ATTACHMENT A

Letter from C.R. Steinhardt (WPSC)

To

Document Control Desk (NRC)

Dated

August 15, 1997

Stevenson & Associates Calculation C-023, Rev. 1

Client: Wisconsin Public Service Corp. Calculation No. C-023

Title: Buckling Analysis of Refueling Water Storage Tank

Project: Kewaunee Nuclear Power Plant, A-46 Project

Method: Methodology in Section 7 of the GIP.

Acceptance Criteria: GIP Criteria

Remarks:

Verification Method: ☒ Design Review Method ☐ Alternate Calculation ☐ Qualification Test ☐ Other ☐ No Verification Necessary

Results: See page 6.

REVISIONS

Revision No.	0	1	
Description	Original Issue	Revised tank shell yield stress based on tests.	
Total Pages (Cumulative)	C. Lu 7/14/97	48	
By/Date	48	T. Tseng 8/6/97	
Checked/Date	T. Tseng 7/14/97	W Djordjevic 8/7/97	
Approved/Date	W Djordjevic 7/21/97	W. Djordjevic 8/7/97	

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CALCULATION COVER SHEET

FIGURE 2.8

CONTRACT NO.

91C2683

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1 Objective

In response to NRC Request for Additional Information No. 3, 4, and 5 of USI A-46 at the Kewaunee Station, this calculation supplements the previous S&A Calculation 91C2683 C-018, Appendix G (Reference B), and performed detailed analyses for the RWST in the following areas to show that the tank meets the GIP criteria.

- Progressive base rotation analysis to illustrate that the tank base does not buckle before the first lateral support engages.
- Detailed tank response analysis to accurately determine the compressive stress in the RWST during the SSE seismic event.
- Use the minimum yield stress from the tank material certificate test to compute the buckling strength of the tank shell. 1

Methodology

Reference B Concluded that the tank shell buckles before the lateral brace arms engage the support pads at the top of the tank. This conclusion was based on the assumption of a fixed support condition of a freestanding tank. A detailed analysis of the tank base rotation is performed in this calculation, taking into account the non-linear tank uplifting.

The overturning of the tank is resisted by the combination of compression in the tank shell and tension in the anchor bolts. Because of the flexibility of the anchor bolts, the tank can rotate without developing much compressive stress in the shell when the gap at the top lateral braces close.

The COSMOS/M models used in Reference B are also used for this study with the following changes:

1. The tank bottom is supported by a non-linear spring, the stiffness of which is evaluated using the methodology of Section 7 of the GIP, Reference A. The tank shell is in compression while the anchored bolts are in tension. By equilibrium, the neutral axis is determined, corresponding to each state of stress in the anchor bolts.

2. The self-weight of the tank is included in the COSMOS/M model for the free standing tank before the top lateral supports engage. The inclusion of the tank weight results in a decreased final rotation of the tank base. It should be noted that the effect of water hold-down is conservatively neglected.

3. The diaphragm action of the roof is modeled using COSMOS/M program in the calculation of the stiffness of the top lateral supports.

4. Amplified Floor Response Spectra of 4% critical damping is used in the calculation of the seismic demand.

2 References

A. SQUG, Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Power Equipment, Section 7, Rev. 2A, March 1993.

B. Stevenson & Associate Calculation 91C2683, C-018, Appendix G, Kewaunee A46/IPEEE Refueling Water Storage Tank (RWST)

C. EPRI NP-6041-SL, A Methodology for Assessment of Nuclear Power Plant Seismic Margin, Revision 1, August 1991.

D. SRAC, COSMOS/M, Version 1.60, User's Manual.

E. EPRI NP-5228-SL, Seismic Verification of Nuclear Plant Equipment Anchorage, Volume 4: Guideline on Tanks and Heat Exchangers, Revision 1, June 1991.

F. Allegheny Ludlum Steel Corporation, Certificate of Test for the RWST tank materials, attached to letter WPSC to S&A dated July 31, 1997.

3 Conclusions

Based on the study of this calculation, it is concluded that the RWST will maintain its structural integrity during and following a SSE event based on GIP acceptance criteria.

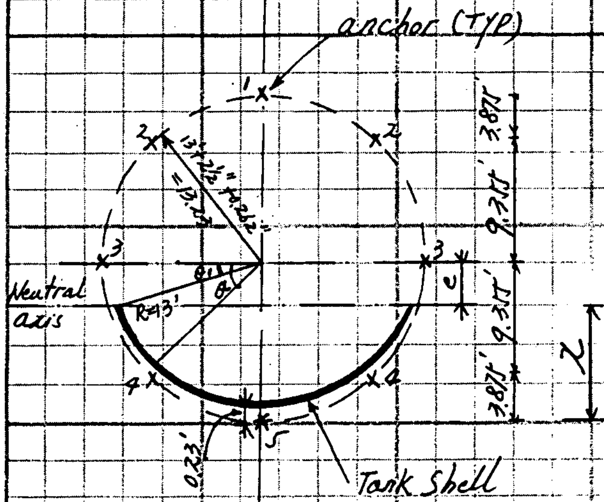
The allowable buckling stress computed based on the GIP criteria is 9.67 ksi, which is greater than the maximum demand of 8.17 ksi computed from the finite element model. It is concluded that the RWST tank shell does not buckle during the SSE event.

4 Body of Calculation

This calculation is an extension to Reference B. Many values used here were extracted directly from that reference.

Refer to reference B page 7 of 28 for the finite element model nodes, elements, and the four lateral support locations. 1

Relation between rotation and moment at the tank bottom



plan

$d = a(26.46 - x)$

$e = 13.23 - x$, $\theta_1 = \sin^{-1}\frac{e}{R}$

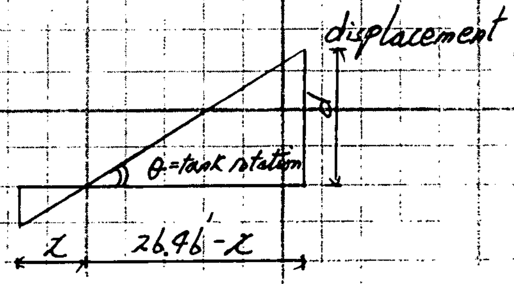
Resultant force in the tank shell F:

$$F_s = 2\int_{\theta_1}^{\pi/2} E_s \frac{\frac{R\sin\theta - e}{26.46 - x} d}{L_s} t \cdot R\, d\theta$$

$$= \frac{2E_s d t R}{L_s(26.46 - x)}\int_{\theta_1}^{\pi/2}(R\sin\theta - e)\, d\theta$$

$$= \frac{2E_s d t R}{L_s(26.46 - x)}\left(-R\cos\theta - e\theta\right)\Big|_{\theta_1}^{\pi/2}$$

$$= \frac{2E_s d t R}{L_s(26.46 - x)}\left[R\cos\theta_1 - e\left(\frac{\pi}{2} - \theta_1\right)\right]$$



Elevation

Say y_i is the distance from the i^{th} anchor to the neutral axis. Force in the i^{th} anchor:

$$F_i = \mathrm{Max}\left(\frac{y_i d}{L_b(26.46 - x)} \cdot E_b,\ 0\right)$$

y_i is positive when in the tension side.

$$F = \Sigma F_i \qquad (1)$$

(note: $L_s = 15''$, $L_b = 39''$).

