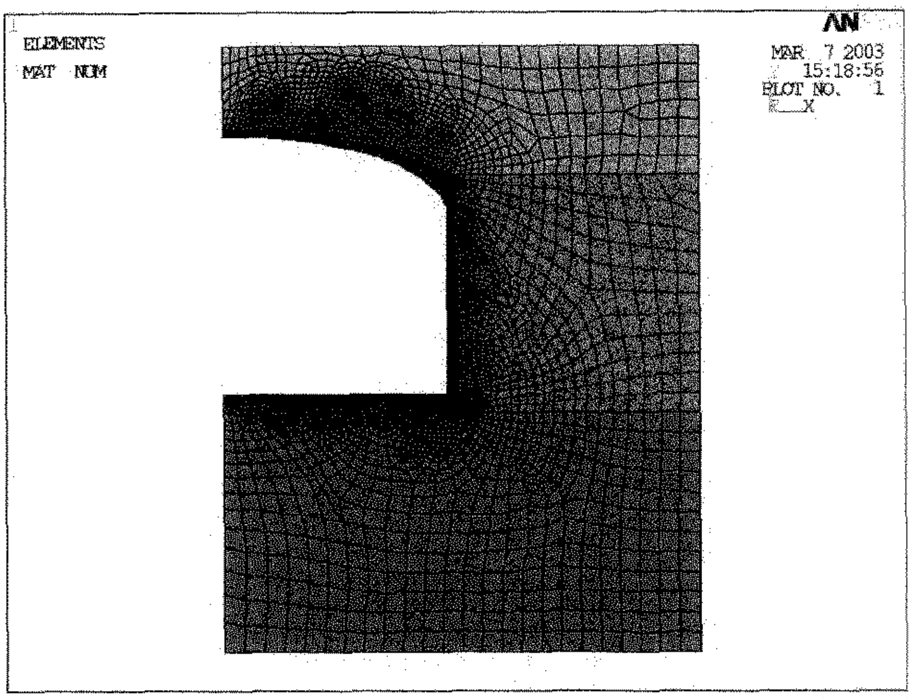

Figure 3. Finite element mesh, showing elements colored by material ID.

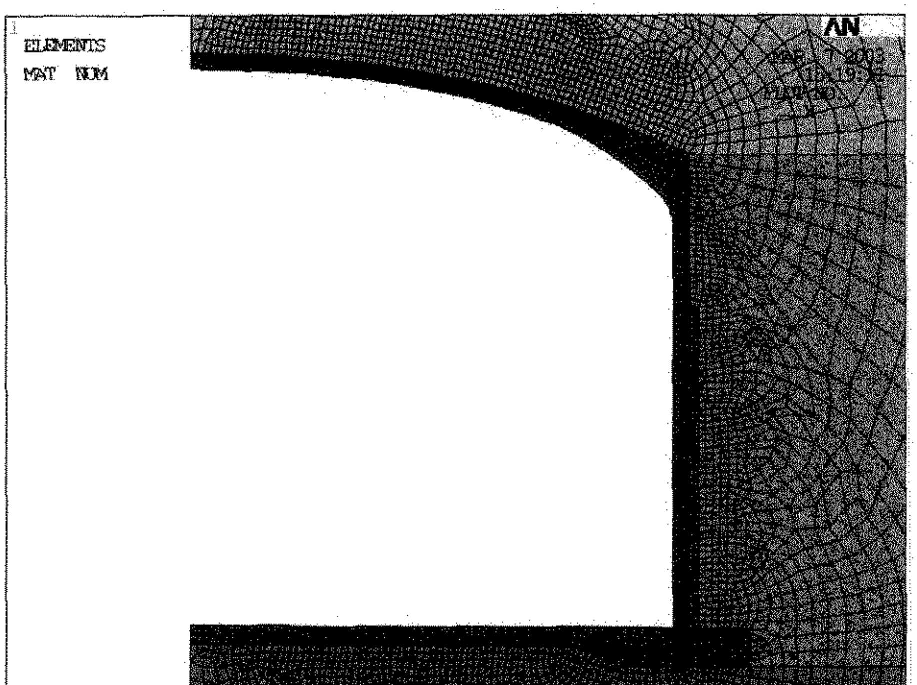

Figure 4. Close-up of finite element mesh.

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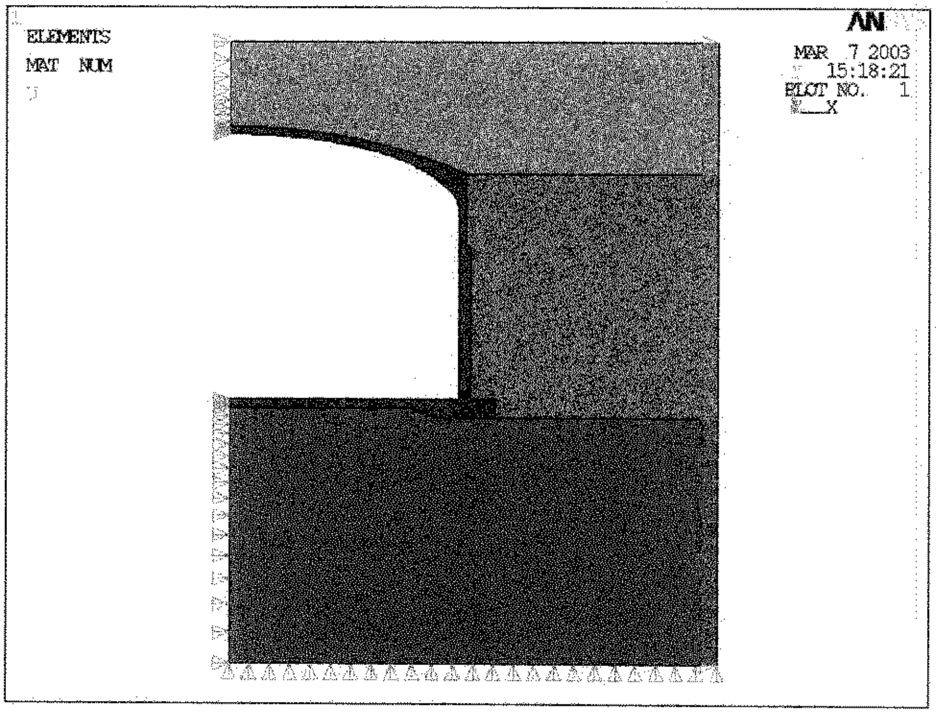

