ES/NRC 14-006
April 4, 2014

Enclosure 9

Calculation No. VSC-04.3200, Revision 1,
MSB-24 Corrosion Calculation
(1 paper copy)

ENERGYSOLUTIONS Spent Fuel Division	**CALCULATION PACKAGE**	Calc. Pkg No. VSC-04.3200 File No.: VSC-04.3200 Revision: 1

PROJECT/CUSTOMER:

VSC-04/VSC-24 General Licensees

TITLE:

MSB-24 Corrosion Calculation

SCOPE:

Product:	☐ FuelSolutions™	☒ VSC-24		☐ Other ______
Service:	☒ Storage	☐ Transportation		☐ Other ______
Conditions:	☒ Normal	☒ Off-Normal	☒ Accident	☐ Other ______

Component(s):

MSB Shell and Bottom Plate

Prepared by: STEVEN SISLEY

[signature] 03/22/12

Verified by: Lazer Vandenhoek

[signature] 3-22-12

Approved by Engineering Manager:

[signature] 03/22/12

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RECORD OF REVISIONS

REV.	AFFECTED PAGES	AFFECTED MEDIA	DESCRIPTION	NAMES (Print or Type)	
				PREPARER	CHECKER
0	All	1 CD-ROM	Initial Issue	S. Sisley	L. Vandenhoek
1	12, 14, 16.	1 CD-ROM	Editorial corrections to address GL review comments. (ECN No. VSC-04-ECN-004, Revision 0)	S. Sisley	L. Vandenhoek

RECORD OF VERIFICATION			
	YES	**NO**	**N/A**
(a) The objective is clear and consistent with the analysis.	☒	☐	
(b) The inputs are correctly selected and incorporated into the design.	☒	☐	☐
(c) References are complete, accurate, and retrievable.	☒	☐	☐
(d) Basis for engineering judgments is adequately documented.	☒	☐	☐
(e) The assumptions necessary to perform the design activity are adequately described and reasonable.	☒	☐	☐
(f) Assumptions and references, which are preliminary, are noted as being preliminary.	☐	☐	☒ None Prelim.
(g) Methods and units are clearly identified.	☒	☐	☐
(h) Any limits of applicability are identified.	☒	☐	☐
(i) Computer calculations are properly identified.	☒	☐	☐
(j) Computer codes used are under configuration control.	☒	☐	☐
(k) Computer codes used are applicable to the calculation.	☒	☐	☐
(l) Input parameters and boundary conditions are appropriate and correct.	☒	☐	
(m) An appropriate design method is used.	☒	☐	
(n) The output is reasonable compared to the inputs.	☒	☐	
(o) Conclusions are clear and consistent with analysis results.	☒	☐	

COMMENTS:

None

Verifier: Lazer Vandenhoek

[signature] 3-22-12

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1. INTRODUCTION

1.1 Objective

This calculation provides the structural evaluation of the MSB shell and bottom plate that demonstrates their structural adequacy with allowance for maximum corrosion after 60 years (i.e., 20 year initial CoC term plus 40-year renewal term).

1.2 Purpose

The VSC-24 storage system was originally designed with a 50-year design life. In order to support a 40-year renewal period of the VSC-24 Certificate of Compliance (CoC), the design life of the VSC-24 system must be extended to 60 years (i.e., 20-year initial CoC term plus 40-year renewal period.) The purpose of this calculation is to evaluate the maximum stresses in the MSB shell and bottom plate with the maximum corrosion allowance for the 60-year design life.

1.3 Scope

The scope of this calculation package includes the MSB shell and bottom plate only for the limiting load combinations (i.e., the load combinations for which the MSB shell and bottom plate safety margins against allowable stresses are lowest for the nominal plate thicknesses.)

2. REQUIREMENTS

2.1 Design Inputs

2.1.1. ASME American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code, *Rules for Construction of Nuclear Power Plant Components*," Section III, Division 1, Subsection NC, "*Class 2 Components*," 1992 Edition, 1994 Addenda.

2.1.2. American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code, *Rules for Construction of Nuclear Power Plant Components*," Section III, Division 1, Appendix F, "*Rules for Evaluation of Service Loadings with Level D Service Limits*," 1992 Edition, 1994 Addenda.

2.2 Regulatory Commitments

None.

3. <u>REFERENCES</u>

3.1 BFS Calculation Packages

3.1.1. Calculation No. VSC02.6.2.3.06, Revision 2, "MSB Corrosion Calculation."

3.1.2. Calculation No. VSC02.6.2.3.02, Revision 3, "MSB-24 Load Combination Evaluation."

3.1.3. Calculation No. VSC02.6.2.5.03, Rev. 0, "VSC-24 Design Parameters."

3.1.4. Calculation No. VSC02.6.2.3.25, Revision 2, "MSB Dead Weight and Vertical Drop Bottom Plate Bending Stress Analysis".

3.1.5. Calculation No. VSC02.6.2.3.21, Revision 2, "Normal and Off-normal Handling Analysis."

3.1.6. Calculation No. VSC02.6.2.3.05, Revision 2, "MSB-24 Normal, Off-normal, and Accident Pressure in the MSB."

3.2 General References

3.2.1. M. G. Fontana, "Corrosion Engineering," McGraw-Hill Book Company, 3rd Edition.

3.2.2. ASTM G101, "Standard Guide for Estimating the Atmospheric Corrosion Resistance of Low-Allow Steels," 1989.

4. <u>ASSUMPTIONS</u>

4.1 Design Configuration

The design parameters for the MSB are taken from Reference 3.1.3.

4.2 Design Criteria

Allowable stresses are taken from Reference 3.1.2.

4.3 Calculation Assumptions

The MSB shell and bottom plate have nominal thicknesses of 1.0" and 0.75", respectively. The plate thicknesses are reduced to account for the maximum corrosion expected to occur over a 60-year storage period. The corrosion rate is based on the conservative assumption that the steel is not coated and the steel is in a marine environment. This assumption is highly conservative for the following reasons:

a) The MSB is coated.

b) High surface temperatures will keep it dry.

c) Storage facilities are typically not located in a marine environment.

d) The MSB is sealed inside the storage cask and hence not directly exposed to the effects of corroding atmosphere.

To allow for manufacturing tolerances it has been assumed in this calculation that the nominal thickness of the MSB wall may be under size from the nominal thickness of 1 inch (Reference 3.1.3) by up to 0.03 inches. Hence, the calculation conservatively considers the wall thickness to be 0.97 inches before corrosion. Additional reduction of wall thickness due to corrosion is included in the analysis as described in Section 6.

5. CALCULATION METHODOLOGY

The methodology used to evaluate the MSB corrosion is identical to that used in the calculation package (Reference 3.1.1) that supports the VSC-24 CoC. The maximum amount of corrosion expected on the external surfaces of the MSB shell and bottom plate are determined using empirical relationships. The stresses in the MSB shell and bottom plate for the corroded condition are determined for the controlling load conditions using finite element analysis methods and the same finite element models from Reference 3.1.1 with adjusted thicknesses for the additional corrosion for 60-years.