From equation (1), x is determined

(An iterative Method is used for x)

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Moment in the tank shell M_s:

$$M_s = \frac{2E_s d t R}{L_s(26.46-x)} \int_{\theta_1}^{\pi/2} (R\sin\theta - e)^2 d\theta$$

$$= \frac{2E_s d t R}{L_s(26.46-x)} \int_{\theta_1}^{\pi/2} (R^2\sin^2\theta - 2Re\sin\theta + e^2) d\theta$$

$$= \frac{2E_s d t R}{L_s(26.46-x)} \int_{\theta_1}^{\pi/2} \left(\frac{R^2}{2}(1-\cos 2\theta) - 2Re\sin\theta + e^2\right) d\theta$$

$$= \frac{2E_s d t R}{L_s(26.46-x)} \left[\frac{R^2}{2}\left(\theta - \frac{1}{2}\sin 2\theta\right) + 2Re\cos\theta + e^2\theta\right]\Bigg|_{\theta_1}^{\pi/2}$$

$$= \frac{2E_s d t R}{L_s(26.46-x)} \left[\frac{R^2}{2}\left[\frac{\pi}{2} - \theta_1 + \frac{1}{2}\sin 2\theta_1\right] - 2Re\cos\theta_1 + e^2(\pi/2 - \theta_1)\right]$$

Moment by the anchor bolts M_b:

$$M_b = (26.46-x)*F_1 + 2(26.46-x-3.875)*F_2 + 2(26.46-x-13.23)*F_3 + 2(26.46-x-22.585)*F_4$$

Total Moment $M = M_s + M_b$

For 1" ϕ bolts with a yield stress of 36 ksi, (A-36, Drawing 237127A-S305-W, General Notes)

Capacity of the bolt $= 0.5^2\pi * 36 = 28.27$ kips

Referring to B, the concrete shear cone and anchor chair have sufficient margin to justify the anchor capacity. △1

When Bolt 1 reaches yielding

x=	1.468 in
d=	0.04841 in

Bolt Strain	
eps1=	0.0012414
eps2=	0.0010489
eps3=	0.0005842
eps4=	0.0001196

Bolt Force (kips)	
p1=	28.27
p2=	23.89
p3=	13.31
p4=	2.72

Moment by each Bolt (kips-ft)	
m1=	706.52
m2=	1008.99
m3=	313.03
m4=	13.11

e=	11.762 in
theta1=	1.1308

Ps=	108.13 kips	(Total Force in the Tank Shell)
Pb=	108.11 kips	(Total Force in the Bolts)
Ss=	4.525 ksi	(Max. Stress in the Tank Shell)
Ms=	106.944 kips-ft	(Moment by Tank Shell)
M=	2148.596 kips-ft	(Total Moment)

When Bolts 2 reach yielding

x=	1.436 in
d=	0.05728 in

Bolt Strain	
eps1=	0.0014688
eps2=	0.0012414
eps3=	0.0006923
eps4=	0.0001432

Bolt Force (kips)	
p1=	28.27
p2=	28.27
p3=	15.77
p4=	3.26

Moment by each Bolt (kips-ft)	
m1=	707.43
m2=	1195.76
m3=	371.93
m4=	15.91

e=	11.794 in
theta1=	1.1367

Ps=	122.84 kips	(Total Force in the Tank Shell)
Pb=	122.87 ki s	(Total Force in the Bolts)
Ss=	5.209 ksi	(Max. Stress in the Tank Shell)
Ms=	118.357 ki s-ft	(Moment b Tank Shell)
M=	2409.382 kips-ft	(Total Moment)

When Bolts 3 reach yielding

x=	1.1935 in
d=	0.10163 in

Bolt Strain	
eps1=	0.0026059
eps2=	0.0022062
eps3=	0.0012414
eps4=	0.0002766

Bolt Force (kips)	
p1=	28.27
p2=	28.27
p3=	28.27
p4=	6.30

Moment by each Bolt (kips-ft)	
m1=	714.28
m2=	1209.48
m3=	680.54
m4=	33.78

e=	12.0365 in
theta1=	1.1834

Ps=	153.98 kips	(Total Force in the Tank Shell)
Pb=	153.95 kips	(Total Force in the Bolts)
Ss=	7.312 ksi	(Max. Stress in the Tank Shell)
Ms=	118.564 kips-ft	(Moment b Tank Shell)
M=	2756.648 kips-ft	(Total Moment)

When Bolts 4 reach yielding

x=	0.699 in
d=	0.39269 in

Bolt Strain	
eps1=	0.0100690
eps2=	0.0085544
eps3=	0.0048979
eps4=	0.0012414

Bolt Force (kips)	
p1=	28.27
p2=	28.27
p3=	28.27
p4=	28.27

Moment by each Bolt (kips-ft)	
m1=	728.26
m2=	1237.43
m3=	708.50
m4=	179.60

e=	12.531 in
theta1=	1.3014

Ps=	197.81 kips	(Total Force in the Tank Shell)
Pb=	197.90 kips	(Total Force in the Bolts)
Ss=	13.488 ksi	(Max. Stress in the Tank Shell)
Ms=	74.180 ki s-ft	(Moment b Tank Shell)
M=	2927.980 kips-ft	(Total Moment)

Spring Stiffness

Theta	M (kips-ft)	k (kip-ft/rad)
(Base Rotation)		
0	0	
0.0001614	2148.6	1.33E+07
0.0001908	2409.4	8.89E+06
0.000335	2756.6	2.40E+06
0.00127	2928	1.83E+05

Note: Theta = d/(26.46-x)/12.

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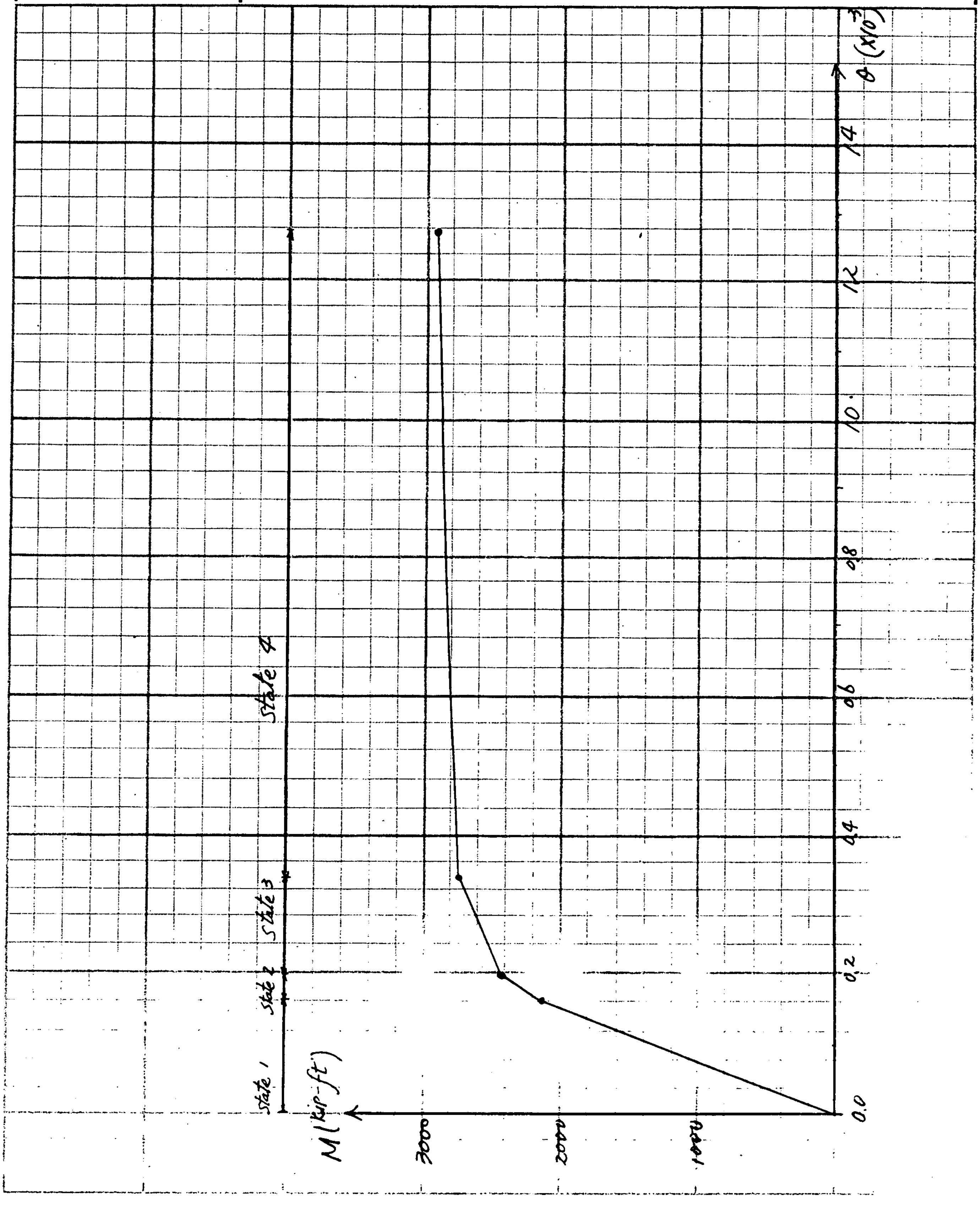