Figure 5. Boundary conditions

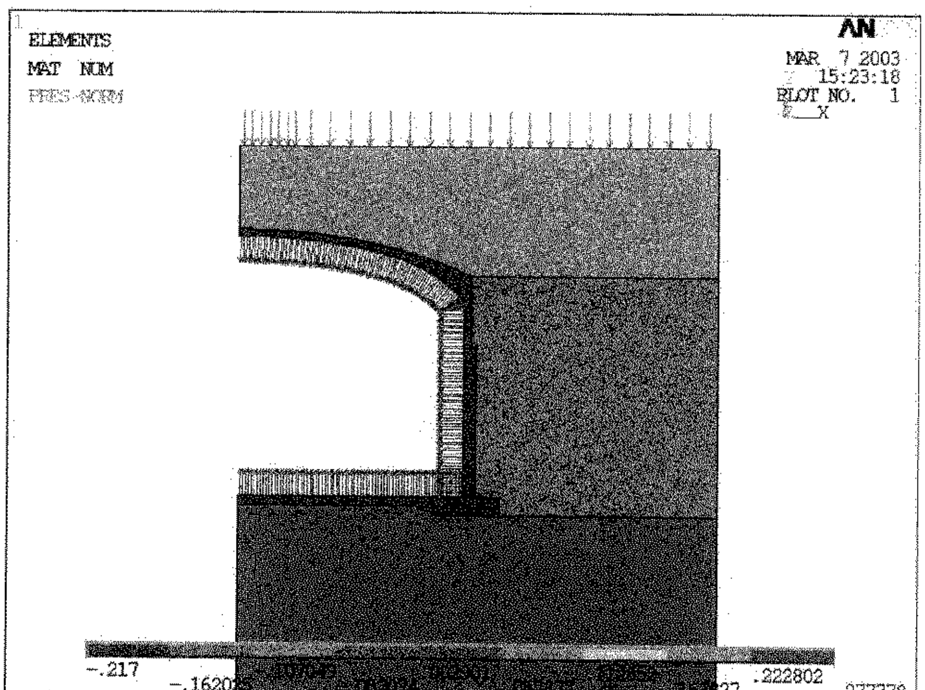

Figure 6. Uniform and vacuum loads for SST-AX tanks

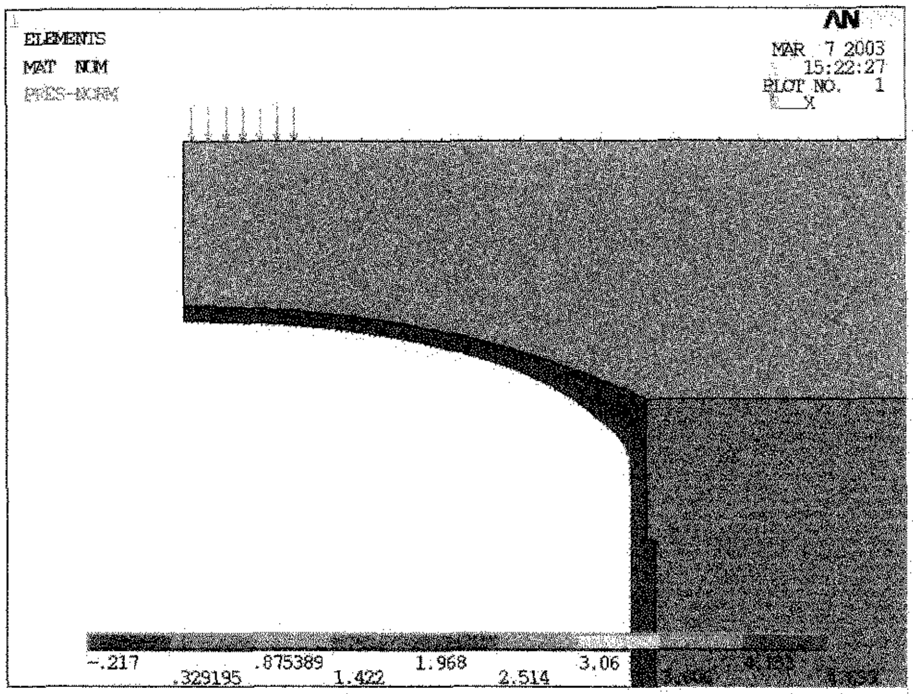

Figure 7. Concentrated load for SST-AX tanks

4.0 RESULTS

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

Figures 8 and 9 summarize the displacement response due to AOR loads identified in Section 3. The peak displacement of the soil mass is 2.52 inches, and this occurs at grade far away from the tank. The peak tank displacement is 1.88 inches, at the dome apex. Figures 10 and 11 show exaggerated views of the tank/soil displacement.

The von Mises equivalent stress contours are presented in Figures 12 and 13. The peak equivalent stress in the tank is approximately 2.2 ksi, and this occurs at the joint of wall and slab. The hoop stress of the tank is shown in Figure 14. The maximum hoop stress is about 574 psi at haunch region, and minimum hoop stress is -759 psi at wall/slab joint.

Force and moment resultants are caculated in **pst_proc_ax.mac**. In order for **pst_proc_ax.mac** to work correctly, the tank has to be map meshed. The mapped mesh resulted in a set of nodes aligned in a straight line, creating a cross section for section force and moment evaluation. Once the cross section nodes and elements attached to one side of the nodes were selected, the macro **get_res.mac** then calculated the nodal forces, determined the location of the neutral axis, and evaluated the moment about the neutral axis. The force and moment per unit length were calculated according to the radius of the neutral axis. Because there is no direct hoop force output for 2D elements, the section hoop force is calculated in macro **get_hpfrc.mac**. The nodal hoop stresses are retrieved and averaged over thickness, hoop force over meridional length is then obtained from the averaged nodal hoop stress and wall thickness. Figures 15 to 18 show the axial force, shear force, hoop force and moment, respectively. The wall/slab joint sees the most severe loading, with maximum axial force of about 165 kip/ft, and maximum moment of 3917 kip-in/ft. Maximum shear force of 41 kip/ft, and maximum hoop force of 181 kip/ft occurred at haunch region.

