Attachment 4 to IPN-97-041

Response to Request for Additional Information on the Resolution of Unresolved Safety Issue A-46

Indian Point 3 Nuclear Power Plant
Docket No. 50-286

Client: New York Power Authority

Calculation No. C001

Title: Refueling Water Storage Tank RWST-31

Project: IPEEE / USI A-46 Outlier Resolution

Method: EPRI NP-6041 Appendix H

Acceptance Criteria: GIP Rev 2 2/14/92 Section 7

Remarks:

NEW YORK POWER AUTHORITY

DOCUMENT REVIEW STATUS

STATUS NO:

1 ☒ ACCEPTED
2 ☐ ACCEPTED AS NOTED RESUBMITTAL NOT REQUIRED
3 ☐ ACCEPTED AS NOTED RESUBMITTAL REQUIRED
4 ☐ NOT ACCEPTED

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REVIEWED BY: [signature] TITLE: Sr. Engineer

DATE: 1/31/97

REVISIONS

No.	Description	By	Date	Chk.	Date	App.	Date
0	Original Issue	[initials]	1/30/97	SA	1/30/97	SA	1/30/97

S&A Stevenson and Associates

CALCULATION COVER SHEET

CONTRACT NO. **96C2915**

S&A STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	JOB NO. 96C2915 Calculation C-001 SUBJECT: NYPA - Indian Point Unit 3. USI A-46 Outlier Resolution	Sheet 1 of 8 Date: 8/26/96 Revision 0
	Refueling Water Storage Tank RWST-31	By: A. Karavoussianis Check: S. Anagnostis

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Objective

The Refueling Water Storage Tank (RWST-31) is a cylindrical flat bottom vertical tank which stands about 48 ft. tall and is 40 ft. in diameter (Ref. 2). The tank is anchored by 24 - 2" cast-in-place bolts, equally spaced in a 40'-6" diameter bolt circle around the tank (Ref. 1).

The A-46 evaluation declared the tank an outlier because the tank's anchorage capacity was less than the seismic demand.

This calculation recompiles the A-46 evaluation and also considers the effect of fluid hold-down forces.

Analytical Approach

This calculation follows the computational methodology described in Appendix H of EPRI NP - 6041. This is essentially the same methodology used in Section 7 of the GIP; the procedure in NP-6041 is "equation-based", and allows for a more accurate calculation than the "chart-based" method in GIP Section 7. It should be noted that the critical GIP Section 7 criteria were maintained, namely:

- GIP Appendix C procedures were used to calculate the anchor bolt allowables,
- 4% damping was used to calculate the impulsive mode response,
- a reduction factor of 0.72 was applied to the computed tank shell buckling stress.

The capacity was calculated both ignoring and including the effects of fluid hold-down. Note that GIP Section 7 ignores the effect of fluid hold-down.

Summary

The attached calculations show that the tank has a seismic demand of 0.24g (at the impulsive mode frequency), and has a seismic capacity of 0.60g if fluid hold-down is ignored, and a seismic capacity of 0.62g if fluid hold-down is included. The tank therefore meets GIP requirements with a factor of safety of 2.5, and has a factor of safety of 2.6 if fluid hold-down is included. Therefore, the tank outlier is resolved.

This evaluation yielded a significantly different result than the original A-46 evaluation (Ref 2), which concluded that the seismic demand exceeded the capacity by about a factor of 2. The principal reasons for the difference are as follows:

1. Both this and the original evaluation computed an impulsive mode frequency of about 6 Hz. Based on this frequency, this evaluation used a spectral acceleration of 0.24g - the ground response spectra, 4% damping, peak value within 20% of the calculated frequency. The original evaluation used a spectral acceleration of 0.41g - this appears to be the 4% damped ground response spectra value multiplied by 1.875 (under certain conditions, GIP Section 4 permits the use of 1.25 x 1.5 the ground response spectra as the estimate of an in-structure response spectrum). The tank is in the yard, therefore there is no requirement to amplify the ground spectrum - the original evaluation overestimated the demand by a factor of 1.7.