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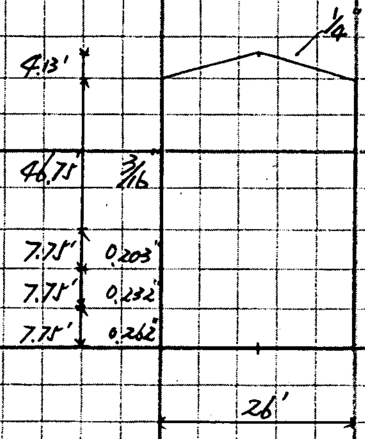
Tank weight



Volumn of the cylinder $= 26\pi(7.75*0.262+7.75*0.232+7.75*0.203$
$+\frac{3}{16}*46.75)/12 = 96.43\ ft^3$

Volumn of the roof $= \pi r(\sqrt{r^2+h^2})t = \pi*13\sqrt{13^2+4.13^2}*\frac{0.25}{12}$
$= 11.61\ ft^3$

weight of the tank $= (96.43+11.61)*0.49 = 52.94^k$

Horizontal ground acceleration $= 0.12g$

Use vertical ground acceleration $= \frac{2}{3}*0.12g = 0.08g$

Minimum Moment Arm $= (13-1.468+0.23) = 11.76'$ (*)

Restoring Moment due to tank weight $= 52.94*11.76*(1-0.08)$
$= 573\ ^{ft\text{-}k}$

(*) The minimum moment arm should be

$$13 - \frac{1.468}{12} + 0.23 = 13.11'$$

Restoring moment due to tank weight

$= 52.94 * 13.11 * (1-0.08) = 638$ ft-kip

Use of 573 ft-k is conservative and has only minor effects on the results.

△1

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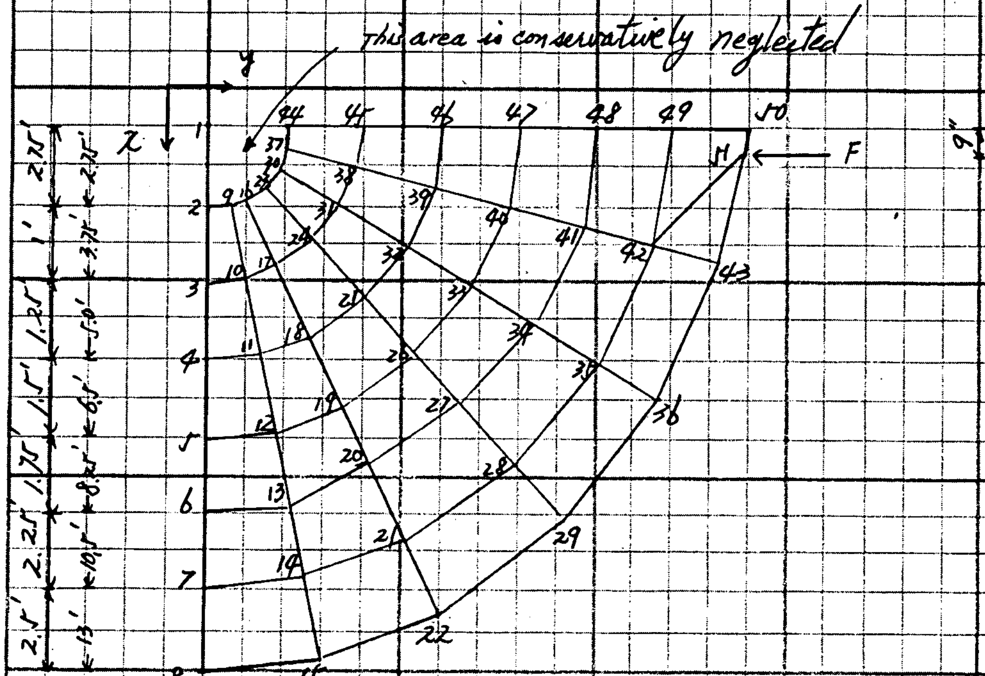
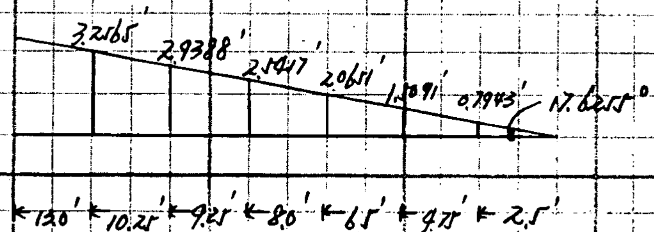
COSMAS/M Model of the tank roof





Because of the symmetry, only one quarter of the roof is modeled.

Symmetry line which runs through nodes 2 to 8 has the following boundary conditions: $U_y = 0$, Rotation $x = 0$, Rotation $z = 0$

Anti-symmetry line which runs through nodes 44 to 50 has the following boundary condition: $U_y = 0$, $U_z = 0$, Rotation $x = 0$

In the model, additional restraints are used to prevent rigid body motion. The roof is modeled by shell elements. The roof ring which runs through nodes 8, 15, 22, 29, 36, 43, 50, and 51 is modeled by beams. The section properties of the ring are obtained from Ref. 6.

Because the shell element does not have rotational stiffness, applying a Unit Moment at node 50 will overestimate the rotational displacement at the joint. To overcome this difficulty, a couple of concentrated forces F, which are equal in magnitude but opposite in direction, is substituted for the Unit Moment.

The depth of the lateral support arm is 18"

$$F = \frac{1^{\text{kip-ft}}}{1.5'} = 0.6667^{\text{kips}}$$

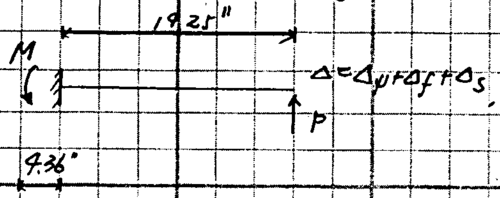
The COSMAS/M input file is shown on the following 2 pages.