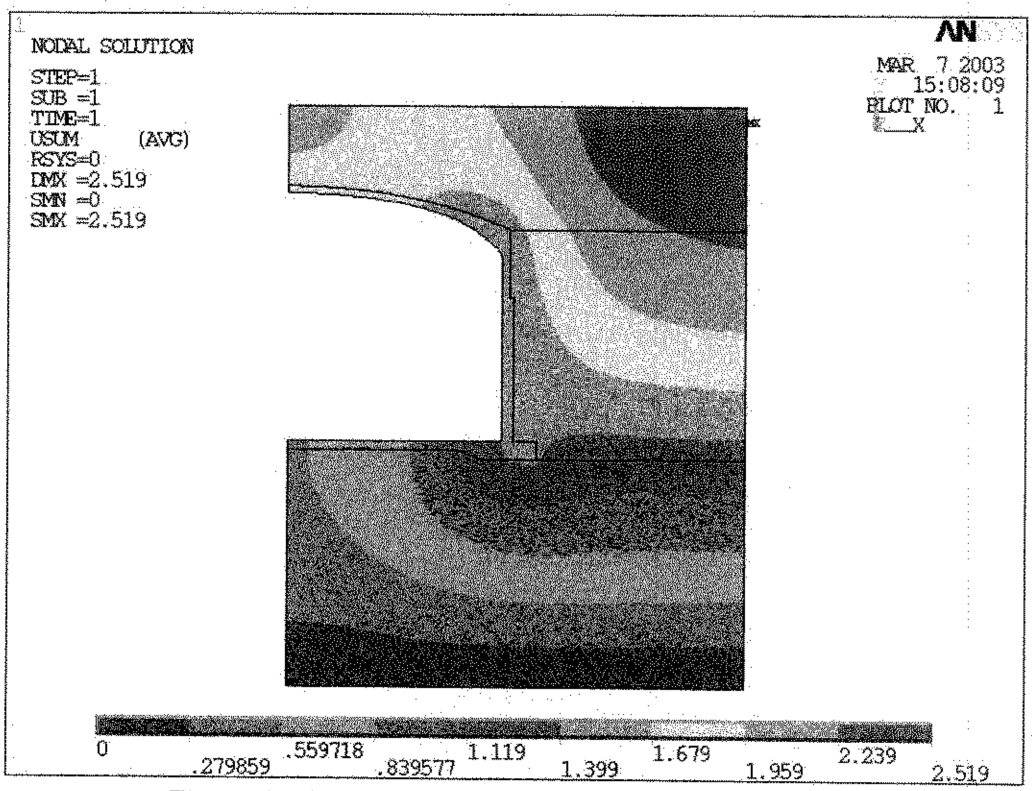

Figure 8. Total displacement contour of soil and tank

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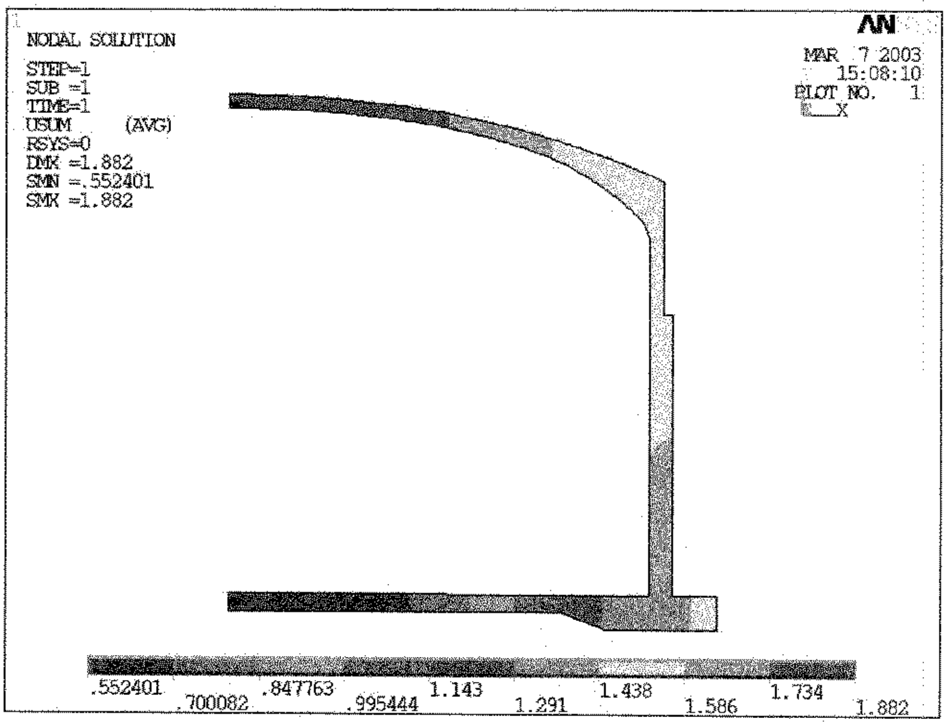