2. The anchor bolt capacity is limited by bending stresses induced in the tank wall by the bolt chair (see GIP Section 7.3.2, Step 9). The critical parameter is the width of the bolt chair's top plate. The original evaluation used the distance between the outside edges of the chair's vertical stiffeners (about 7"). The GIP procedure assumes that each chair has a top plate that spans between the vertical stiffeners, but the IP3 RWST has a top plate that is a continuous ring. The continuous ring top plate is a much stronger design than the individual top plate design assumed in the original evaluation. The AISI design guide for steel tanks (Ref. 14) - which is the source of the bolt chair evaluation procedure contained in the GIP - recommends that continuous ring top plates be evaluated as continuous rings, not as individual plates. This evaluation did so, and the anchor bolt capacity increased from 18.9 kips in the original evaluation to 55.7 kips, a factor of about 3.

STEVENSON & ASSOCIATES a structural-mechanical consulting engineering firm	JOB NO. 96C2915 Calculation C-001 SUBJECT: NYPA - Indian Point Unit 3. USI A-46 Outlier Resolution	Sheet 3 of 8 Date: 8/26/96 Revision 0
	Refueling Water Storage Tank RWST-31	By: A. Karavoussianis Check: S. Anagnostis

Calculation

The capacity calculations are attached as appendix A (w/o fluid hold-down) and Appendix B (with fluid hold-down). This section of the calculation computes the bolt hold-down capacity and other various input parameters common to both appendices.

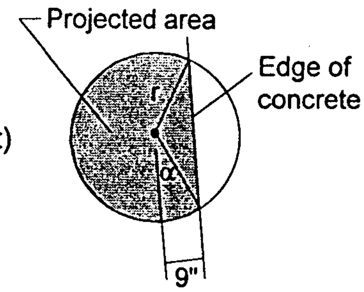
Tank shell material is SA 240 Type 304 Stainless Steel. (Ref. 2)

$\sigma_Y = 30$ ksi , $\sigma_U = 75$ ksi & $E_S = 28300$ ksi (ref. 10)

Nominal capacity = 350,000 gal = 46823 ft^3 (ref. 2)
Fluid height, H = $46823 / [\pi (20 - 0.285 / 12)^2] = 37.35$ ft = 448 in

Bolt Hold-Down Capacity: (ref. 5 & 6)

1. Bolt tensile capacity, (assume A307 bolts)
   2" Cast-in-Place bolts,
   Bolt nominal area = 3.14 in^2
   $T_{nom} = 1.7 \times 20 \times 3.14 = 107$ kip



2. Anchorage of bolt into concrete foundation:
   Embedment, L = 33" - 2" (anchor fitting) - 10" (chair height) -3" (thread above chair) = 18"
   Edge distance, E = 9"

   $\alpha = 90 - \cos^{-1}(9 / r)$; r = L = 18"; $\alpha = 30^\circ$

   Ignoring concrete pad curvature:

   $$\text{Projected area} = A = \frac{180 + 2 \times 30}{360} \times \pi \times 18^2 + 9 \times 18 \times \cos(30) = 819\ in^2$$

   Concrete Pull-out Strength, (ref. 12)

   $$P_c = A \times 4\, \Phi \sqrt{f_c'} = 819 \times 4 \times 0.85 \times \sqrt{3000} = 152500\ lbs = 153\ kip$$

   A-46 Concrete Pull-out Strength = $P_c / 2 = 77$ kip

Part of the bolt hold-down capacity calculation requires the dimension of the bolt chairs. The following dimension designations are shown in EPRI 5228, Vol. 4. figure 2-14. (ref. 3 page 19)

a = g + 2j + 2b	c = 1.375"	f = 1.5"	j = 0.50"
a = 17.25" (avg.)	d = 2"	g = 5.25" (avg.)	k = 3.50" (avg.)
b = 5.5"	e = 3"	h = 10"	$t_b = 0.185$"

3. Capacity of plate to transfer load to chair gussets; (ref. 6)

$$S_P = \frac{(0.375g - 0.22d)T_{BS}}{f\,c^2} = \frac{(0.375 \times 5.25 - 0.22 \times 2) \times 77000}{1.5 \times 1.375^2} = 41500 \ psi$$

$$S_P = 41500 \ psi > f_y = 30000 \ psi \quad \therefore \ T_P = 77.0 \times \frac{30000}{41500} = 55.7 \ kip$$