COSMOS/M INPUT FILE FOR THE TANK ROOF

```
TITLE, Kewaunee -- Stiffness Analysis of Tank Roof
C* ALL UNITS KIPS, FT AND DEGREE
EG, 1, SHELL4, 1, 0
EG, 2, BEAM3D
EG, 3, RBAR
N,  1,  0.0,  0.00, 0.0
N,  2, 2.75,  0.00, 3.2565
N,  3, 3.75,  0.00, 2.9388
N,  4, 5.00,  0.00, 2.5417
N,  5, 6.50,  0.00, 2.0651
N,  6, 8.25,  0.00, 1.5091
N,  7, 10.5,  0.00, 0.7943
N,  8, 13.0,  0.00, 0.0
N, 50,  0.0, 13.00, 0.0
N, 51, 0.75, 12.98, 0.0
CS, 3, 1, 1, 8, 50
NGEN, 6, 7, 2, 8, 1, 0., 15.0, 0.
NCLIST, 0, 2, 51, 1
ACTIVE, CS, 0
D,  1, ALL, 0.0
D,  2, UX, 0.0
D,  2, UY, 0.0, 8,  1, UZ, ROTX, ROTZ
D, 44, UY, 0.0, 50, 1, UZ, ROTX,
C* TANK ROOF
EX,   1, 4075200.
NUXY, 1, 0.30
DENS, 1, 0.0152
C*, TOP RING
EX,   2, 4176000.
NUXY, 2, 0.30
DENS, 2, 0.0153
ACTIVE, GROUP, 1
ACTIVE, MAT, 1
RC, 1, 1, 0.02083
ACTIVE, REAL, 1
E,  1, 2, 3, 10, 9
EGEN, 5, 1, 1, 1, , , , , 1
EGEN, 4, 7, 1, 6, 1, , , , 6
E, 31, 37, 38, 45, 44
```

```
EGEN, 4, 1, 31, 31, , , , , 1
E, 36, 42, 43, 51, 51
E, 37, 42, 51, 49, 49
E, 38, 49, 51, 50, 50
ACTIVE, GROUP, 2
ACTIVE, MAT, 2
RC, 2, 2, 0.135, 1, 0.006178
RCMORE, 2, , 1.E-5, 10., 10.
ACTIVE, REAL, 2
E, 40, 8, 15, 1
E, 41, 15, 22, 1
E, 42, 22, 29, 1
E, 43, 29, 36, 1
E, 44, 36, 43, 1
E, 45, 43, 51, 1
ACTIVE, GROUP, 3
RC, 3, 3, 1.E11
ACTIVE, REAL, 3
E, 46, 51, 50
ELIST, 1, 38, 1
ACTIVE, CS, 0
F, 51, FY, 0.6667
C* F, 50, MZ; 0.5
RUN_STATIC
```

Rotation at node 50 from the COSMOS/M run is 2.552×10^{-5} rad under a moment of $1^{k\text{-}ft}$.



So, $K_\psi = \dfrac{1}{2.552\times10^{-5}} = 0.3918\times10^{5}$ k-ft/rad

$$K_{\Delta\psi} = \frac{0.3918\times10^{5}\times12}{(19.25+4.36)^2} = 843.44\ ^k/_{in} = 10121\ ^k/_{ft}$$

$$K_{\Delta f} = \frac{3EI}{L^3} = \frac{3\times29\times10^3\times554}{19.25^3} = 6757\ ^k/_{in} = 81081\ ^k/_{ft}$$

$$K_{\Delta s} = \frac{GA_s}{L} = \frac{29\times10^3/2.6\times18\times0.45}{19.25} = 4693\ ^k/_{in} = 56320\ ^k/_{ft}$$

$$\frac{1}{K_m} = \frac{1}{K_{\Delta\psi}} + \frac{1}{K_{\Delta f}} + \frac{1}{K_{\Delta s}} = \frac{1}{10121} + \frac{1}{81081} + \frac{1}{56320} = 1.29\times10^{-4}$$

$$K_m = 1/1.29\times10^{-4} = 7758\ ^k/_{ft}$$

FINITE ELEMENT ANALYSIS OF THE TANK

The finite element models used in Reference b are also used in this calculation with the following changes:

1. A non-linear spring is added at the tank bottom.
2. Tank self weight is included.
3. The stiffness of the lateral supports at the top of the tank is modified to account for the diaghragm action of the roof.

In order to model non-linearity of the bottom spring and engagement of the lateral supports at different elevations, a total of 7 cases are considered. COSMOS/M input files for all of the 7 cases are listed on pages 23 to 36.

Following are the Descriptions of the 7 cases:

Case 1: Free-Standing tank and bottom spring is in state 1.

Case 2: Gap at node 11 is closed and bottom spring is in state 1.

Case 3: Gaps at nodes 9 and 11 are closed and bottom spring is in state 1.

Case 4: Gaps at nodes 7, 9, and 11 are closed and bottom spring is in state 1.

Case 5: Gaps at nodes 7, 9, and 11 are closed and bottom spring is in state 2.

Case 6: Gaps at nodes 7, 9, and 11 are closed and bottom spring is in state 3.

Case 7: Gaps at nodes 4, 7, 9, and 11 are closed and bottom spring is in state 4.

COSMOS/M INPUT FILE FOR CASE 1

```
TITLE, Kewaunee -- RWST Dynamic Model Free-Standing Tank with Bottom Spring
EG, 1, MASS
EG, 2, BEAM2D
EG, 3, SPRING, 2
N, 1, 0.0, 0.00, 0.0
N, 2, 0.0, 7.75, 0.0
N, 3, 0.0, 15.50, 0.0
N, 4, 0.0, 19.50, 0.0
N, 5, 0.0, 23.25, 0.0
N, 6, 0.0, 31.375, 0.0
N, 7, 0.0, 39.50, 0.0
N, 8, 0.0, 47.625, 0.0
N, 9, 0.0, 55.75, 0.0
N, 10, 0.0, 62.875, 0.0
N, 11, 0.0, 70.00, 0.0
N, 12, 0.0, 0.00, 1.0
D, 2, UZ, 0.0, 11, 1, ROTX, ROTY
D, 1, UZ, 0.0, , , UX, UY, ROTX, ROTY
D, 12, ALL, 0.0
ACTIVE, GROUP, 2
EX, 1, 4075200.
NUXY, 1, 0.33
ACTIVE, MAT, 1
RC, 2, 1, 1.783, 150.695, 2.,000000,000000, 0.5306
ACTIVE, REAL, 1
E, 1, 1, 2
RC, 2, 2, 1.579, 133.440, 2.,000000,000000, 0.5306
ACTIVE, REAL, 2
E, 2, 2, 3
RC, 2, 3, 1.382, 116.760, 2.,000000,000000, 0.5306
ACTIVE, REAL, 3
E, 3, 3, 4
E, 4, 4, 5
RC, 2, 4, 1.276, 107.845, 2.,000000,000000, 0.5306
ACTIVE, REAL, 4
E, 5, 5, 6
E, 6, 6, 7
E, 7, 7, 8
E, 8, 8, 9
```

```
E, 9, 9, 10
E, 10, 10, 11
ACTIVE, GROUP, 3
RC, 3, 5, , 1.33E7
ACTIVE, REAL, 5
E, 11, 1, 12
ACTIVE, ECS, 0
C* EPB, 1, X, , 33.81, , 33.81, 10, 1
EPB, 1, X, , 0.649, , 0.649, 10, 1
F, 1, MZ, 573., , ,
RUN_STATIC
```