The controlling loading conditions for both the MSB shell and MSB bottom plate are identified in the load case combination calculation (Reference 3.1.2). Each of the membrane (P_m), and membrane plus bending ($P_L + P_b$) stresses are addressed. The worst conditions, as identified by lowest design margins, are summarized as follows.

Component	Stress Type	Limiting Load Combination	Limiting Design Margin
MSB Shell	P_m	Vertical Drop + Pressure	0.03
	$P_L + P_b$	Vertical Drop + Pressure	0.23
MSB Base	P_m	Horizontal Drop + Pressure	0.48
	$P_L + P_b$	Dead Weight + Off-Normal Pressure + Off-Normal Handling	0.02

6. CALCULATIONS

From Figure 6-1 (Figure 8.1, in Reference 3.2.1), the corrosion rate for a marine atmosphere is 3 mpy.

$$60 \text{ years x } 0.003 \cdot {in}/{year} = 0.18 \text{ inches}$$

From Figure 6-2 (graphs for ASTM A-588 and A-242 steels from Reference 3.2.2), for the amount of corrosion in a marine environment over 60 years is estimated to be 400 μm. ASTM G101 (Reference 3.2.2) also states that the corrosion rate of weather-resistant steels such as A-588 and A-242 is 1/4 that of regular carbon steels such as A-516 Gr70. Therefore, the penetration of A-516 Gr 70 shell and base material (Reference 3.1.3) can be estimated as follows:

$$t = (400 \text{ x } 10^{-6} \text{ m})(39.4 \text{ in/m}) \text{ x } 4 = 0.063 \text{ inches}$$

For conservatism, use the higher value of 0.18 inches from above.

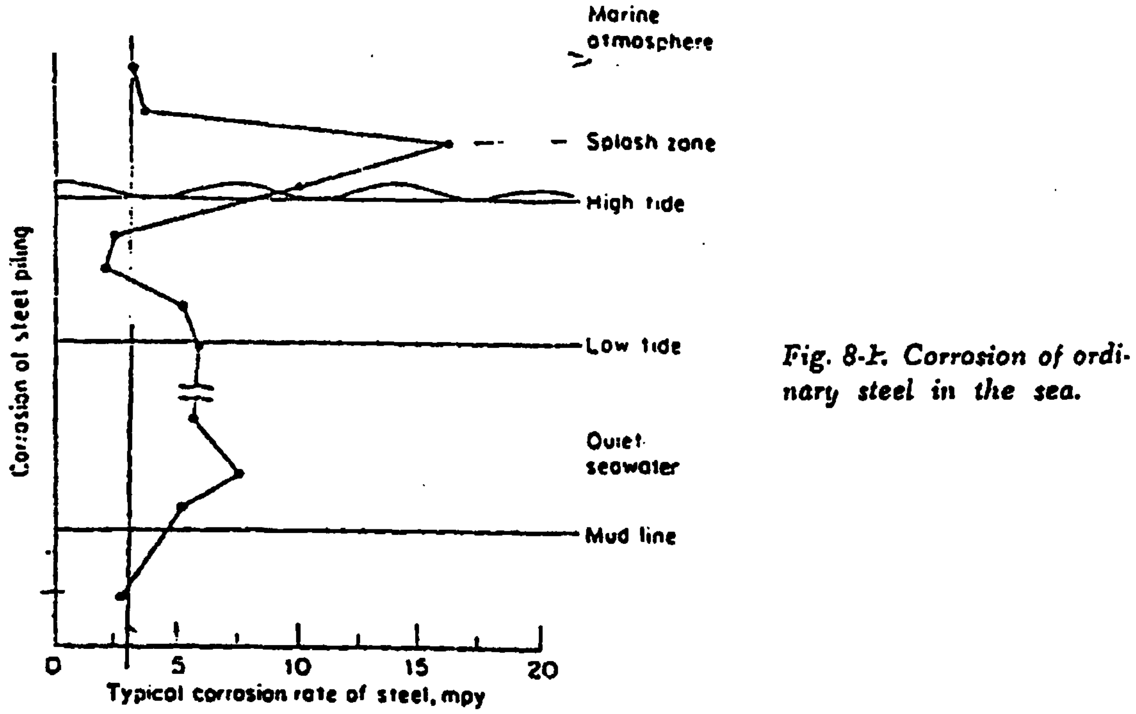


Figure 6-1 Corrosion of Steel in a Marine Atmosphere (Reference 3.2.1)

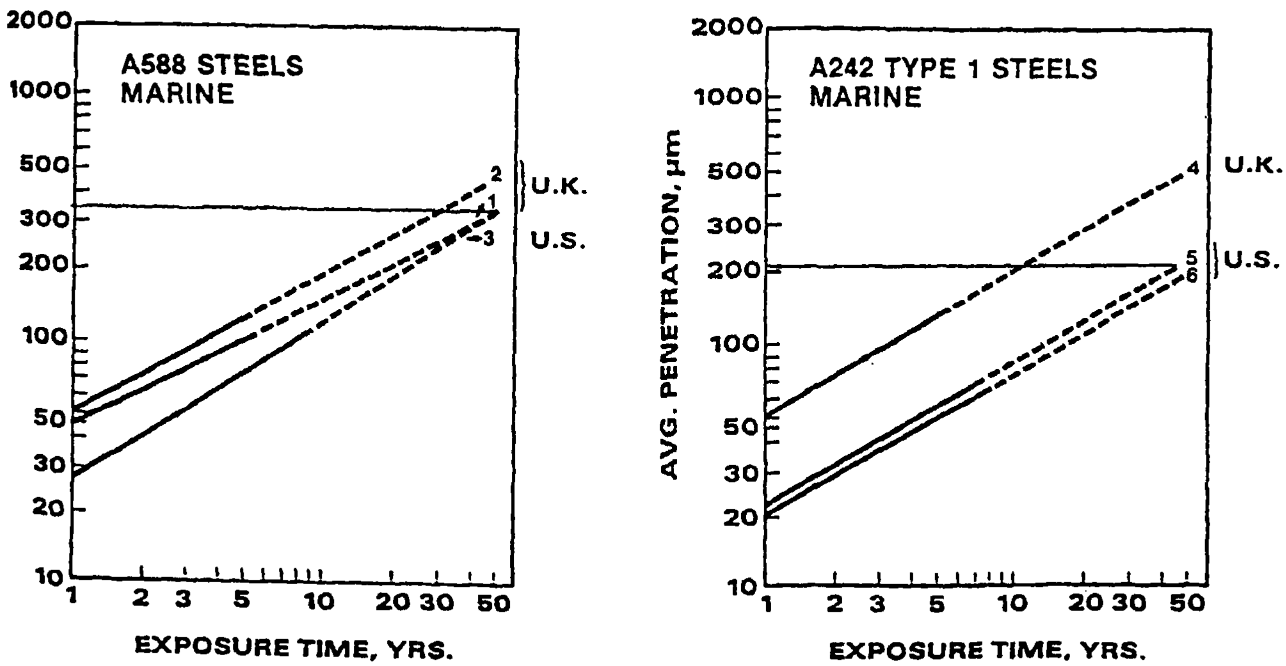


Figure 6-2 Corrosion of Steel in a Marine Atmosphere (Reference 3.2.2)

6.1 MSB Shell

As noted above in Section 5, the vertical drop load combination produces the lowest design margin for the MSB shell. Since the vertical drop analysis was non-linear, direct scaling of stresses to account for the corroded wall thickness is not valid. For this reason the analysis of Reference 3.1.4 was repeated with the following changes.