4. Capacity of vertical gusset plates: (ref. 6)

- $\frac{k}{j} = \frac{3.50}{0.5} = 7.0 < \frac{95}{\sqrt{\frac{f_y}{1000}}} = \frac{95}{\sqrt{\frac{30000}{1000}}} = 17.35$ (O.K.)
- j = 0.5" > 0.04 (h - c) = 0.04 (10 - 1.375) = 0.35" and j = 0.5 = 0.5"
- $\frac{T_P}{2\,k\,j} = \frac{55700}{2 \times 3.50 \times 0.5} = 15900$ psi < 0.6 x 30000 = 18000 psi

5a. Tank shell capacity based on 17.25" wide bolt chair top plate (ref. 6):

$$S_S = \frac{T_P\,e}{t_s^2}\left[\frac{1.32\,Z}{\frac{1.43\,a\,h^2}{R\,t_s} + \left(4\,a\,h^2\right)^{0.333}} + \frac{0.031}{\sqrt{R\,t_s}}\right]$$

$$Z = \frac{1.0}{\frac{\left(0.177\ in^{-1}\right)a\,t_b}{\sqrt{R\,t_s}}\left[\frac{t_b}{t_s}\right]^2 + 1.0} = \frac{1.0}{\frac{\left(0.177\ in^{-1}\right)\times 17.25 \times 0.1875}{\sqrt{240 \times 0.285}} \times \left[\frac{0.1875}{0.285}\right]^2 + 1.0} = 0.971$$

$$S_S = \frac{55700 \times 3}{0.285^2} \times \left[\frac{1.32 \times 0.971}{\frac{1.43 \times 17.25 \times 10^2}{240 \times 0.285} + \left(4 \times 17.25 \times 10^2\right)^{0.333}} + \frac{0.031}{\sqrt{240 \times 0.285}}\right]$$

$$S_S = 2.057x10^6 \times (0.0233 + 0.00375) = 55640 \text{ psi} > f_y = 30000 \text{ psi}$$

Therefore, T_p = 55.7 x 30 / 55.64 = 30.0 kip

Check the weld between the chair and the tank wall:

$$W_w = T_P \sqrt{\left[\frac{1}{a+2\,h}\right]^2 + \left[\frac{e}{a\,h + 0.667\,h^2}\right]^2}$$

$$W_w = 55700\sqrt{\left[\frac{1}{17.25 + 2\times 10}\right]^2 + \left[\frac{3}{17.25\times 10 + 0.667\times 10^2}\right]^2} = 55700\sqrt{0.0268^2 + 0.0125^2}$$

$$W_w = 1650 \text{ lbs / in} \le \frac{30600\,t_w}{\sqrt{2}} = \frac{30600\times 0.1875}{\sqrt{2}} = 4057 \text{ lbs / in} \quad \therefore \text{ Weld is adequate.}$$

5b. Tank shell capacity based on continuous ring bolt chair top plate:

Per Reference 14, Volume 2, Part VII (which is the source for the bolt chair evaluation in the GIP), when the top plate is a continuous ring the evaluation should be to "*check for maximum stress in the circumferential direction, considering the ring as though it were loaded with equally spaced concentrated loads equal to Pe/h. Portion of the shell within 16t either side of the attachment may be counted as part of the ring.*"

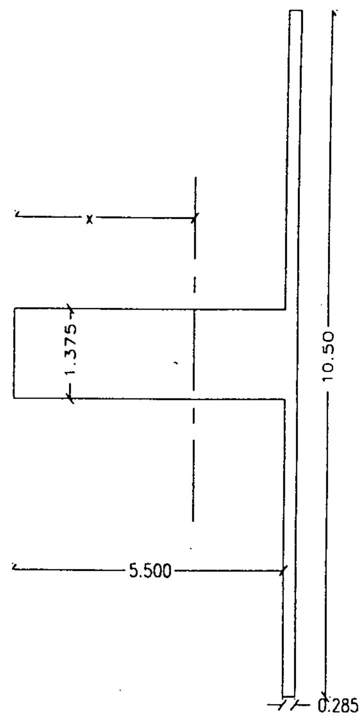
The ring cross section is shown below:

$$A = (10.5)(.285) + (1.375)(5.5) = 10.55 \text{ in}^2$$

$$1.375x^2 / 2 = 1.375(5.5 - x)^2 / 2 + .285(10.50)(5.5 - x + .143)$$
$$7.56x + 2.99x = 20.80 + 16.89$$
$$x = 3.57 \text{ in.}$$

$$I = 1.375(3.57)^3 / 12 + 1.375(3.57)(3.57/2)^2$$
$$+ 1.375(1.93)^3 / 12 + 1.375(1.93)(1.93/2)^2$$
$$+ 10.50(.285)^3 / 12 + 10.50(.285)(1.93 + .285/2)^2 = 37.0 \text{ in}^4$$

$$S = 37.0 / 3.57 = 10.4 \text{ in}^3$$



The ring is loaded with 24 equal radial forces, F. From Reference 15, Table 17, the maximum hoop load, N, and moment, M, are:

$$N = \frac{F}{2}(\sin(7.5°) + \sin(22.5°) + ... + \sin(172.5°)) = 3.83F$$

$$M = \frac{FR}{2}(\frac{24}{\pi} - \sin(0°) - \sin(15°) - ... - - \sin(165°)) = 0.0218FR$$

The maximum allowable F is calculated by equating the total stress to the yield stress:

$$\frac{N}{A} + \frac{M}{S} = 30 \text{ ksi}, \quad (\frac{3.83}{10.55} + \frac{0.0218(240)}{10.4})F = 30 \text{ ksi}, \quad F = 34.6 \text{ k}$$

Finally, the maximum allowable bolt load is Fh / e = 34.6(10 / 3) = 115 k. This is larger than the 30 k computed is Step 5a above, and governs.

The conclusion is that the allowable bolt load is governed by bending of the bolt chair's top plate (Step 3 above), which has a value of 55.7 k, and is ductile.

The maximum uplift height, "deltae0" is equal to 1% of the effective bolt length = 0.01(33" - 2" (anchor fitting) - 3" (threaded length above bolt chair)) = 0.28".

Tank Shell Thickness: (ref. 6)

Section Number	Thickness (in)	To Height (ft)
1	0.285	8.25
2	0.227	16.50
3	0.1875	24.75
4	0.1875	33.00
5	0.1875	41.25

$$t_{av} = \frac{\sum_{i=1}^{5} t_i h_i}{H'} = \frac{(0.285 + 0.227 + 3 \times 0.1875) \times 8.25}{41.25} = 0.215 \text{ in}$$

$$t_{ef} = \frac{t_{av} + t_{min}}{2} = \frac{0.215 + 0.1875}{2} = 0.201 \text{ in}$$

Check the flexibility of the concrete foundation:

The tank is supported on a concrete foundation mat (42' Ø x 2' thk) which is at grade. Below grade, the mat is supported by a 2' concrete ring around its perimeter and an 11' square concrete block at the center. Both the concrete ring and block are approx. 10' tall and doweled into concrete fill which sits directly on rock.

$W_{Top} = W_{Foundation\ Mat} + W_H + W_S + W_W$ (see appendix A)

$W_{Top} = \pi \times 21^2 \times 2 \times 0.150 + 10 + 46 + 2927 = 3400$ kip

$E = 57000 \times (f'_c)^{0.5} = 57000 \times (3000)^{0.5} = 3.122 \times 10^6$ psi (ref. 13)

$$\nu = 0.15 \quad G = \frac{E}{2\,(1+\nu)} = \frac{3.122 \times 10^6}{2\,(1+0.15)} = 1.36 \times 10^6 \text{ psi}$$

$$K = kGA/L = 1.35 \times 10^6 (0.5\pi\,(21^2 - 19^2) + 0.83(11)^2)(144)/10/12 = 3.66 \times 10^8 \text{ lb/in}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{K}{m}} = \frac{1}{2\pi}\sqrt{\frac{3.66 \times 10^8 \times 386}{3400 \times 10^3}} = 32 \text{ Hz.}$$

Therefore, the tank's foundation may be considered to be rigid.

References

1. "Refueling Water Storage Tank Foundation, Concrete & Reinforcing Details", Dwg. No. 9321-F14683-2

2. "Design Calculations, 1-40'-0 ϕ x 41'-3 DRT Refueling Water Storage Tank T-31, 350,000 Gal. Nom. Capacity", Excerpts, SEWS for RWST 21, S&A Log 96C2915-DC-008.