COSMOS/M INPUT FILE FOR CASE 2

```
TITLE, Kewaunee -- RWST Dynamic Model with Springs at Base and at Top
EG, 1, MASS
EG, 2, BEAM2D
EG, 3, SPRING, 2
N, 1, 0.0, 0.00, 0.0
N, 2, 0.0, 7.75, 0.0
N, 3, 0.0, 15.50, 0.0
N, 4, 0.0, 19.50, 0.0
N, 5, 0.0, 23.25, 0.0
N, 6, 0.0, 31.375, 0.0
N, 7, 0.0, 39.50, 0.0
N, 8, 0.0, 47.625, 0.0
N, 9, 0.0, 55.75, 0.0
N, 10, 0.0, 62.875, 0.0
N, 11, 0.0, 70.00, 0.0
N, 12, 10.0, 70.00, 0.0
N, 13, 0.0, 0.0, 1.0
D, 2, UZ, 0.0, 11, 1, ROTX, ROTY
D, 1, UZ, 0.0, , , UX, UY, ROTX, ROTY
D, 12, ALL, 0.0, 13, 1
ACTIVE, GROUP, 2
EX, 1, 4075200.
NUXY, 1, 0.33
ACTIVE, MAT, 1
RC, 2, 1, 1.783, 150.695, 2.,000000,000000, 0.5306
ACTIVE, REAL, 1
E, 1, 1, 2
RC, 2, 2, 1.579, 133.440, 2.,000000,000000, 0.5306
ACTIVE, REAL, 2
E, 2, 2, 3
RC, 2, 3, 1.382, 116.760, 2.,000000,000000, 0.5306
ACTIVE, REAL, 3
E, 3, 3, 4
E, 4, 4, 5
RC, 2, 4, 1.276, 107.845, 2.,000000,000000, 0.5306
ACTIVE, REAL, 4
E, 5, 5, 6
E, 6, 6, 7
E, 7, 7, 8
```

```
E, 8, 8, 9
E, 9, 9, 10
E, 10, 10, 11
ACTIVE, GROUP, 3
RC, 3, 5, 15516., 0.0
ACTIVE, REAL, 5
E, 11, 11, 12
RC, 3, 6, , 1.33E7
ACTIVE, REAL, 6
E, 12,  1, 13
ACTIVE, ECS, 0
EPB, 1, X, , 33.81, , 33.81, 10, 1
RUN_STATIC
```

COSMOS/M INPUT FILE FOR CASE 3

```
TITLE, Kewaunee -- RWST Dynamic Model with Springs at Base and at Top
EG, 1, MASS
EG, 2, BEAM2D
EG, 3, SPRING, 2
N, 1, 0.0, 0.00, 0.0
N, 2, 0.0, 7.75, 0.0
N, 3, 0.0, 15.50, 0.0
N, 4, 0.0, 19.50, 0.0
N, 5, 0.0, 23.25, 0.0
N, 6, 0.0, 31.375, 0.0
N, 7, 0.0, 39.50, 0.0
N, 8, 0.0, 47.625, 0.0
N, 9, 0.0, 55.75, 0.0
N, 10, 0.0, 62.875, 0.0
N, 11, 0.0, 70.00, 0.0
N, 12, 10.0, 70.00, 0.0
N, 13, 10.0, 55.75, 0.0
N, 14, 0.0, 0.0, 1.0
D, 2, UZ, 0.0, 11, 1, ROTX, ROTY
D, 1, UZ, 0.0, , , UX, UY, ROTX, ROTY
D, 12, ALL, 0.0, 14, 1
ACTIVE, GROUP, 2
EX, 1, 4075200.
NUXY, 1, 0.33
ACTIVE, MAT, 1
RC, 2, 1, 1.783, 150.695, 2.,000000,000000, 0.5306
ACTIVE, REAL, 1
E, 1, 1, 2
RC, 2, 2, 1.579, 133.440, 2.,000000,000000, 0.5306
ACTIVE, REAL, 2
E, 2, 2, 3
RC, 2, 3, 1.382, 116.760, 2.,000000,000000, 0.5306
ACTIVE, REAL, 3
E, 3, 3, 4
E, 4, 4, 5
RC, 2, 4, 1.276, 107.845, 2.,000000,000000, 0.5306
ACTIVE, REAL, 4
E, 5, 5, 6
E, 6, 6, 7
```

```
E, 7, 7, 8
E, 8, 8, 9
E, 9, 9, 10
E, 10, 10, 11
ACTIVE, GROUP, 3
RC, 3, 5, 15516., 0.0
ACTIVE, REAL, 5
E, 11, 11, 12
RC, 3, 6,  5740., 0.0
ACTIVE, REAL, 6
E, 12,  9, 13
RC, 3, 7, , 1.33E7
ACTIVE, REAL, 7
E, 13,  1, 14
ACTIVE, ECS, 0
EPB, 1, X, , 33.81, , 33.81, 10, 1
RUN_STATIC
```

COSMOS/M INPUT FILE FOR CASE 4

```
TITLE, Kewaunee -- RWST Dynamic Model with Springs at Base and at Top
EG, 1, MASS
EG, 2, BEAM2D
EG, 3, SPRING, 2
N, 1, 0.0, 0.00, 0.0
N, 2, 0.0, 7.75, 0.0
N, 3, 0.0, 15.50, 0.0
N, 4, 0.0, 19.50, 0.0
N, 5, 0.0, 23.25, 0.0
N, 6, 0.0, 31.375, 0.0
N, 7, 0.0, 39.50, 0.0
N, 8, 0.0, 47.625, 0.0
N, 9, 0.0, 55.75, 0.0
N, 10, 0.0, 62.875, 0.0
N, 11, 0.0, 70.00, 0.0
N, 12, 10.0, 70.00, 0.0
N, 13, 10.0, 55.75, 0.0
N, 14, 10.0, 39.50, 0.0
N, 15, 0.0, 0.0, 1.0
D, 2, UZ, 0.0, 11, 1, ROTX, ROTY
D, 1, UZ, 0.0, , , UX, UY, ROTX, ROTY
D, 12, ALL, 0.0, 15, 1
ACTIVE, GROUP, 2
EX, 1, 4075200.
NUXY, 1, 0.33
ACTIVE, MAT, 1
RC, 2, 1, 1.783, 150.695, 2.,000000,000000, 0.5306
ACTIVE, REAL, 1
E, 1, 1, 2
RC, 2, 2, 1.579, 133.440, 2.,000000,000000, 0.5306
ACTIVE, REAL, 2
E, 2, 2, 3
RC, 2, 3, 1.382, 116.760, 2.,000000,000000, 0.5306
ACTIVE, REAL, 3
E, 3, 3, 4
E, 4, 4, 5
RC, 2, 4, 1.276, 107.845, 2.,000000,000000, 0.5306
ACTIVE, REAL, 4
E, 5, 5, 6
```

```
E, 6, 6, 7
E, 7, 7, 8
E, 8, 8, 9
E, 9, 9, 10
E, 10, 10, 11
ACTIVE, GROUP, 3
RC, 3, 5, 15516., 0.0
ACTIVE, REAL, 5
E, 11, 11, 12
RC, 3, 6,  5740., 0.0
ACTIVE, REAL, 6
E, 12,  9, 13
E, 13,  7, 14
RC, 3, 7, , 1.33E7
ACTIVE, REAL, 7
E, 14,  1, 15
ACTIVE, ECS, 0
EPB, 1, X, , 33.81, , 33.81, 10, 1
RUN_STATIC
```