- Normal operating pressure of 8.9 psig (bounds the value from Reference 3.1.6) was applied to both the base and shell walls of the finite element model.
- The MSB shell was modeled with a nominal thickness of 0.97 inches to allow for lower bound manufacturing tolerance.
- Both MSB wall and MSB base thicknesses were reduced by 0.18 inches to account for the effects of 60 years of corrosion.

The combined effect of vertical drop, internal pressure and corroded walls was then determined by running the finite element model. The ANSYS input for this analysis is included as Attachment 1 of this calculation.

Allowable stresses are taken from Reference 3.1.2.

Plots of distribution of stress intensity are shown in Figure 6-3, Figure 6-4, and Figure 6-5 for shell top, middle and bottom respectively.

It is noted that the highest stresses concentrate in the region of the ceramic tiles. By observation of the figures and tables noted above it can be seen that virtually all of the stress in the shell is membrane stress. This is expected since the support provided by the ceramic tiles is directly underneath the MSB wall, giving rise to high bearing stress. The bearing stress is discernable as membrane stress in the finite element analysis. Since a plastic systems analysis is being performed to the requirements of Service Level D, the rules of Appendix F (Design Input 2.1.2) of the ASME code apply. Paragraph F-1341.6 of Design Input 2.1.2 specifies that "bearing stresses need not be evaluated for loads for which Level D Service limits apply." Hence, for this reason, the local regions in which the bearing stress occurs has not been evaluated in this analysis. Values of membrane (P_m) stress and membrane plus bending ($P_L + P_b$) stress are conservatively evaluated at a location of one node up vertically from the support location. This approach is conservative since the reported stress is still mainly due to membrane (bearing) effects. Stress summaries for shell top, middle and bottom locations are recorded in Table 6-1.

The results of the above analysis are summarized below. (See Table 6-1 for results)

P_m	=	47.0 ksi	<	49.0 ksi	acceptable.
P_L+P_b	=	47.3 ksi	<	63.0 ksi	acceptable.

6.2 MSB Bottom Plate

As noted above in Section 5, the lowest design margins for the MSB base come from two load conditions. The lowest P_m design margin comes from the horizontal drop load combination, and the lowest $P_L + P_b$ design margin from the dead load + off-normal pressure + off-normal handling load combination.

The values of allowable stress are taken from Reference 3.1.2.

6.2.1 Evaluation of Pm

Since the horizontal drop analysis is a linear analysis, the value of P_m with corroded MSB base can be calculated by scaling the un-corroded P_m stress by the ratio of the nominal to corroded wall thicknesses (since membrane stress is inversely proportional to wall thickness). The pressure stress is added to this revised drop stress. The horizontal drop and pressure stresses are from Reference 3.1.2.

Hence,

$$P_m \text{ corroded} = \frac{0.75}{0.75-0.18}\cdot\sigma_{horiz\_drop} + \frac{0.75}{0.75-0.18}\cdot\sigma_{pressure}$$

$$= (1.32 \text{ x } 32.6) + (1.32 \text{ x } 0.40)$$

$$= 43.6 \text{ ksi} \quad < \quad 49.0 \quad \text{acceptable}$$

6.2.2 Evaluation of $P_L + P_b$

The lowest design margin for this condition comes from the combination of the dead weight stress with MSB supported on ceramic tiles, off-normal internal pressure, and off-normal handling loads. Since the evaluation of bending stress $P_L + P_b$ for this condition is calculated by adding stress intensity from different load cases, no account is made for the way the different loads would interact with each when considered to act simultaneously. In order to quantify the combined effect, the dead weight finite element analysis (Ref. 3.1.4) was re-run with the following changes.

- An off-normal operating pressure of 10.9 psig was applied to both the base and shell walls of the finite element model. (Note: The design-basis off-normal internal pressure load is associated with the maximum temperatures for a 24 kW heat load. After 60 years, the decay heat and the resulting MSB temperatures and internal pressure will be significantly lower (i.e., less than ½ the initial values.) Therefore, it is very conservative to apply the maximum internal pressure loading to the MSB with the maximum corrosion allowance for 60 years.)

- The MSB shell was modeled with a nominal thickness of 0.97 inches to allow for lower bound manufacturing tolerance.

- Both MSB wall and MSB base thicknesses were reduced by 0.18 inches to account for the effects of 60 years of corrosion.

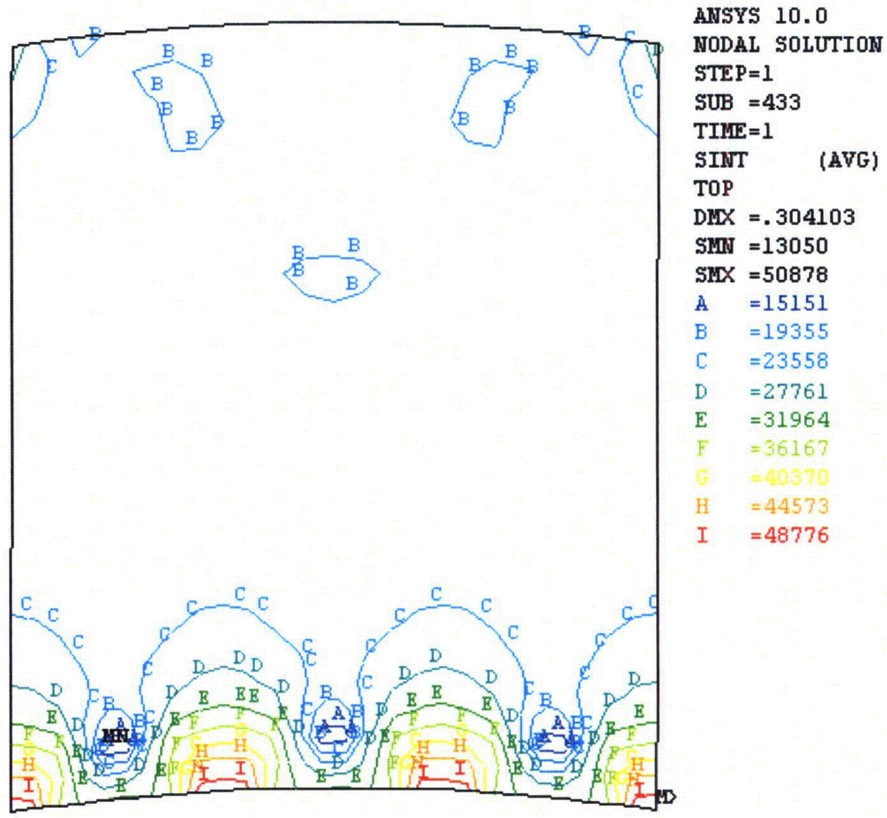
- The off-normal handling acceleration resulting from the lowering of the MSB at 0.75 ft/sec into the storage cask, identified in Ref. 3.1.5 to be 1g, was applied in addition to the 1g due to dead weight. (Note: This load would also apply when raising the MSB assembly during cask unloading operations.)