3. Atometrics Calculation No. 18904-IP3-SQ017, Rev. 0., SEWS for CST, S&A Log 96C2915-DC-008.

4. "Summary of Seismic Response Spectra Characteristic", NYPA File No. 44-B-0181, S&A Log 96C2915-DC-005.

5. "A Methodology for Assessment of Nuclear Power Plant Seismic Margin (Revision 1)", EPRI NP-6041-SL, Revision 1, Project 2722-23, Final Report, August 1991.

6. "Seismic Verification of Nuclear Plant Equipment Anchorage (Revision 1), Volume 4: Guidelines on Tanks and Heat Exchangers", EPRI NP-5228-SL, Revision 1, Volume 4, Project 2925-1, Final Report, June 1991.

7. "Seismic Design of Liquid Storage Tanks", Journal of the Technical Council of ASCE, April 1981

8. Mark's Standard Handbook, 9th Edition, Table 3.3.2.

9. Manual of Steel Construction, Allowable Stress Design, AISC, 9th Edition.

10. ASME Boiler and Pressure Vessel Code, 1980 Edition, Appendices.

11. "Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment", SQUG, Revision 2, Corrected 2/14/92.

12. "Code Requirement for Nuclear Safety Related Concrete Structures (ACI 349-80)", Appendix B.

13. "Building Code Requirement for Reinforced Concrete and Commentary (ACI 318-89)".

14. AISI, "Steel Plate Engineering Data - Volumes 1 and 2 - Revised Edition - 1992"

15. Young, Warren C., "Roark's Formulas for Stress & Strain", 6th Edition, 1989.

Refueling Water Storage Tank, RWST 31, GIP Criteria, w/o Fluid Holddown

$R := 240 \cdot in$	Radius	<u>Definitions</u>
$H := 448 \cdot in$	Fluid Height	$kip := 1000 \cdot lb$
$H_s := 495 \cdot in$	Shell Height	$ksi := \frac{kip}{in^2}$
$H_d := 78 \cdot in$	Dome Height	
$t_s := 0.285 \cdot in$	Shell thickness	$psi := \frac{lb}{in^2}$
$t_h := 0.1875 \cdot in$	Head shell thickness	
$t_a := 0.215 \cdot in$	Average shell thickness	$pcf := \frac{lb}{ft^3}$
$t_b := 0.1875 \cdot in$	Bottom plate thickness	
$E_s := 28300 \cdot ksi$	Shell Young's modulus	$minx(x,y) := if(x>y,y,x)$
$\nu := 0.33$	Poisson's ratio	$maxx(x,y) := if(x>y,x,y)$

$K := 316 \cdot ksi$ Water bulk modulus, Mark's Standard Handbook, 9th Ed., Table 3.3.2

$\sigma_{ys} := 30 \cdot ksi$	Shell yield stress
$\sigma_{us} := 75 \cdot ksi$	Shell ultimate stress
$\sigma_{yb} := 30 \cdot ksi$	Bottom plate yield stress
$\sigma_{ub} := 75 \cdot ksi$	Bottom plate ultimate stress
$\gamma_f := 62.4 \cdot pcf$	Fluid weight
$\gamma_s := 490 \cdot pcf$	Shell weight

$$\rho_f := \frac{\gamma_f}{g}$$

$$\rho_s := \frac{\gamma_s}{g}$$

$$I_b := \frac{t_b^{\,3}}{12 \cdot \left(1 - \nu^2\right)} \qquad I_b = 0.000616 \cdot in^3$$

$A_v := 0.10 \cdot g$ 2/3 ZPA of ground spectra

$Scale := 2.50$ Spectral acceleration scale factor. Assumed, must iterate so that the demand M_{sh} is close to the capacity M_{sc}, (factor of safety = 1.0)

Weight Summary

$W_H := \pi \cdot R \cdot \sqrt{R^2 + H_d^2} \cdot t_h \cdot \gamma_s$ $\qquad W_H = 10 \cdot kip$

$X_H := H_s + \frac{H_d}{2}$ $\qquad X_H = 534 \cdot in$

$W_s := \pi \cdot 2 \cdot R \cdot t_a \cdot H_s \cdot \gamma_s$ $\qquad W_s = 46 \cdot kip$