Figure 9. Total displacement contour of tank

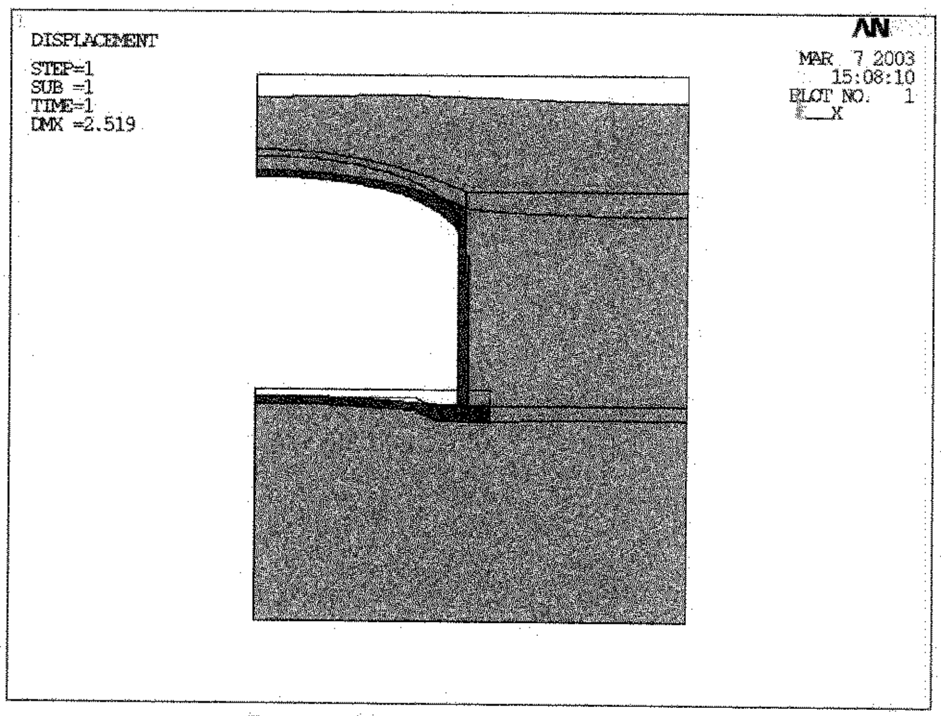

Figure 10. Deformed shape of soil

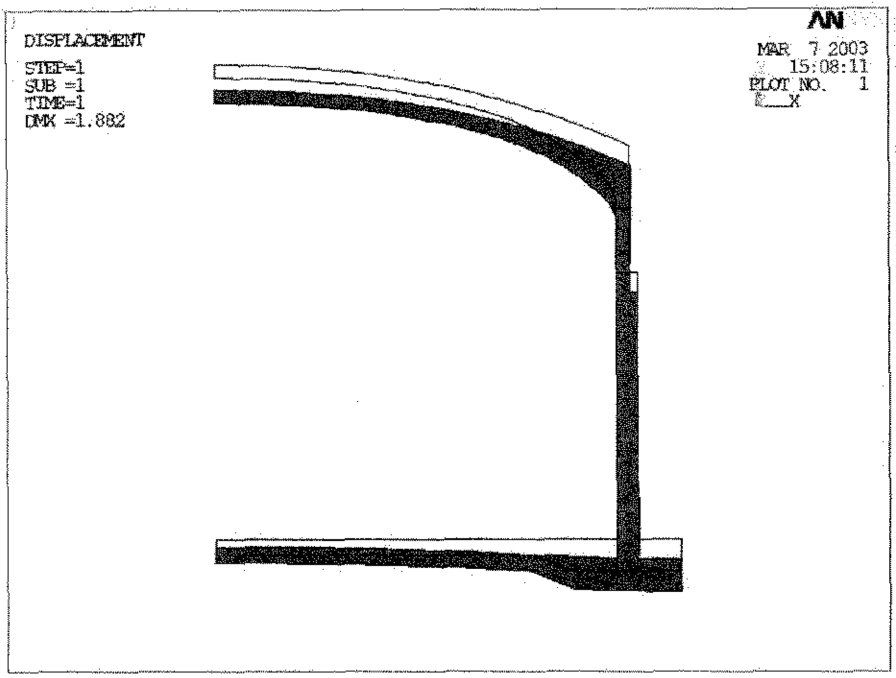

Figure 11. Deformed shape of tank

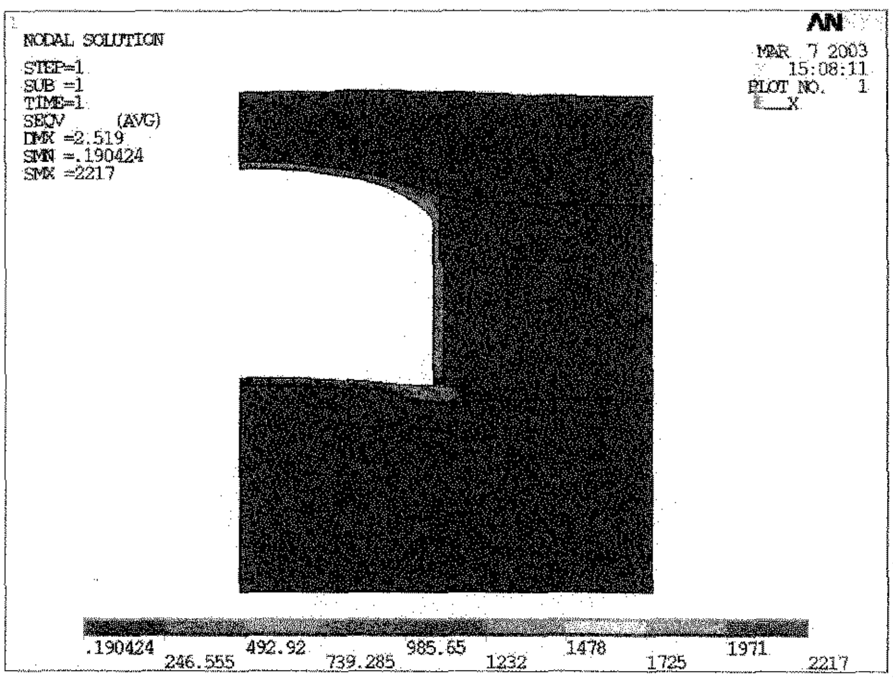

Figure 12. Equivalent stress contours of tank and soil (psi).

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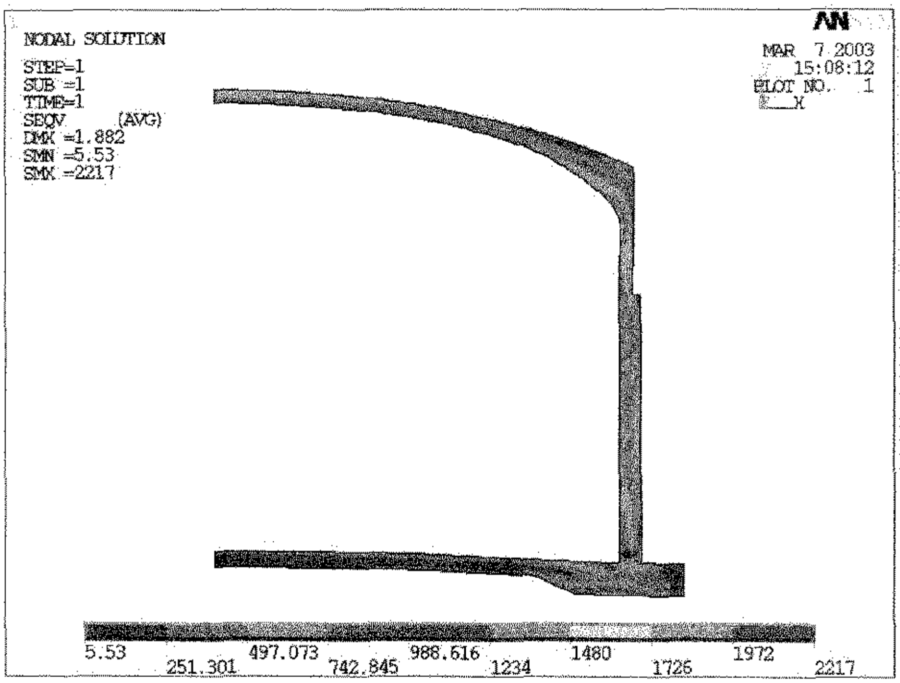