The combined effect of dead weight, internal pressure, corroded walls, and handling acceleration was then determined by running the finite element model. The ANSYS input for this analysis is included as Attachment 2 of this calculation.

Plots of distribution of stress intensity are shown in Figure 6-6 and Figure 6-7 for shell element top and bottom, respectively. Stress summaries for shell element top and bottom locations are recorded in Table 6-2. As permitted by the ASME code (Design Input 2.1.1), local stresses at the structural discontinuity cause by the ceramic tiles have been discounted.

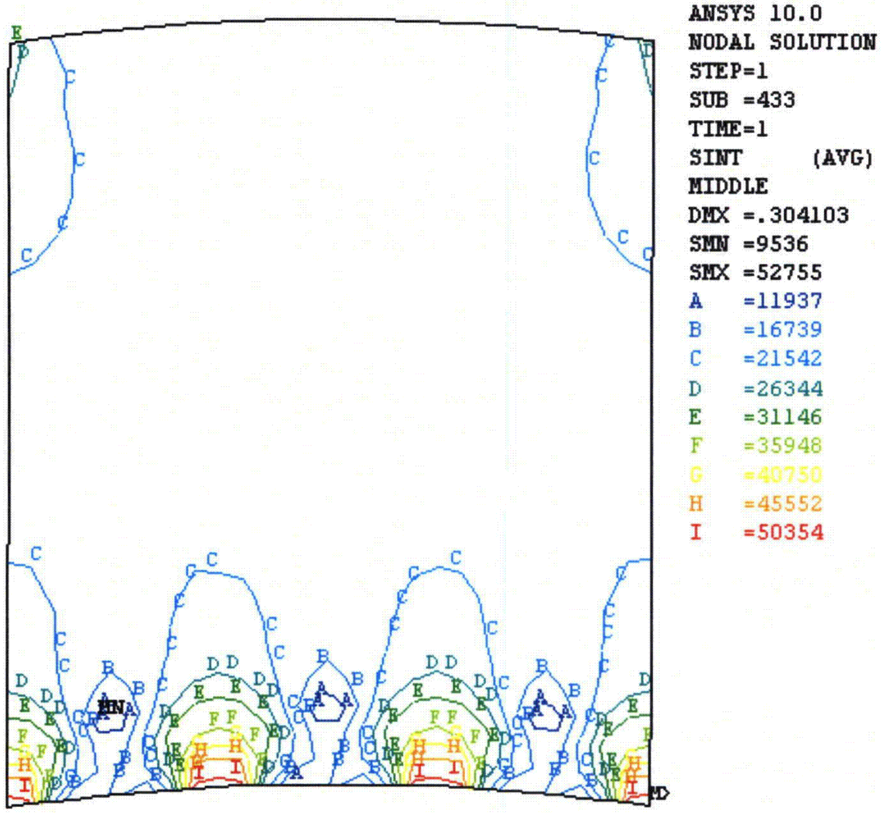
The final value of $P_L + P_b$ is then,

$P_L + P_b =$ 35.5 ksi $<$ 40.5 ksi acceptable.



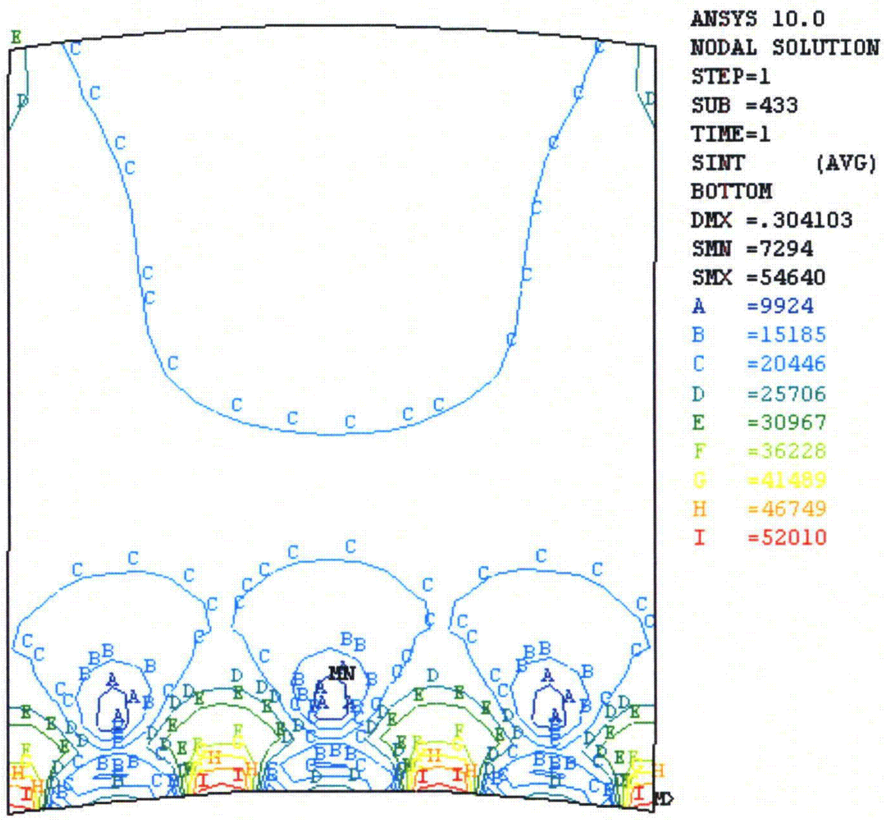
(Note: Units of stress intensity are psi.)

Figure 6-3 STRESS INTENSITY IN MSB SHELL TOP SURFACE LOCATION. VERTICAL DROP + NORMAL PRESSURE + CORRODED WALLS



(Note: Units of stress intensity are psi.)

Figure 6-4 STRESS INTENSITY IN MSB SHELL MID SURFACE LOCATION. VERTICAL DROP + NORMAL PRESSURE + CORRODED WALLS



(Note: Units of stress intensity are psi.)

Figure 6-5 STRESS INTENSITY IN MSB SHELL BOTTOM SURFACE LOCATION. VERTICAL DROP + NORMAL PRESSURE + CORRODED WALLS

Table 6-1 Summary of Stress Intensity in MSB Shell
Vertical Drop + Normal Pressure + Corroded Walls

(Note: Units of stress intensity are psi.)