$X_s := \frac{H_s}{2}$

$W_w := \pi \cdot R^2 \cdot H \cdot \gamma_f$ $\qquad W_w = 2927 \cdot kip$

Impulsive Mode

$\frac{t_a}{R} = 0.0009$ $\qquad \frac{H}{R} = 1.867$

$C_{WI} := 0.09$ Frequency coefficient from Haroun and Housner (1981)

$C_{LI} := C_{WI} \cdot \sqrt{\frac{0.127 \cdot \rho_s}{\rho_f}}$ $\qquad C_{LI} = 0.09$

$f_I := \frac{C_{LI}}{2 \cdot \pi \cdot H} \cdot \sqrt{\frac{E_s}{\rho_s}}$

$f_I = 6.268 \cdot Hz$ $\qquad 0.8 \cdot f_I = 5.014 \cdot Hz$ $\qquad 1.2 \cdot f_I = 7.521 \cdot Hz$

$S_{AI} := 0.24 \cdot g$ From IP3 SSE Ground Spectra 5% Damping, x (5/4)^0.5 to estimate 4% damping

$S_{AI} := Scale \cdot S_{AI}$ $\qquad S_{AI} = 0.6 \cdot g$

$$W_I := \begin{cases} \left(1 - 0.436 \cdot \frac{R}{H}\right) \cdot W_w & \text{if } \frac{H}{R} \ge 1.5 \\ \left(0.764 \cdot W_w\right) & \text{if } \frac{H}{R} < 1.5 \end{cases}$$

$W_I = 2244 \cdot kip$

$$X_I := \begin{cases} \left[\left(0.5 - 0.188 \cdot \frac{R}{H}\right) \cdot H\right] & \text{if } \frac{H}{R} \ge 1.5 \\ \left(0.304 \cdot H \cdot \frac{W_w}{W_I}\right) & \text{if } \frac{H}{R} < 1.5 \end{cases}$$

$X_I = 178.9 \cdot in$

$V_I := \frac{S_{AI}}{g} \cdot (W_H + W_s + W_I)$ $\qquad V_I = 1380 \cdot kip$

$M_I := \frac{S_{AI}}{g} \cdot (W_H \cdot X_H + W_s \cdot X_s + W_I \cdot X_I)$ $\qquad M_I = 20901 \cdot kip \cdot ft$

Sloshing Mode

$$f_c := \sqrt{\frac{1.5 \cdot \frac{ft}{sec^2}}{R} \cdot \tanh\left[1.835 \cdot \left(\frac{H}{R}\right)\right]} \qquad f_c = 0.274 \cdot Hz$$

$S_{Ac} := 0.100 \cdot g$ IP3 SSE Ground Spectra @ 0.5% Damping at 0.5 Hz

$S_{Ac} := Scale \cdot S_{Ac}$ $\qquad S_{Ac} = 0.25 \cdot g$

$W_c := 0.46 \cdot \frac{R}{H} \cdot \tanh\left[1.835 \cdot \left(\frac{H}{R}\right)\right] \cdot W_w$ $\qquad W_c = 720 \cdot kip$

$$X_c := \left(1 - \frac{\cosh\left(1.835 \cdot \frac{H}{R}\right) - 1}{1.835 \cdot \frac{H}{R} \cdot \sinh\left(1.835 \cdot \frac{H}{R}\right)}\right) \cdot H \qquad X_c = 325.5 \cdot in$$

$V_c := \frac{S_{Ac}}{g} \cdot W_c$ $\qquad V_c = 180 \cdot kip$

$M_c := \frac{S_{Ac}}{g} \cdot W_c \cdot X_c$ $\qquad M_c = 4881 \cdot kip \cdot ft$

Vertical Mode

$$f_v := \frac{1}{4 \cdot H} \left[\rho_f \cdot \left(\frac{2 \cdot R}{t_s \cdot E_s} + \frac{1}{K}\right)\right]^{-\frac{1}{2}}$$

$f_v = 7.288 \cdot Hz$ $\qquad 0.8 \cdot f_v = 5.831 \cdot Hz$ $\qquad 1.2 \cdot f_v = 8.746 \cdot Hz$

$S_{Av} := 0.15 \cdot g$ 2/3 Horizontal, 5% Damping x (5/4)^0.5 to estimate 4% damping