Figure 13. Equivalent stress contours of tank (psi).

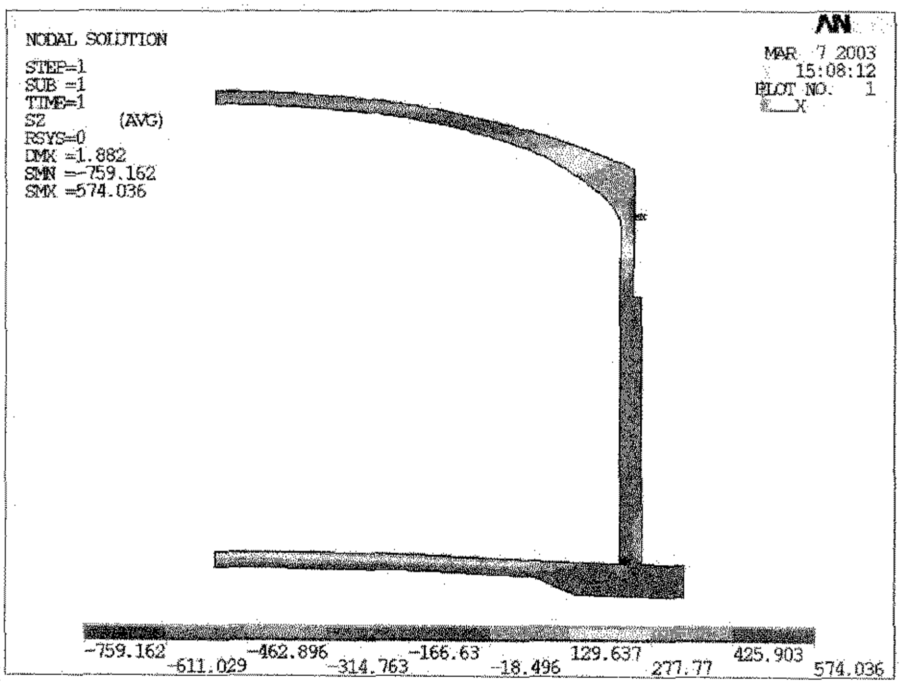

Figure 14. Hoop stress of tank (psi)

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Checker	Jim Radochia *JR*	Date	3/11/03

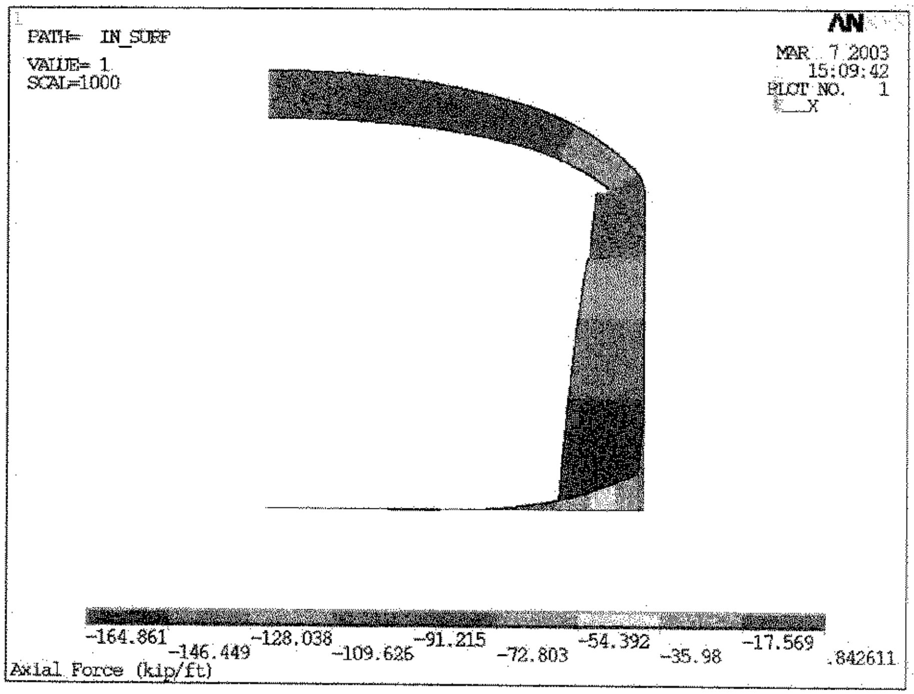

Figure 15. Unit section axial force (kip/ft)