Shell Top

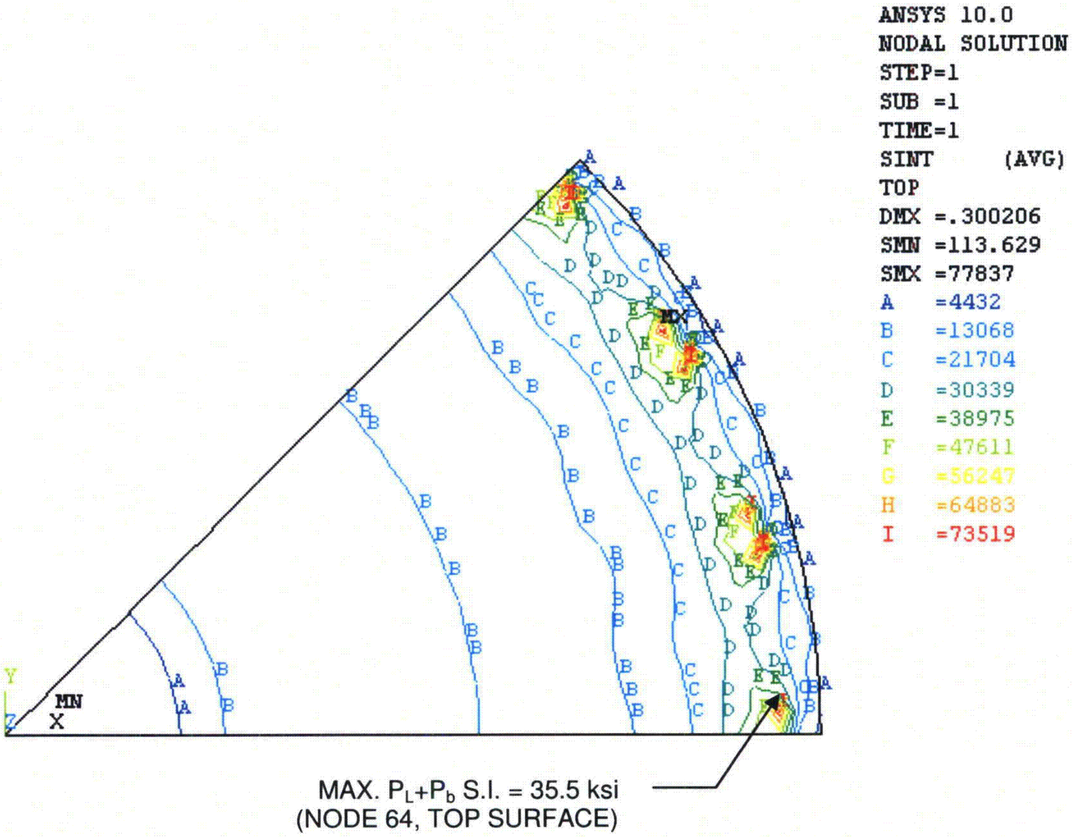
NODE	S1	S2	S3	SINT	SEQV
2	15.657	-25304.	-50862.	50878.	44062.
11	2.7544	-25347.	-50811.	50813.	44006.
28	16.021	-25395.	-50795.	50811.	44004.
.					
.					
.					
529	-2.8752	-16817.	-46833.	46830.	41090.
711	-2.6453	-16562.	-46776.	46773.	41078.
594	-9.4306	-18132.	-46165.	46155.	40278.
653	-9.4560	-18110.	-46162.	46153.	40278.
541	-9.5475	-18125.	-46158.	46148.	40272.

Shell Middle

NODE	S1	S2	S3	SINT	SEQV
2	14.635	-26390.	-52741.	52755.	45687.
20	2.7792	-26459.	-52701.	52703.	45643.
11	2.7086	-26459.	-52697.	52700.	45640.
.					
.					
.					
529	0.27926	-17145.	-47041.	47041.	41234.
711	0.45649	-16943.	-47000.	47001.	41229.
654	-6.7815	-17928.	-46151.	46144.	40292.
595	-6.8051	-17924.	-46148.	46141.	40290.
653	-5.1172	-17208.	-45780.	45775.	40048.

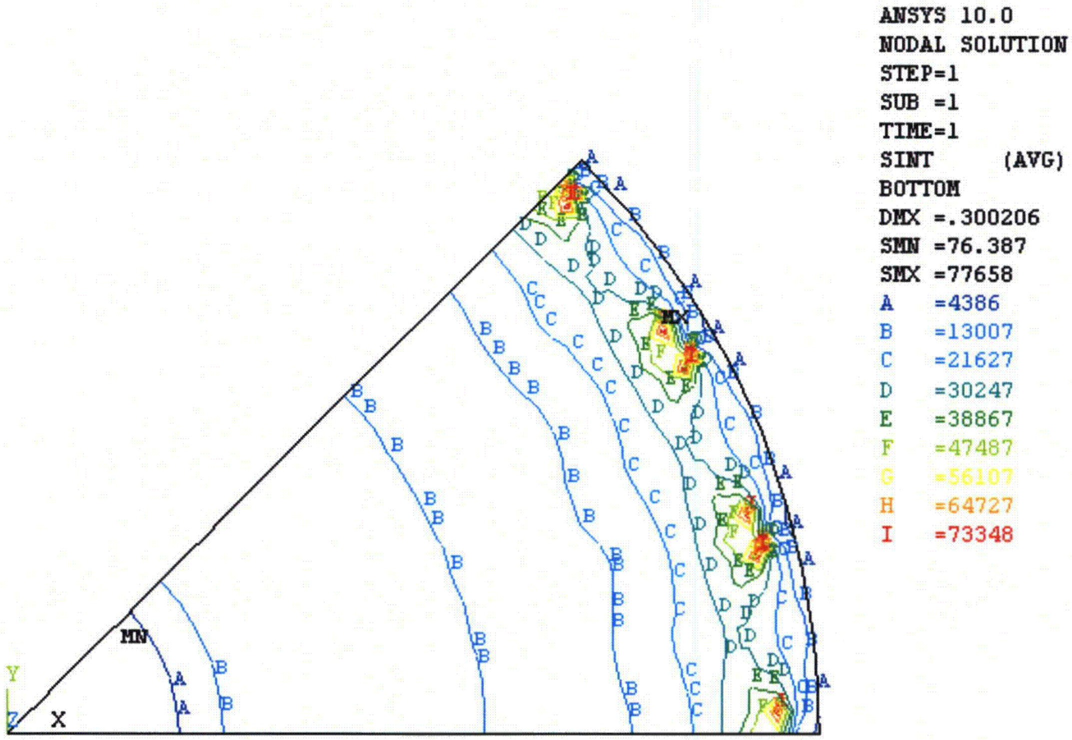
Shell Bottom

NODE	S1	S2	S3	SINT	SEQV
2	14.491	-27470.	-54626.	54640.	47320.
20	3.4632	-27577.	-54597.	54601.	47286.
28	14.591	-27593.	-54579.	54594.	47281.
.					
.					
.					
529	3.6538	-17473.	-47249.	47253.	41382.
711	3.7818	-17323.	-47226.	47230.	41383.
654	-3.9311	-18244.	-46409.	46405.	40493.
595	-3.9485	-18236.	-46405.	46401.	40490.
653	-0.66525	-16306.	-45400.	45399.	39833.



(Note: Units of stress intensity are psi.)

Figure 6-6 STRESS INTENSITY IN MSB BASE TOP SURFACE LOCATION.
Dead Weight + Off-Normal Pressure + Corroded Walls + Off-Normal Handling



(Note: Units of stress intensity are psi.)

Figure 6-7 STRESS INTENSITY IN MSB BASE BOTTOM SURFACE LOCATION. Dead Weight + Off-Normal Pressure + Corroded Walls + Off-Normal Handling

Table 6-2 Summary of Stress Intensity in MSB Shell
Dead Weight + Off-Normal Pressure + Corroded Walls + Off-Normal Handling

(Note: Units of stress intensity are psi.)