$S_{Av} := Scale \cdot S_{Av}$ $\qquad S_{Av} = 0.375 \cdot g$

Demand

$$SRSS(x,y) := \sqrt{x^2 + y^2}$$

$$V_{sh} := SRSS(V_l, V_c) \qquad V_{sh} = 1391 \cdot kip$$

$$M_{sh} := SRSS(M_l, M_c) \qquad M_{sh} = 21463 \cdot kip \cdot ft$$

Pressures

$$y := (H - 198 \cdot in), H .. H$$

$$P_{st}(y) := \gamma_f \cdot y \qquad P_i := \frac{W_l \cdot X_l \cdot \frac{S_{Al}}{g}}{1.36 \cdot R \cdot H^2} \qquad P_i = 3.676 \cdot psi$$

$$P_c(y) := \frac{0.267 \cdot W_w \cdot \frac{S_{Ac}}{g}}{R \cdot H} \cdot \frac{\cosh\left[1.835 \cdot \left(\frac{H-y}{R}\right)\right]}{\cosh\left[1.835 \cdot \left(\frac{H}{R}\right)\right]}$$

$$P_v(y) := 0.8 \cdot \gamma_f \cdot H \cdot \frac{S_{Av}}{g} \cdot \cos\left(\frac{\pi}{2} \cdot \frac{H-y}{H}\right)$$

$$P_{sh}(y) := SRSS(P_i, P_c(y))$$

$$P_{sm}(y) := SRSS(P_{sh}(y), P_v(y))$$

$\frac{y}{in}$	$\frac{P_{st}(y)}{psi}$	$\frac{P_c(y)}{psi}$	$\frac{P_v(y)}{psi}$	$\frac{P_{sh}(y)}{psi}$	$\frac{P_{sm}(y)}{psi}$
250	9.028	0.281	3.73	3.687	5.244
448	16.178	0.118	4.853	3.678	6.089

$$P_{cp} := P_{st}(H) + P_{sh}(H) + 0.4 \cdot P_v(H) \qquad P_{cp} = 21.797 \cdot psi$$

$$P_{cm} := P_{st}(H) + P_{sh}(H) - 0.4 \cdot P_v(H) \qquad P_{cm} = 17.914 \cdot psi$$

$$P_{tm} := P_{st}(H) - P_{sh}(H) - 0.4 \cdot P_v(H) \qquad P_{tm} = 10.559 \cdot psi$$

$$P_a := P_{st}(H) - 0.4 \cdot P_v(H) \qquad P_a = 14.236 \cdot psi$$

Elephant Foot Buckling

$S_1 := \frac{R}{400 \cdot t_s}$ $\qquad$ $S_1 = 2.105$

$\sigma_{ye} := \sigma_{ys}$ $\qquad$ $\sigma_{ye} = 30 \cdot ksi$

$$\sigma_p := \frac{0.6 \cdot E_s}{\left(\frac{R}{t_s}\right)} \cdot \left[1 - \left(\frac{P_{cp} \cdot R}{\sigma_{ye} \cdot t_s}\right)^2\right] \cdot \left(1 - \frac{1}{1.12 + S_1^{1.5}}\right) \cdot \left(\frac{S_1 + \frac{\sigma_{ye}}{36 \cdot ksi}}{S_1 + 1}\right)$$

$\sigma_p = 9079 \cdot psi$

$C_{Be} := \sigma_p \cdot t_s$ $\qquad$ $C_{Be} = 2587 \cdot \frac{lb}{in}$

Diamond Shape Buckling

$\phi := \frac{1}{16} \cdot \sqrt{\frac{R}{t_s}}$ $\qquad$ $\phi = 1.814$

$\gamma := 1 - 0.73 \cdot \left(1 - e^{-\phi}\right)$ $\qquad$ $\gamma = 0.389$ $\qquad$ $\frac{P_{cm}}{E_s} \cdot \left(\frac{R}{t_s}\right)^2 = 0.449$

$\Delta\gamma := 0.19$ $\qquad$ Manually from Figure Figure 6 of NASA SP-8007 based on Pc-

$$\sigma_{cb} := (0.6 \cdot \gamma + \Delta\gamma) \cdot \frac{E_s}{\left(\frac{R}{t_s}\right)}$$