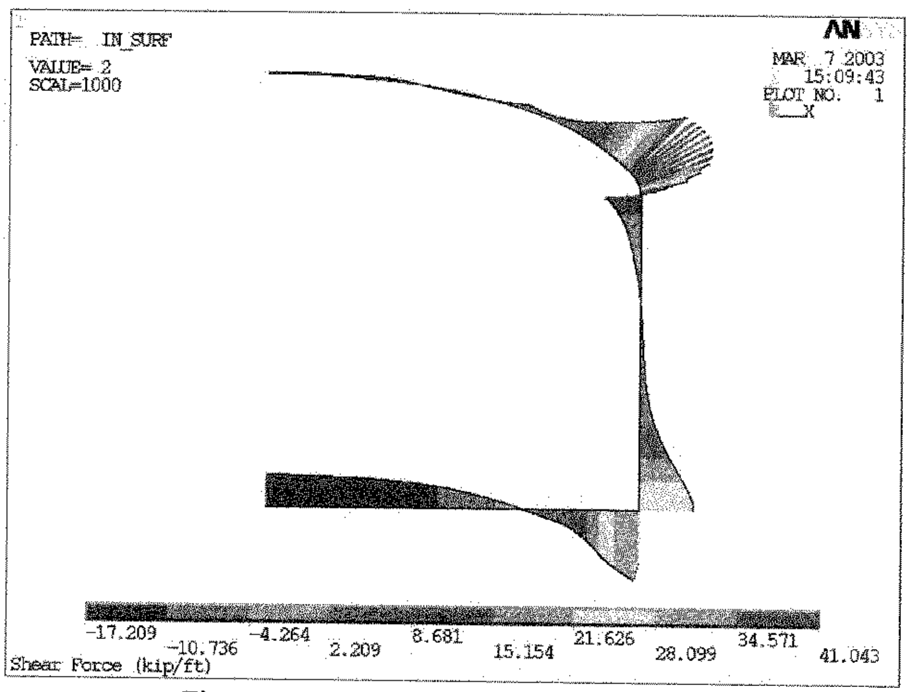

Figure 16. Unit section shear force (kip/ft)

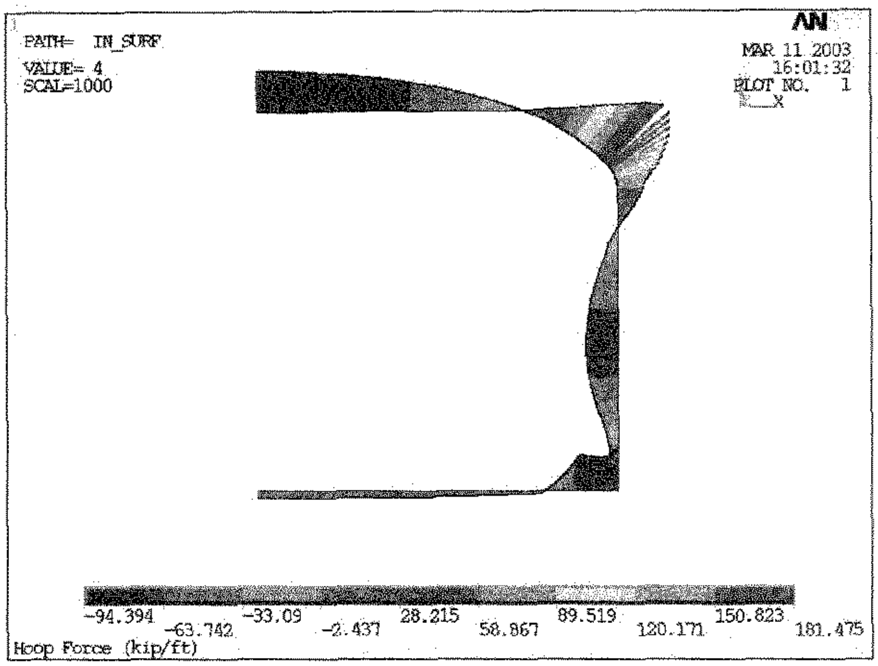

Figure 17. Unit section hoop force (kip/ft)

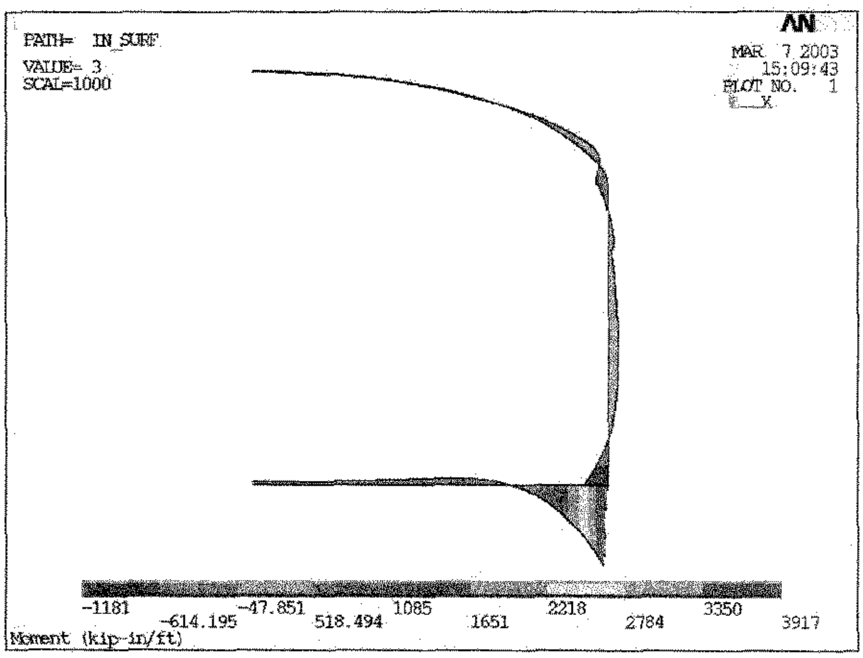

Figure 18. Unit section moment (kip-in/ft)

5.0 CONCLUSIONS

The simplified linear parametric model is capable of giving a quick estimation of tank behavior under AOR loads. A sample calculation demonstrates the use of the parametric model for tank SST-AX, and provides examples of the types of inputs that can be defined and the types of outputs that can be obtained. The parametric model can be used effectively to evaluate the tank response to a broad range of loading conditions and material properties.