Shell Top

NODE	S1	S2	S3	SINT	SEQV
21	77799.	45592.	-37.972	77837.	67742.
16	77748.	45557.	-37.972	77786.	67697.
7	77687.	45560.	-37.972	77725.	67648.
.					
.					
.					
64	35448.	1395.9	-37.972	35486.	34792.
81	35444.	1371.4	-37.972	35482.	34799.
69	35427.	1330.7	-37.972	35465.	34801.
75	35368.	1311.9	-37.972	35405.	34750.
76	35326.	1298.3	-37.972	35364.	34715.
70	35319.	1320.2	-37.972	35357.	34698.

Shell Bottom

NODE	S1	S2	S3	SINT	SEQV
21	0.0000	-45286.	-77658.	77658.	67563.
16	0.0000	-45252.	-77607.	77607.	67518.
7	0.0000	-45254.	-77546.	77546.	67469.
.					
.					
.					
64	0.0000	-1065.0	-35373.	35373.	34853.
81	0.0000	-1040.4	-35369.	35369.	34860.
69	0.0000	-1001.3	-35352.	35352.	34862.
75	0.0000	-982.71	-35293.	35293.	34812.
76	0.0000	-968.04	-35252.	35252.	34778.
70	0.0000	-990.40	-35244.	35244.	34760.

7. CONCLUSIONS

7.1 Results

Based on conservative corrosion calculation the thickness of the MSB shell and base are reduced by 0.18 inches over a 60 year period. The maximum shell and base plate membrane (P_m) and membrane plus bending ($P_L + P_b$) stresses for the most onerous design margins have been recalculated with the reduced wall thicknesses. All values of stress are acceptable, demonstrating that adequate margin has been provided for corrosion in the MSB over 60 years.

7.2 Compliance With Requirements

The results of this evaluation demonstrate that the MSB shell and bottom plate satisfy the applicable allowable stress design criteria for the maximum corroded condition.

7.3 Range of Validity

The results of this calculation package are valid for the design life of 60-years.

7.4 Summary of Conservatism

The corrosion rate used for this calculation is conservatively based on un-coated steel in a marine environment. This is conservative since the MSB is coated, and the sheltered environment inside the VCC will keep the MSB dry and not directly exposed to the effects of the corroding atmosphere.

7.5 Limitations or Special Instructions

None.

8. ELECTRONIC FILES

8.1 Computer Runs

Filename	File Date	Computer Code	Cat	Version	Platform	Machine
MSB_Shell_60yr.out	4/5/11	ANSYS	2	10.0	NT	26838-D
MSB_Btmpl_60yr.out	4/5/11	ANSYS	2	10.0	NT	26838-D

File Description

MSB_Shell_60yr.out — ANSYS output data file. Vertical Drop (108g) + Normal press (8.9 psig), 0.18-inch corrosion allowance in MSB shell and bottom plate.

MSB_Btmpl_60yr.out — ANSYS output data file. Dead weight (1g) + Off-normal press (10.9 psig) + off-normal handling (1g), 0.18-inch corrosion allowance in MSB shell and bottom plate.

8.2 Other Electronic Files

None.