COSMOS/M INPUT FILE FOR CASE 5

```
TITLE, Kewaunee -- RWST Dynamic Model with Springs at Base and at Top
EG, 1, MASS
EG, 2, BEAM2D
EG, 3, SPRING, 2
N, 1, 0.0, 0.00, 0.0
N, 2, 0.0, 7.75, 0.0
N, 3, 0.0, 15.50, 0.0
N, 4, 0.0, 19.50, 0.0
N, 5, 0.0, 23.25, 0.0
N, 6, 0.0, 31.375, 0.0
N, 7, 0.0, 39.50, 0.0
N, 8, 0.0, 47.625, 0.0
N, 9, 0.0, 55.75, 0.0
N, 10, 0.0, 62.875, 0.0
N, 11, 0.0, 70.00, 0.0
N, 12, 10.0, 70.00, 0.0
N, 13, 10.0, 55.75, 0.0
N, 14, 10.0, 39.50, 0.0
N, 15, 0.0, 0.0, 1.0
D, 2, UZ, 0.0, 11, 1, ROTX, ROTY
D, 1, UZ, 0.0, , , UX, UY, ROTX, ROTY
D, 12, ALL, 0.0, 15, 1
ACTIVE, GROUP, 2
EX, 1, 4075200.
NUXY, 1, 0.33
ACTIVE, MAT, 1
RC, 2, 1, 1.783, 150.695, 2.,000000,000000, 0.5306
ACTIVE, REAL, 1
E, 1, 1, 2
RC, 2, 2, 1.579, 133.440, 2.,000000,000000, 0.5306
ACTIVE, REAL, 2
E, 2, 2, 3
RC, 2, 3, 1.382, 116.760, 2.,000000,000000, 0.5306
ACTIVE, REAL, 3
E, 3, 3, 4
E, 4, 4, 5
RC, 2, 4, 1.276, 107.845, 2.,000000,000000, 0.5306
ACTIVE, REAL, 4
E, 5, 5, 6
```

```
E, 6, 6, 7
E, 7, 7, 8
E, 8, 8, 9
E, 9, 9, 10
E, 10, 10, 11
ACTIVE, GROUP, 3
RC, 3, 5, 15516., 0.0
ACTIVE, REAL, 5
E, 11, 11, 12
RC, 3, 6,  5740., 0.0
ACTIVE, REAL, 6
E, 12,  9, 13
E, 13,  7, 14
RC, 3, 7, , 8.89E6
ACTIVE, REAL, 7
E, 14,  1, 15
ACTIVE, ECS, 0
EPB, 1, X, , 33.81, , 33.81, 10, 1
RUN_STATIC
```

COSMOS/M INPUT FILE FOR CASE 6

```
TITLE, Kewaunee -- RWST Dynamic Model with Springs at Base and at Top
EG, 1, MASS
EG, 2, BEAM2D
EG, 3, SPRING, 2
N,  1,  0.0,  0.00, 0.0
N,  2,  0.0,  7.75, 0.0
N,  3,  0.0, 15.50, 0.0
N,  4,  0.0, 19.50, 0.0
N,  5,  0.0, 23.25, 0.0
N,  6,  0.0, 31.375, 0.0
N,  7,  0.0, 39.50, 0.0
N,  8,  0.0, 47.625, 0.0
N,  9,  0.0, 55.75, 0.0
N, 10,  0.0, 62.875, 0.0
N, 11,  0.0, 70.00, 0.0
N, 12, 10.0, 70.00, 0.0
N, 13, 10.0, 55.75, 0.0
N, 14, 10.0, 39.50, 0.0
N, 15,  0.0,  0.0,  1.0
D,  2, UZ, 0.0, 11, 1, ROTX, ROTY
D,  1, UZ, 0.0, , , UX, UY, ROTX, ROTY
D, 12, ALL, 0.0, 15, 1
ACTIVE, GROUP, 2
EX,   1, 4075200.
NUXY, 1, 0.33
ACTIVE, MAT, 1
RC, 2, 1, 1.783, 150.695, 2.,000000,000000, 0.5306
ACTIVE, REAL, 1
E, 1, 1, 2
RC, 2, 2, 1.579, 133.440, 2.,000000,000000, 0.5306
ACTIVE, REAL, 2
E, 2, 2, 3
RC, 2, 3, 1.382, 116.760, 2.,000000,000000, 0.5306
ACTIVE, REAL, 3
E, 3, 3, 4
E, 4, 4, 5
RC, 2, 4, 1.276, 107.845, 2.,000000,000000, 0.5306
ACTIVE, REAL, 4
```

```
E, 5, 5, 6
E, 6, 6, 7
E, 7, 7, 8
E, 8, 8, 9
E, 9, 9, 10
E, 10, 10, 11
ACTIVE, GROUP, 3
RC, 3, 5, 15516., 0.0
ACTIVE, REAL, 5
E, 11, 11, 12
RC, 3, 6,  5740., 0.0
ACTIVE, REAL, 6
E, 12,  9, 13
E, 13,  7, 14
RC, 3, 7, , 2.404E6
ACTIVE, REAL, 7
E, 14,  1, 15
ACTIVE, ECS, 0
EPB, 1, X, , 33.81, , 33.81, 10, 1
RUN_STATIC
```

COSMOS/M INPUT FILE FOR CASE 7

```
TITLE, Kewaunee -- RWST Dynamic Model with Springs at Base and at Top
EG, 1, MASS
EG, 2, BEAM2D
EG, 3, SPRING, 2
N, 1, 0.0, 0.00, 0.0
N, 2, 0.0, 7.75, 0.0
N, 3, 0.0, 15.50, 0.0
N,. 4, 0.0, 19.50, 0.0
N, 5, 0.0, 23.25, 0.0
N, 6, 0.0, 31.375, 0.0
N, 7, 0.0, 39.50, 0.0
N, 8, 0.0, 47.625, 0.0
N, 9, 0.0, 55.75, 0.0
N, 10, 0.0, 62.875, 0.0
N, 11, 0.0, 70.00, 0.0
N, 12, 10.0, 70.00, 0.0
N, 13, 10.0, 55.75, 0.0
N, 14, 10.0, 39.50, 0.0
N, 15, 10.0, 19.50, 0.0
N, 16, 0.0, 0.0, 1.0
D, 2, UZ, 0.0, 11, 1, ROTX, ROTY
D, 1, UZ, 0.0, , , UX, UY, ROTX, ROTY
D, 12, ALL, 0.0, 16, 1
ACTIVE, GROUP, 2
EX, 1, 4075200.
NUXY, 1, 0.33
ACTIVE, MAT, 1
RC, 2, 1, 1.783, 150.695, 2.,000000,000000, 0.5306
ACTIVE, REAL, 1
E, 1, 1, 2
RC, 2, 2, 1.579, 133.440, 2.,000000,000000, 0.5306
ACTIVE, REAL, 2
E, 2, 2, 3
RC, 2, 3, 1.382, 116.760, 2.,000000,000000, 0.5306
ACTIVE, REAL, 3
E, 3, 3, 4
E, 4, 4, 5
RC, 2, 4, 1.276, 107.845, 2.,000000,000000, 0.5306
```

```
ACTIVE, REAL, 4
E, 5, 5, 6
E, 6, 6, 7
E, 7, 7, 8
E, 8, 8, 9
E, 9, 9, 10
E, 10, 10, 11
ACTIVE, GROUP, 3
RC, 3, 5, 15516., 0.0
ACTIVE, REAL, 5
E, 11, 11, 12
RC, 3, 6,  5740., 0.0
ACTIVE, REAL, 6
E, 12,  9, 13
E, 13,  7, 14
RC, 3, 7, 3562, 0.0
ACTIVE, REAL, 7
E, 14,  4, 15
RC, 3, 8, , 1.83E5
ACTIVE, REAL, 8
E, 15,  1, 16
ACTIVE, ECS, 0
EPB, 1, X, , 33.81, , 33.81, 10, 1
RUN_STATIC
```

The eigenvalue analysis for case 7 where the lateral supports at all the elevations engage is performed in order to determine the seismic demand. The fundamental frequency is 4.17 Hz from the COSMOS/M run, whose input file is listed as follows:

COSMOS/M input file for eigenvalue analysis

```
TITLE, Kewaunee -- RWST Dynamic Model with Springs at Base and at Top
EG, 1, MASS
EG, 2, BEAM2D
EG, 3, SPRING, 2
N, 1, 0.0, 0.00, 0.0
N, 2, 0.0, 7.75, 0.0
N, 3, 0.0, 15.50, 0.0
N, 4, 0.0, 19.50, 0.0
N, 5, 0.0, 23.25, 0.0
N, 6, 0.0, 31.375, 0.0
N, 7, 0.0, 39.50, 0.0
N, 8, 0.0, 47.625, 0.0
N, 9, 0.0, 55.75, 0.0
N, 10, 0.0, 62.875, 0.0
N, 11, 0.0, 70.00, 0.0
N, 12, 10.0, 70.00, 0.0
N, 13, 10.0, 55.75, 0.0
N, 14, 10.0, 39.50, 0.0
N, 15, 10.0, 19.50, 0.0
N, 16, 0.0, 0.0, 1.0
D, 2, UZ, 0.0, 11, 1, ROTX, ROTY
D, 1, UZ, 0.0, , , UX, UY, ROTX, ROTY
D, 12, ALL, 0.0, 16, 1
ACTIVE, GROUP, 2
EX, 1, 4075200.
NUXY, 1, 0.33
DENSITY, 1, 0.5927
ACTIVE, MAT, 1
RC, 2, 1, 1.783, 150.695, 2.,000000,000000, 0.5306
ACTIVE, REAL, 1
E, 1, 1, 2
EX, 2, 4075200.
NUXY, 2, 0.33
DENSITY, 2, 0.6674
ACTIVE, MAT, 2
```

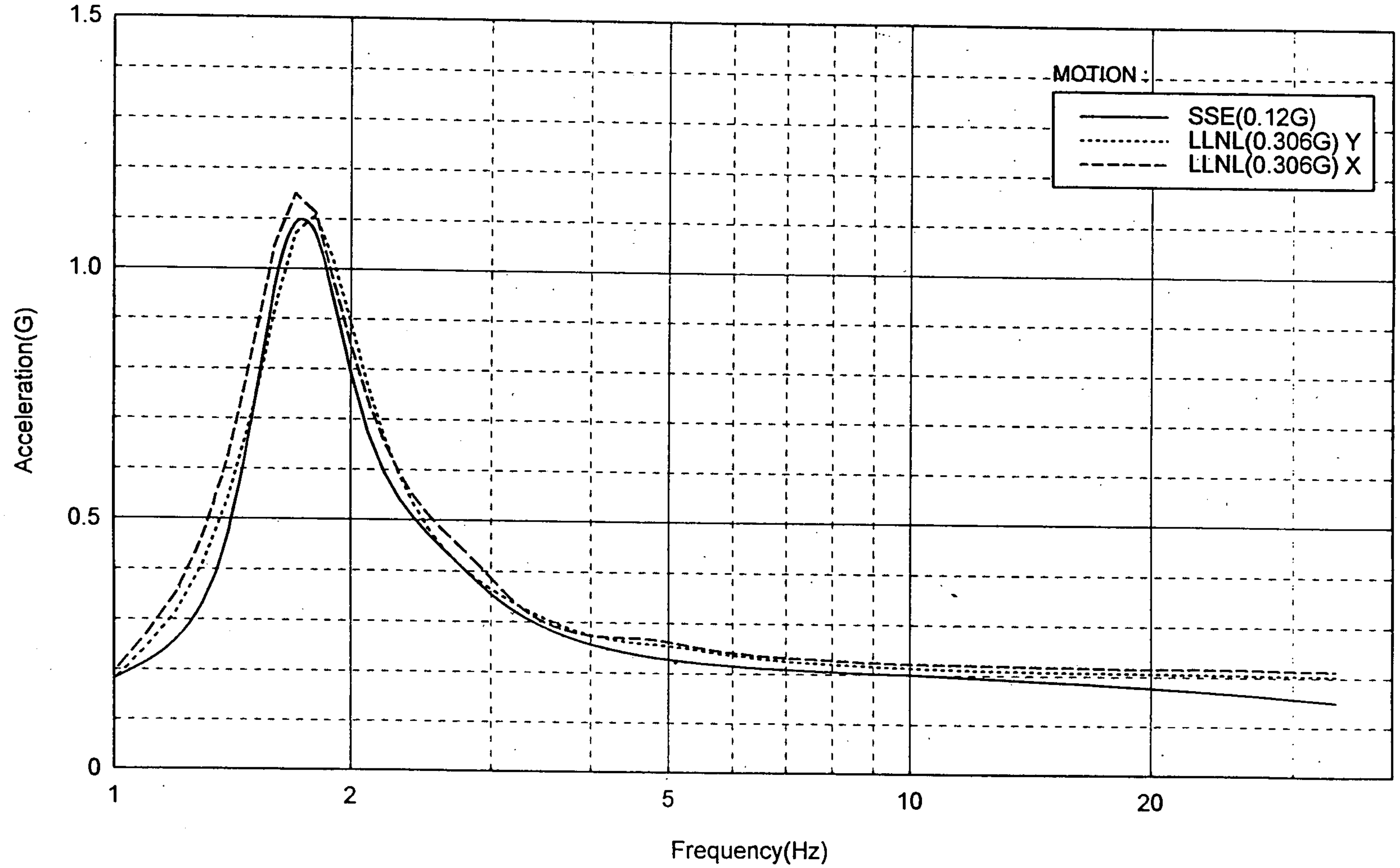
```
RC, 2, 2, 1.579, 133.440, 2.,000000,000000, 0.5306
ACTIVE, REAL, 2
E, 2, 2, 3
EX,   3, 4075200.
NUXY, 3, 0.33
DENSITY, 3, 0.7605
ACTIVE, MAT, 3
RC, 2, 3, 1.382, 116.760, 2.,000000,000000, 0.5306
ACTIVE, REAL, 3
E, 3, 3, 4
E, 4, 4, 5
EX,   4, 4075200.
NUXY, 4, 0.33
DENSITY, 4, 0.8221
ACTIVE, MAT, 4
RC, 2, 4, 1.276, 107.845, 2.,000000,000000, 0.5306
ACTIVE, REAL, 4
E, 5, 5, 6
E, 6, 6, 7
E, 7, 7, 8
E, 8, 8, 9
E, 9, 9, 10
E, 10, 10, 11
ACTIVE, GROUP, 3
RC, 3, 5, 15516., 0.0
ACTIVE, REAL, 5
E, 11, 11, 12
RC, 3, 6,  5740., 0.0
ACTIVE, REAL, 6
E, 12,  9, 13
E, 13,  7, 14
RC, 3, 7, 3562, 0.0
ACTIVE, REAL, 7
E, 14,  4, 15
RC, 3, 8, , 1.83E5
ACTIVE, REAL, 8
E, 15,  1, 16
ANALYSIS, FREQ, 5, S, , 1, 0, 0.0, , , 0, 0.0
PRINT, , , , 1, , , , 1
RUN_FREQ
```

Using 20% broadened floor response spectra, acceleration at 3.48 Hz (4.17/1.20) is 0.29g for 5% critical damping, obtained from the floor response spectrum curve on the next page. For 4% critical damping,

Acceleration at the same frequency = $0.29\sqrt{\frac{0.05}{0.04}}$ = 0.324g

Wisconsin Public Service Corp.
Kewaunee Nuclear Power Plant
Amplified Floor Response Spectra

BUILDING :Auxiliary
ELEVATION :586'
DAMPING :5%



<u>Summary of the finite element results for all the 7 cases</u>

case	accel. increment (g)	scale factor	Node 11 displ. (in)	Node 11 remaining gap (in)	Node 9 displ. (in)	Node 9 remaining gap (in)	Node 7 displ. (in)	Node 7 remaining gap (in)	Node 4 displ. (in)	Node 4 remaining gap (in)	accumulative accel. (g)	base rotation	accumulative base rotation	comments
1	0.0192	1	0.125	0	0.0987	0.0263	0.0675	0.0575	0.03	0.095	0.0192	7.647E-05	7.647E-05	gep at node 11 closes.
2	0.0309	0.0309			0.0263	0	0.0248	0.0327	0.0146	0.0804	0.0501	3.434E-05	1.108E-04	gap at node 9 closes.
3	0.0494	0.0494					0.0327	0	0.0202	0.0602	0.0995	4.626E-05	1.571E-04	gap at node 7 closes.
4	0.0049	0.0049							0.0017	0.0585	0.1044	3.930E-06	1.610E-04	spring reaches state 2.
5	0.0317	0.0317							0.0117	0.0468	0.1361	3.060E-05	1.910E-04	spring reaches state 3.
6	0.1127	0.1127							0.0464	0	0.2488	1.440E-04	3.350E-04	gap at node 4 closes and spring reaches state 4.
7	0.0753	0.0753									0.3241	1.033E-04	4.383E-04	

Note: (1) displacements in the table are obtained by multiplying COSMOS/M results by the scale factors.
(2) total acceleration for case 7 is 0.324g, which is equal to the demand. So, the ccrresponding base rotation is the maximum rotation.