6.0 REFERENCES

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

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

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

[Ref_4] Drawing H-2-44562, March 29, 1963

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Checker	Jim Radochia JRA	Date	3/11/03

7.0 ATTACHMENTS AND APPENDICES

sst_ax.mac

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

/INPUT,'parm_ax','mac'

!--Create dome
/TRIAD,RTOP
wpcsys,-1,0
wpoff,,dm_r1,
csys,4
k,1,r1,-h1
k,2,r2,-h2
k,3,r3,-h3
k,4,r4,-h4
k,5,r5,-h5
k,6,r6,-h6
k,7,r7,-h7
k,8,r8,-h8
k,9,r9,-h9
k,10,r10,-h10
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larc,14,15,10,hnch_r
larc,15,16,10,dm_r5
```

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larc,16,17,10,dm_r4
larc,17,18,10,dm_r2
lstr,1,18
al,all

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

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

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

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

!--cut soil for different soil properties
kwpave,3
wprot,,90
asbw,all
kwpave,8
```

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

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

!--Set Elelment type, real constants, and material properties
r_liner=1
r,1,liner_t

mat_liner=1
mat_tank=2
mat_tsoil=3 !for top soil
mat_msoil=4     !for mid soil
mat_bsoil=5 !for bottom soil

type_liner=1
type_tank=2
type_soil=3

et,type_liner,shell61
et,type_tank,plane42
et,type_soil,plane42

keyopt,2,3,1
keyopt,3,3,1

![1]                steel (for liner)

mp,ex,mat_liner,steel_ex
mp,dens,mat_liner,steel_dens
mp,prxy,mat_liner,steel_prxy
mp,alpx,mat_liner,steel_alpx
mp,kxx,mat_liner,steel_kx
mp,c,mat_liner,steel_c

![2]                structural concrete
mp,ex,mat_tank,conc_ex
mp,dens,mat_tank,conc_dens
mp,prxy,mat_tank,conc_prxy
mp,alpx,mat_tank,conc_alpx
mp,kxx,mat_tank,conc_kx
mp,c,mat_tank,conc_c


![3]                top soil
```

```
mp,ex,mat_tsoil,tsoil_ex
mp,dens,mat_tsoil,tsoil_dens
mp,prxy,mat_tsoil,tsoil_prxy

![4]              mid soil
mp,ex,mat_msoil,msoil_ex
mp,dens,mat_msoil,msoil_dens
mp,prxy,mat_msoil,msoil_prxy

![5]              bottom soil
mp,ex,mat_bsoil,bsoil_ex
mp,dens,mat_bsoil,bsoil_dens
mp,prxy,mat_bsoil,bsoil_prxy


!---Meshing

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

esize,tank_size
type,type_tank
mat,mat_tank

mshkey,1
amesh,all

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

esize,soil_esize
type,type_soil

mopt,trans,1.25
mopt,expnd,1.25

lesize,45,,,8,4
lesize,46,,,15,4
lesize,50,,,7
lesize,43,,,20,4
lesize,47,,,20,4

mshkey,0
amesh,all

wpcsys,-1,0
kwpave,1
csys,4
cmsel,s,a_soil
```

```
asel,r,loc,y,-h3,999999
esla
emodif,all,mat,mat_tsoil

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

cmsel,s,a_soil
asel,r,loc,y,-h8,-99999
esla
emodif,all,mat,mat_bsoil

/pnum,type,1
/num,1

allsel
set_load_ax
allsel
finish
/filname,sst_ax

save
/solu
solve
```

parm_ax.mac

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

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

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

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

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

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

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

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

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

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

r6=r5
h6=h5+25*12

r7=r6+4*12
h7=h6

r8=r7
h8=h7+36

r9=r6-t2-48
h9=h8

r10=r9-4*12
```

```
h10=h9-18

r11=0
h11=h10

r12=0
h12=h7

r13=r6-t2
h13=h12

r14=r13
h14=144+15

r18=0
h18=15

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

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

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

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

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

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

!--mid soil
msoil_ex=13e3
msoil_prxy=0.27
msoil_dens=125/1728/386

!-top soil
tsoil_ex=7e3
tsoil_prxy=0.27
tsoil_dens=125/1728/386

!---Element size control
liner_size=5
tank_size=6
soil_esize=40
dr4_div=10
dr6_div=10
dh4_div=20
dh6_div=40
drsoil_div=20
tsoil_hdiv=8

msoil_hdiv=10
bsoil_hdiv=15
cload_div=11

!---liner thickness
liner_t=3/8

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

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

set_load_ax.mac

```
finish
/prep7
!--set BCs
wpcsys,-1,0
kwpave,1
csys,4
ksel,s,loc,x,soil_r
lslk,,1
nsll,,1
d,all,ux,0

allsel
ksel,s,loc,y,-h8-soil_h
lslk,,1
nsll,,1
d,all,uy,0

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

lsel,s,,,49,50
nsll,,1
esln
sf,all,pres,p_uniform

p_cload=ff/(3.14159*cload_l**2)
lsel,s,,,50
nsll,,1
sf,all,pres,p_cload+p_uniform
allsel

acel,,386

!Apply -6" w.g. to dome
lsel,s,line,,14,17
lsel,a,,,26,27
lsel,a,,,33
lsel,a,,,35,36
nsll,,1
sf,all,pres,vac_pres

allsel
```

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Subject	**Sample AOR Calculation using ANSYS Axisymmetric Parametric Model for Tank SST-AX**		
Originator	Xianghong Li	Date	3/11/03
Checker	Jim Radochia	Date	3/11/03

pst_proc_ax.mac

```
finish
/clear
resume,sst_ax,db
/post1
file,sst_ax
set,last
/sys,del *.png

/COLOR,NUM,CYAN,1
/COLOR,NUM,BMAG,2
/COLOR,NUM,YGRE,3
/COLOR,NUM,CBLU,4
/COLOR,NUM,MRED,5
/COLOR,NUM,GREE,6
/COLOR,NUM,ORAN,7
/COLOR,NUM,MAGE,8
/COLOR,NUM,YGRE,9
/COLOR,NUM,BLUE,10
/COLOR,NUM,GCYA,11

!------total disp. contour of soil
/dscale,,1
allsel
/auto
plnsol,u,sum
plpng

!-----total disp. contour of tank
esel,s,type,,2
/auto
plnsol,u,sum
plpng

!-----deformed shape of soil
/edge,,1
/dscale
allsel
pldisp,2
plpng

!-----deformed shape of tank
esel,s,type,,2
/rep
plpng

!-----von mises stress of soil
/edge
allsel
plnsol,s,eqv
```

```
plpng

!-----von mises stress of tank
esel,s,type,,2
/rep
plpng

!-----hoop stress of tank
plnsol,s,z
plpng

allsel

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

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

csys,0

pstart=0  !starting point of consequent path points

!=========================dome + upper haunch
lsel,s,,,1
lsel,a,,,20,21
nsll,,1
cm,nd_out,node

lsel,s,,,15,17
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
lsla
nsla,,1
cm,dome_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,dome_nd
    nsel,r,loc,y,-1,1
    cm,ntemp,node
    esln
    esel,r,type,,2
    nsle
    nsel,r,loc,y,-1,99999
    esln,,1
    cm,etemp,elem
```