9. ATTACHMENT A - ANSYS INPUT FILE *MSB_SHELL_60YR.INP*

Vertical Drop + Normal Pressure, with 0.18-inch corrosion allowance in MSB shell and bottom plate

```
!
! * 3D ANALYSIS OF BASE PLATE STRESS WITH
! * MSB BASE SUPPORTED BY CERAMIC TILES AROUND EDGE
! * END DROP ACCELERATION OF 108g
! * CALCULATION BASED THINNEST SHELL OF 0.97 INCHES
! * MINUS CORRODED THICKNESSES OF 0.18 INCHES (AFTER 60 YR)
!
/filname,MSB_Shell_60yr
!
/Prep7
/Title,VSC Base Plate Stress Analysis
!
! Element Types
et,1,shell143           ! Plastic Shell elements
et,2,contac52           ! 3-D Point to Point Gap Elements
keyopt,2,3,1            ! Use soft spring across open gap
keyopt,2,7,1            ! Use reasonable time increment
!
!*** CHECK MATERIAL PROPERTIES
! Material Properties
! SA-516, Grade 70 Ferritic Carbon Steel, 300 deg.F
dens,1,0.284
nuxy,1,0.29
ex,1,28.3E6
tb,bkin,1,1
tbdata,1,33.7E3,355.1E3  ! Yield Stress and Tangent Modulus
!
*afun,deg                ! Angles in degrees as default
!
!******************
!*** Parameters ***
!******************
OD  = 62.5               ! Outside diameter
ID  = 60.5               ! Inside diameter
WTH = 0.97               ! Wall thickness
BRAD = ID/2+WTH/2        ! C/L radius of basket
BTH = 0.75               ! Base plate thickness
LET = 1.7                ! Length of ceramic tile
TTH = 0.30               ! Ceramic tile thickness
TR1 = 30.0               ! C/L radius ceramic tiles
THETA = asin((LET/2)/TR1) ! Angle between center & edge of tiles
VLE = 30.0               ! Length of modeled vertical portion of vessel
ACC = 108                ! Acceleration due to end drop
TOL = 0.001              ! Select tolerance
!
! Real constants
r,1,BTH-0.18             ! Thickness of base plate (non tile regions)
r,2,BTH-0.18             ! Thickness of base plate (tiles region)
r,3,WTH-0.18             ! Thickness of basket wall
r,4,1e6,TTH,3            ! Contact stiffness, MSB to base
!
!*****************
!*** Keypoints ***
!*****************
csys,1
k,1,
k,2,TR1-LET/2,0,0
k,3,BRAD,0,0
k,4,TR1-LET/2,THETA,0
k,5,BRAD,THETA,0
k,6,TR1-LET/2,15-THETA,0
k,7,BRAD,15-THETA,0
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k,8,TR1-LET/2,15+THETA,0
k,9,BRAD,15+THETA,0
k,10,TR1-LET/2,30-THETA,0
k,11,BRAD,30-THETA,0
k,12,TR1-LET/2,30+THETA,0
k,13,BRAD,30+THETA,0
k,14,TR1-LET/2,45-THETA,0
k,15,BRAD,45-THETA,0
k,16,TR1-LET/2,45,0
k,17,BRAD,45,0
!
ksel,s,loc,x,BRAD
kgen,2,all,,,,,VLE/4,100
ksel,s,loc,z,VLE/4
kgen,2,all,,,,,VLE*3/4,100
ksel,all
!
! Areas
! Tile areas first
csys,1
a,2,3,5,4
a,6,7,9,8
a,10,11,13,12
a,14,15,17,16
type,1
mat,1
real,2
esize,0.9
amesh,1,4
!
! Rest of Base
a,1,2,4,6,8,10,12,14,16
a,4,5,7,6
a,8,9,11,10
a,12,13,15,14
!
lsel,s,line,,22,24
lesize,all,,,7
lsel,all
real,1
amesh,5,8
!
! Basket shell
numstr,area,21
a,3,103,105,5
a,5,105,107,7
a,7,107,109,9
a,9,109,111,11
a,11,111,113,13
a,13,113,115,15
a,15,115,117,17
!
a,103,203,205,105
a,105,205,207,107
a,107,207,209,109
a,109,209,211,111
a,111,211,213,113
a,113,213,215,115
a,115,215,217,117
!
esize,1.2
real,3
amesh,21,27
esize,2.0
amesh,28,34
!
!****************
!*** Contacts ***
!****************
! Contact between basket base & cask
! Select nodes on ceramic tile elements
```

```
esel,s,real,,1
nsle,s
! Generate coincident set of nodes
ngen,2,2000,all,,,0,0,-TTH
! Generate contact elements
esel,s,real,,1
nsle,s
*get,numnodes,node,,count
nsel,a,node,,1999,3999
*get,nextnode,node,,num,min
type,2
real,4
*do,i,1,numnodes
  *if,i,eq,1,then
     e,nextnode,nextnode+2000
     *get,nextnode,node,nextnode,nxth
  *elseif,i,ge,2,then
     e,nextnode,nextnode+2000
     *get,nextnode,node,nextnode,nxth
  *endif
*enddo
!
! Remove contacts on periphery of tiles
asel,s,area,,1,4
esla,s
nsle,s,ext
esln,s
esel,r,type,,2
edel,all
nall
eall
!
!*******************
!*** Constraints ***
!*******************
! Symmetry BC's
esel,s,type,,1
nsle,s
csys,1
nsel,s,loc,y,45
nrotat,all
dsym,symm,y,1
esel,s,type,,1
nsle,s
nsel,s,loc,y,0
dsym,symm,y
!
! Contacts at ground
esel,s,type,,2
nsle,s
nsel,r,,,1999,3999
d,all,all,0
nall
!
! Base of tiles
esel,s,real,,2
nsle
d,all,uz,0
!
!*********************
!*** Applied Loads ***
!*********************
! Pressure on basket base due to contents + Normal Operating
esel,s,real,,1,2
nsle,s
sfe,all,2,pres,,(13.536*ACC) + 8.9
nall
eall
!
! Normal Operating Pressure on walls of MSB
esel,s,real,,3
```

```
nsle,s
sfe,all,2,pres,,8.9
nall
eall
!
! Force on side wall due to part of
! Basket not included in model.
! Interior nodes first
FORCE = 3442.5*ACC   ! Calculated mass missing in 1/8 model
csys,1
nsel,s,loc,x,BRAD
nsel,r,loc,z,VLE
*get,NUMNODES,node,,count
nsel,r,loc,y,1,44
NODEFORC = FORCE/(NUMNODES-1)
f,all,fz,-NODEFORC
nall
! Exterior nodes (half the load)
csys,1
nsel,s,loc,x,BRAD
nsel,r,loc,z,VLE
nsel,r,loc,y,0
f,all,fz,-NODEFORC/2
nsel,s,loc,x,BRAD
nsel,r,loc,z,VLE
nsel,r,loc,y,45
f,all,fz,-NODEFORC/2
nall
!
! Drop Acceleration
acel,,,ACC           ! Body load acceleration
!
allsel
!
!****************
!*** Solution ***
!****************
/solu
nlgeom,on            ! Include large deformation effects
autots,on            ! Automatic time stepping
nsubst,50,1000,10    ! 50 substeps 1000max 10min for load step
solcon,on,on
cnvtol,f,,0.01       ! Convergence for force at 1%
cnvtol,m,,0.01       ! Convergence for moment at 1%
!
solve
finish
/post1
set
/page,,,3000
prrsol
!
/com, **** MSB BASE ****
esel,s,real,,1,2            ! MSB Base
nsle,s
!
/title,MSB Base - Shell Top Stress Intensity
top
nsort,s,int,0,1,50          ! Sort top 50 stress intensities
prnsol,s,prin               ! List principal stresses
!
/title,MSB Base - Shell Mid Stress Intensity
mid
nsort,s,int,0,1,50          ! Sort top 50 stress intensities
prnsol,s,prin               ! List principal stresses
!
/title,MSB Base - Shell Bot Stress Intensity
bot
nsort,s,int,0,1,50          ! Sort top 50 stress intensities
prnsol,s,prin               ! List principal stresses
!
```

```
/com, **** MSB SHELL ****
esel,s,real,,3              ! MSB Shell
nsle,s
!
/title,MSB Shell - Shell Top Stress Intensity
top
nsort,s,int,0,1,50          ! Sort top 50 stress intensities
prnsol,s,prin               ! List principal stresses
!
/title,MSB Shell - Shell Mid Stress Intensity
mid
nsort,s,int,0,1,50          ! Sort top 50 stress intensities
prnsol,s,prin               ! List principal stresses
!
/title,MSB Shell - Shell Bot Stress Intensity
bot
nsort,s,int,0,1,50          ! Sort top 50 stress intensities
prnsol,s,prin               ! List principal stresses
!
/com,**** MSB Shell/Base - WELD ****
esel,s,real,,3
nsle,s
csys,1
nsel,r,loc,x,BRAD
!
/title,Shell/Base Weld - Shell Top Stress Intensity
top
nsort,s,int,0,1,50          ! Sort top 50 stress intensities
prnsol,s,prin               ! List principal stresses
!
/title,Shell/Base Weld - Shell Mid Stress Intensity
mid
nsort,s,int,0,1,50          ! Sort top 50 stress intensities
prnsol,s,prin               ! List principal stresses
!
/title,Shell/Base Weld - Shell Bot Stress Intensity
bot
nsort,s,int,0,1,50          ! Sort top 50 stress intensities
prnsol,s,prin               ! List principal stresses
!
finish
/exit,nosa
```