Stress in the Tank Shell when the Lateral Supports at the Top of the Tank Engage (Rotation = 7.647E-5)

x=	1.468 in
d=	0.0229 in

eps1=	0.0005880	p1=	13.39361 kips
eps2=	0.0004969	p2=	11.31694 kips
eps3=	0.0002768	p3=	6.303443 kips
eps4=	0.0000566	p4=	1.29 kips

e=	11.762	in
theta1=	1.1308	

Ps=	51.221 kips	(total force in the tank shell)
Pb=	51.214 kips	(total force in the bolts)
Ss=	2.143 ksi	(Max. stress in the tank shell

Maximum Stress in the Tank Shell for the Final Base Rotation: 4.383E-4

x=	1.053 in
d=	0.1336 in

eps1=	0.0034264	p1=	28.27 kips
eps2=	0.0029038	p2=	28.27 kips
eps3=	0.0016422	p3=	28.27 kips
eps4=	0.0003806	p4=	8.67 kips

e=	12.177	in
theta1=	1.2131	

Ps=	158.870 kips	(total force in the tank shell)

Pb=	158.687 kips	(total force in the bolts)

Ss=	8.167 ksi	(Max. Stress in the tank shell

Based on the certificate test physical properties for the RWST tank shell (Reference F), the following results are available for the four sheets that composed the bottom portion of the tank:

Test	Yield Strength (psi)	Tensile Strength (psi)
343069-41	37,900	85,300
343069-42	44,700	88,700
343069-43	46,100	92,900
343069-44	44,900	88,800

Since the test sample is the actual shell material, the uncertainty in the test strength is minimal. It is reasonable to use the minimum test value for the design. The minimum yield strength of 37.9 ksi will be used in the calculation of the allowable buckling stress.

Elephant-Foot Buckling

Maximum S_{af} = 0.324 g

From GIP Figure 7-7 with S_{af} = 0.324 g and H/R = 5.35,

$P_e^{'}$ = 6.2

$P_e = P_e^{'}\gamma_f R = 6.2*62.4/144*13 =$ 34.93 psi

The elephant-foot buckling stress capacity is

$$\sigma_{pe} = \frac{0.6E_s}{R/t_s}\left[1-\left(\frac{P_e*R}{\sigma_y*t_s}\right)^2\right]\left[1-\frac{1}{1.12+S_1^{1.5}}\right]\left[\frac{S_1+\sigma_y/36}{S_1+1}\right]$$

where

$$S_1 = \frac{R}{400t_s} = \frac{13*12}{400*0.262} = 1.49$$

E_s = 28,300 ksi

σ_y = 37.9 ksi

t_s = 0.262 in.

$$\sigma_{pe} = \frac{0.6*28{,}300}{13*12/0.262}\left[1-\left(\frac{34.93*13*12}{37{,}900*0.262}\right)^2\right]\left[1-\frac{1}{1.12+1.49^{1.5}}\right]\left[\frac{1.49+37.9/36}{1.49+1}\right] = 13.43\,\text{ksi}$$

Diamond-Shape Buckling

From GIP, Figure 7-9 with S_{af} = 0.324 g and H/R = 5.35,

P_d' = 5.40

$P_d = P_d'\gamma_f R$ = 5.40 * 62.4 / 144 * 13 = 30.42 psi

The diamond-shape buckling stress capacity is

$$\sigma_{pd} = (0.6\gamma + \Delta\gamma)\frac{E_s}{R/t_s}$$

where

$$\gamma = 1-0.73\left(1-e^{-\phi}\right) = 1-0.73\left[1-e^{-\sqrt{13*12/0.262}/16}\right] = 0.43$$

$$\phi = \frac{1}{16}\sqrt{\frac{R}{t_s}}$$

From GIP, Figure 7-11, with

$$\frac{P_d}{E_s}\left[\frac{R}{t_s}\right]^2 = \frac{30.42}{28{,}300{,}000}\left[\frac{13*12}{0.262}\right]^2 = 0.38$$

$$\Delta\gamma = 0.18$$

$$\sigma_{pd} = (0.6*0.43+0.18)\frac{28{,}300}{13*12/0.262}$$ = 20.82 ~~psi~~ ksi

It is clear that the elephant-foot buckling governs.

The allowable buckling stress based on GIP, Section 7, is

$$0.72 * 13.43 = 9.67 \text{ ksi}$$

is greater than the demand of 8.17 ksi calculated on page 43. Therefore, it can be concluded that the tank will maintain its structural integrity during the design basis seismic event.

DESCRIPTION OF ANALYSIS: RWST Tank Roof Stiffness

COMPUTER CODE: COSMOS/M VERSION: 1.60

RELEASE DATE: August 1990 AUTHOR/VENDOR: SRAC

COMPUTER TYPE/SYSTEM: IBM PC

PROGRAM STATUS: ☐ Project Specific ☒ General Use/QA Approved

VERIFICATION/VALIDATION DOCUMENTATION: ☐ Attached ☒ On File

RUN NUMBER:

	ORIGINATOR	DATE	CHECKER	DATE
INPUT REPRODUCED ON LISTING	C. Xu	7/14/97	TMT	7/14/97
MODEL VALID AND ASSUMPTIONS DOCUMENTED	C. Xu	7/14/97	TMT	7/14/97
PROGRAM APPROPRIATE AND ADEQUATE	C. Xu	7/14/97	TMT	7/14/97
MODEL BEHAVES REASONABLE	C. Xu	7/14/97	TMT	7/14/97
RESULTS PROPERLY INTERPRETED	C. Xu	7/14/97	TMT	7/14/97

REMARKS:

S&A Stevenson & Associates	COMPUTER PROGRAM COVER SHEET FIGURE 2.9	CONTRACT NO. 91C9683

DESCRIPTION OF ANALYSIS: RWST Tank Response Analyses

COMPUTER CODE: COSMOS/M VERSION: 1.60

RELEASE DATE: August 1990 AUTHOR/VENDOR: SRAC

COMPUTER TYPE/SYSTEM: IBM PC

PROGRAM STATUS: ☐ Project Specific ☒ General Use/QA Approved

VERIFICATION/VALIDATION DOCUMENTATION: ☐ Attached ☒ On File

RUN NUMBER:				
	ORIGINATOR	DATE	CHECKER	DATE
INPUT REPRODUCED ON LISTING	C. Xu	7/14/97	TMT	7/14/97
MODEL VALID AND ASSUMPTIONS DOCUMENTED	C. Xu	7/14/97	TMT	7/14/97
PROGRAM APPROPRIATE AND ADEQUATE	C. Xu	7/14/97	TMT	7/14/97
MODEL BEHAVES REASONABLE	C. Xu	7/14/97	TMT	7/14/97
RESULTS PROPERLY INTERPRETED	C. Xu	7/14/97	TMT	7/14/97

REMARKS:

S&A Stevenson & Associates

COMPUTER PROGRAM COVER SHEET

FIGURE 2.9

CONTRACT NO. **91C9683**