```
    cmsel,s,ntemp
    cmsel,s,etemp
    csys,0
    get_res
    theta=atan((y_out-y_in)/(x_out-x_in))

    path_fa(pstart+ii)=unit_fsumx*sin(theta)-unit_fsumy*cos(theta)
    path_ft(pstart+ii)=unit_fsumx*cos(theta)+unit_fsumy*sin(theta)
    path_mz(pstart+ii)=unit_mz

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

*enddo

pstart=pstart+in_num
!===================== Lower haunch + upper wall region
lsel,s,,,23,25,2
nsll,,1
cm,nd_out,node

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

!--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,,,4,5
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,type,,2
    nsle
    nsel,r,loc,y,-1,99999
    esln,,1
    cm,etemp,elem
    cmsel,s,ntemp
    cmsel,s,etemp
    csys,0
    get_res
    theta=atan((y_out-y_in)/(x_out-x_in))

    path_fa(pstart+ii)=unit_fsumx*sin(theta)-unit_fsumy*cos(theta)
    path_ft(pstart+ii)=unit_fsumx*cos(theta)+unit_fsumy*sin(theta)
    path_mz(pstart+ii)=unit_mz
```

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

*enddo

pstart=pstart+in_num
!========================== lower wall region
lsel,s,,,5
nsll,,1
cm,nd_out,node

lsel,s,,,27
nsll,,1
cm,nd_in,node

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

cmsel,s,nd_in
*get,y_min,node,,mnloc,y
*get,y_max,node,,mxloc,y
nsel,u,loc,y,y_max-.1,y_max+.1
!nsel,u,loc,y,y_min-.1,y_min+.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,,,13
asel,a,,,11
lsla
nsla,,1
cm,wall_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,wall_nd
    nsel,r,loc,y,-1,1
    cm,ntemp,node
    esln
    esel,r,type,,2
    nsle
    nsel,r,loc,y,-1,99999
    esln,,1
    cm,etemp,elem
    cmsel,s,ntemp
    cmsel,s,etemp
    csys,0
    get_res
    theta=atan((y_out-y_in)/(x_out-x_in))

    path_fa(pstart+ii)=unit_fsumx*sin(theta)-unit_fsumy*cos(theta)
    path_ft(pstart+ii)=unit_fsumx*cos(theta)+unit_fsumy*sin(theta)
    path_mz(pstart+ii)=unit_mz

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

```
*enddo

pstart=pstart+in_num
!=========================slab region
lsel,s,,,9,10
lsel,a,,,32
nsll,,1
cm,nd_out,node

lsel,s,,,33
lsel,a,,,35,36
nsll,,1
cm,nd_in,node

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

cmsel,s,nd_in
*get,x_max,node,,mxloc,x
*get,x_min,node,,mnloc,x
nsel,u,loc,x,x_max-.1,x_max+.1
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_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,,,9,10
asel,a,,,12
lsla
nsla,,1
cm,slab_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,slab_nd
    nsel,r,loc,y,-1,1

    cm,ntemp,node
    esln
    esel,r,type,,2
    nsle
    nsel,r,loc,y,-1,99999
    esln,,1
    cm,etemp,elem
    cmsel,s,ntemp
    cmsel,s,etemp
    csys,0
    get_res
    theta=3.14159/2

    path_fa(pstart+ii)=unit_fsumx*sin(theta)-unit_fsumy*cos(theta)
    path_ft(pstart+ii)=unit_fsumx*cos(theta)+unit_fsumy*sin(theta)
    path_mz(pstart+ii)=unit_mz

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

*enddo
```

```
pstart=pstart+in_num


!=======Define path
allsel
dof,rotx
path,in_surf,pstart
*do,i,1,pstart
      ppath,i,path_nd(i)
        dnsol,path_nd(i),u,x,path_fa(i)
        dnsol,path_nd(i),u,y,path_ft(i)
        dnsol,path_nd(i),u,z,path_mz(i)
        dnsol,path_nd(i),rot,x,path_fh(i)
*enddo

AVPRIN,0,0,
!*

PDEF,1,U,X,AVG
/PBC,PATH, ,0
!*
AVPRIN,0,0,
!*
PDEF,2,U,Y,AVG
/PBC,PATH, ,0
!*
AVPRIN,0,0,
!*
PDEF,3,U,Z,AVG
/PBC,PATH, ,0

PDEF,4,rot,x,AVG
/PBC,PATH, ,0

/gresume,path_ax,plt

PLPAGM,1,1000,Blank
/title,Axial Force (kip/ft)
/rep
plpng

PLPAGM,2,1000,Blank
/title,Shear Force (kip/ft)
/rep
plpng

PLPAGM,3,1000,Blank
/title,Moment (kip-in/ft)
/rep
plpng
```

```
PLPAGM,4,1000,Blank
/title,Hoop Force (kip/ft)
/rep
plpng

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

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

get_res.mac

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

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

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

xmean=0
ymean=0
zmean=0

fsumx=0
fsumy=0
fsumz=0

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

```
*enddo

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

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

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

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

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

get_hpfrc.mac

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

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

csys,0

hp_f=0
sz_sum=0
nn=0
*do,i,1,nnode
      ndnxt=ndnext(nn)
      nsel,s,,,ndnxt
        esln
        esel,r,type,,2
        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
```

plpng.mac

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

path_ax.plt

```
/NOPR
/RESET
/DEVICE,VECT,OFF
! General Graphics Settings
/NUM,  1
/PLOP,INFO, 3
/TRIAD,RTOP
/GTHIC,CURV,  2
/GROPT,CGRI,ON
/GROPT,CURL,  1
/PNUM,TYPE, 1
/COL, NUM ,YGRE, 3
/TRLCY,ON
/TXTRE,ON
! Window Settings
/VIEW,1,  0.0000    ,  0.0000    ,  1.0000
/FOC, 1,  229.60    ,  1083.0    , 0.50000
/DIST,1,  400.86
/TYPE,1, 6
/EDG, 1, 0,  45.000
/CONT,1,  9,AUTO
/GO
```