10. ATTACHMENT B - ANSYS INPUT FILE *MSB_BTMPL_60YR.INP*

Dead Weight + Off-Normal Pressure + Off-Normal Handling, with 0.18-inch corrosion allowance in MSB shell and bottom plate

```
!
! * 3D ANALYSIS OF BASE PLATE STRESS WITH
! * MSB BASE SUPPORTED BY CERAMIC TILES AROUND EDGE
! * NORMAL OPERATING CONDITION 1g + off-normal pressure 10.9 psi
! * CORRODED SHELL AND BASE AFTER 60 YR. (THICKNESSES REDUCED BY 0.18")
! * WALL THICKNESS OF SHELL AT 0.97"
! * VERTICAL HANDLING COMPONENT 0.5g x 2 DLF = 1.0g ADDED
!
/filname,MSB_Btmpl_60yr
!
/Prep7
/Title,VSC Base Plate Stress Analysis
!
! Element Types
et,1,shell63            ! Elastic Shell elements
et,2,contac52           ! 3-D Point to Point Gap Elements
keyopt,2,3,1            ! Use soft spring across open gap
keyopt,2,7,1            ! Use reasonable time increment
!
!*** CHECK MATERIAL PROPERTIES
! Material Properties
! SA-516, Grade 70 Ferritic Carbon Steel, 300 deg.F
dens,1,0.284
nuxy,1,0.29
ex,1,28.3E6
!
*afun,deg                 ! Angles in degrees as default
!
!******************
!*** Parameters ***
!******************
OD  = 62.5                ! Outside diameter
ID  = 60.5                ! Inside diameter
WTH = 0.97                ! Wall thickness
BRAD = ID/2+WTH/2         ! C/L radius of basket
BTH = 0.75                ! Base plate thickness
LET = 1.7                 ! Length of ceramic tile
TTH = 0.30                ! Ceramic tile thickness
TR1 = 30.0                ! C/L radius ceramic tiles
THETA = asin((LET/2)/TR1) ! Angle between center & edge of tiles
VLE = 30.0                ! Length of modeled vertical portion of vessel
TOL = 0.001               ! Select tolerance
!
! Real constants
r,1,BTH-0.18              ! Thickness of base plate (non tile regions)
r,2,BTH-0.18              ! Thickness of base plate (tiles region)
r,3,WTH-0.18              ! Thickness of basket wall
r,4,1e6,TTH,3             ! Contact stiffness, MSB to base
!
!*****************
!*** Keypoints ***
!*****************
csys,1
k,1,
k,2,TR1-LET/2,0,0
k,3,BRAD,0,0
k,4,TR1-LET/2,THETA,0
k,5,BRAD,THETA,0
k,6,TR1-LET/2,15-THETA,0
k,7,BRAD,15-THETA,0
k,8,TR1-LET/2,15+THETA,0
k,9,BRAD,15+THETA,0
```

```
k,10,TR1-LET/2,30-THETA,0
k,11,BRAD,30-THETA,0
k,12,TR1-LET/2,30+THETA,0
k,13,BRAD,30+THETA,0
k,14,TR1-LET/2,45-THETA,0
k,15,BRAD,45-THETA,0
k,16,TR1-LET/2,45,0
k,17,BRAD,45,0
!
ksel,s,loc,x,BRAD
kgen,2,all,,,,,VLE/4,100
ksel,s,loc,z,VLE/4
kgen,2,all,,,,,VLE*3/4,100
ksel,all
!
! Areas
! Tile areas first
csys,1
a,2,3,5,4
a,6,7,9,8
a,10,11,13,12
a,14,15,17,16
type,1
mat,1
real,2
esize,0.9
amesh,1,4
!
! Rest of Base
a,1,2,4,6,8,10,12,14,16
a,4,5,7,6
a,8,9,11,10
a,12,13,15,14
!
lsel,s,line,,22,24
lesize,all,,,7
lsel,all
real,1
amesh,5,8
!
! Basket shell
numstr,area,21
a,3,103,105,5
a,5,105,107,7
a,7,107,109,9
a,9,109,111,11
a,11,111,113,13
a,13,113,115,15
a,15,115,117,17
!
a,103,203,205,105
a,105,205,207,107
a,107,207,209,109
a,109,209,211,111
a,111,211,213,113
a,113,213,215,115
a,115,215,217,117
!
esize,1.2
real,3
amesh,21,27
esize,2.0
amesh,28,34
!
!****************
!*** Contacts ***
!****************
! Contact between basket base & cask
! Select nodes on ceramic tile elements
esel,s,real,,1
nsle,s
```

```
! Generate coincident set of nodes
ngen,2,2000,all,,,0,0,-TTH
! Generate contact elements
esel,s,real,,1
nsle,s
*get,numnodes,node,,count
nsel,a,node,,1999,3999
*get,nextnode,node,,num,min
type,2
real,4
*do,i,1,numnodes
  *if,i,eq,1,then
     e,nextnode,nextnode+2000
     *get,nextnode,node,nextnode,nxth
  *elseif,i,ge,2,then
     e,nextnode,nextnode+2000
     *get,nextnode,node,nextnode,nxth
  *endif
*enddo
!
! Remove contacts on periphery of tiles
asel,s,area,,1,4
esla,s
nsle,s,ext
esln,s
esel,r,type,,2
edel,all
nall
eall
!
!*******************
!*** Constraints ***
!*******************
! Symmetry BC's
esel,s,type,,1
nsle,s
csys,1
nsel,s,loc,y,45
nrotat,all
dsym,symm,y,1
esel,s,type,,1
nsle,s
nsel,s,loc,y,0
dsym,symm,y
!
! Contacts at ground
esel,s,type,,2
nsle,s
nsel,r,,,1999,3999
d,all,all,0
nall
!
! Base of tiles
esel,s,real,,2
nsle
d,all,uz,0
!
!*********************
!*** Applied Loads ***
!*********************
! Pressure on basket base due to contents
esel,s,real,,1,2
nsle,s
sfe,all,2,pres,,13.536*2.0+10.9
nall
eall
! Normal pressure on MSB wall
esel,s,real,,3
nsle,s
sfe,all,2,pres,,10.9
nall
```

```
eall
!
! Force on side wall due to part of
! Basket not included in model.
! Interior nodes first
FORCE = 3442.5*2.0     ! Calculated mass missing in 1/8 model
csys,1
nsel,s,loc,x,BRAD
nsel,r,loc,z,VLE
*get,NUMNODES,node,,count
nsel,r,loc,y,1,44
NODEFORC = FORCE/(NUMNODES-1)
f,all,fz,-NODEFORC
nall
! Exterior nodes (half the load)
csys,1
nsel,s,loc,x,BRAD
nsel,r,loc,z,VLE
nsel,r,loc,y,0
f,all,fz,-NODEFORC/2
nsel,s,loc,x,BRAD
nsel,r,loc,z,VLE
nsel,r,loc,y,45
f,all,fz,-NODEFORC/2
nall
!
! Drop Acceleration
acel,,,1+1      ! 1.0g Body load acceleration + 1.0g vertical handling acceleration
!
allsel
!
!****************
!*** Solution ***
!****************
/solu
solve
finish
!
/post1
set
/page,,,3000
prrsol
!
/title,Base - Shell Top Stress Intensity
top
nsort,s,int,0,1,100        ! Sort top 100 stress intensities
prnsol,s,prin              ! List principal stresses
!
/title,Base - Shell Mid Stress Intensity
mid
nsort,s,int,0,1,100        ! Sort top 100 stress intensities
prnsol,s,prin              ! List principal stresses
!
/title,Base - Shell Bot Stress Intensity
bot
nsort,s,int,0,1,100        ! Sort top 100 stress intensities
prnsol,s,prin              ! List principal stresses
!
/com,**** MSB BASE - WELD ****
esel,s,real,,1,2
nsle,s
csys,1
nsel,r,loc,x,BRAD
!
!
!
/title,Base Weld - Shell Top Stress Intensity
top
nsort,s,int,0,1,10         ! Sort top 10 stress intensities
prnsol,s,prin              ! List principal stresses
!
```

```
/title,Base Weld - Shell Mid Stress Intensity
mid
nsort,s,int,0,1,10          ! Sort top 10 stress intensities
prnsol,s,prin               ! List principal stresses
!
/title,Base Weld - Shell Bot Stress Intensity
bot
nsort,s,int,0,1,10          ! Sort top 10 stress intensities
prnsol,s,prin               ! List principal stresses
!
!
!/com,*** DISPLACEMENT AT CENTER OF BASE PLATE
esel,s,real,,1,2
nsle,s
nsort,u,z,0,1,10            ! Sort top 10 displacements
prnsol,u,z                  ! List the displacements
!
finish
/exit,nosa
```