$C_{Bd} := \sigma_{cb} \cdot t_s$ $\qquad$ $C_{Bd} = 4055 \cdot \frac{lb}{in}$

$C_B := 0.72 \cdot \text{minx}\left(C_{Be}, C_{Bd}\right)$ $\qquad$ $C_B = 1863 \cdot \frac{lb}{in}$

Compute Base Moment and Shear Capacity

$h_a := 28 \cdot in$

$\delta_{e0} := 0.01 \cdot (h_a)$ $\quad\quad \delta_{e0} = 0.28 \cdot in$

$h_c := 10 \cdot in$ $\quad\quad$ Assumed, not sensitive

$$W_{te} := (W_H + W_s) \cdot \left(1 - 0.4 \cdot \frac{Scale \cdot A_v}{g}\right) \quad\quad W_{te} = 50 \cdot kip$$

$$C_1(\beta) := \frac{1 + \cos(\beta)}{\sin(\beta) + (\pi - \beta) \cdot \cos(\beta)}$$

$$C_2(\beta) := \frac{\sin(\beta) \cdot \cos(\beta) + \pi - \beta}{1 + \cos(\beta)}$$

$\beta 1 := 1.800$ $\quad$ Initial Guess $\quad\quad N_b := 24$

$i := 1, 2 .. N_b$ $\quad\quad A_b := 3.140 \cdot in^2$

$\alpha_i := i \cdot \frac{360}{N_b} \cdot deg$ $\quad\quad T_{BC} := 55.7 \cdot kip$

$$\delta_{e_i} := \delta_{e0} \cdot \frac{\cos(\alpha_i) - \cos(\beta 1)}{1 - \cos(\beta 1)} \quad\quad K_b := \frac{A_b \cdot E_s}{h_a}$$

$$T_{b_i} := maxx\left(minx\left(\delta_{e_i} \cdot K_b, T_{BC}\right), 0 \cdot kip\right)$$

$$\beta := root\left[\frac{W_{te} + \sum_i T_{b_i}}{2 \cdot R} \cdot C_1(\beta 1) - minx\left[\frac{E_s \cdot t_s \cdot \left(\delta_{e0} \cdot \frac{1 + \cos(\beta 1)}{1 - \cos(\beta 1)}\right)}{h_c}, C_B\right], \beta 1\right]$$

$\beta = 1.8$

$$\delta_c := \delta_{e0} \cdot \frac{1 + \cos(\beta)}{1 - \cos(\beta)}$$

$$C_m := minx\left(\frac{E_s \cdot t_s \cdot \delta_c}{h_c}, C_B\right) \quad\quad C_m = 1863 \cdot \frac{lb}{in}$$

$$M_{sc} := C_m \cdot C_2(\beta) \cdot R^2 + \sum_i T_{b_i} \cdot R \cdot \cos(\alpha_i)$$

$M_{sc} = 21425 \cdot kip \cdot ft$

$COF := 0.55$

$W_{ve} := W_{te} + P_a \cdot \pi \cdot R^2$

$V_{sc} := COF \cdot W_{ve}$ $\qquad V_{sc} = 1444 \cdot kip$

$Factor\_of\_Safety := minx\left(\frac{M_{sc}}{M_{sh}}, \frac{V_{sc}}{V_{sh}}\right)$ $\qquad Factor\_of\_Safety = 0.998$

Capacity: $S_{AI} = 0.6 \cdot g$

Refueling Water Storage Tank, RWST 31, GIP Criteria, w/ Fluid Holddown

$R := 240\cdot in$	Radius	Definitions
$H := 448\cdot in$	Fluid Height	$kip := 1000\cdot lb$
$H_s := 495\cdot in$	Shell Height	$ksi := \frac{kip}{in^2}$
$H_d := 78\cdot in$	Dome Height	
$t_s := 0.285\cdot in$	Shell thickness	$psi := \frac{lb}{in^2}$
$t_h := 0.1875\cdot in$	Head shell thickness	
$t_a := 0.215\cdot in$	Average shell thickness	$pcf := \frac{lb}{ft^3}$
$t_b := 0.1875\cdot in$	Bottom plate thickness	
$E_s := 28300\cdot ksi$	Shell Young's modulus	$minx(x,y) := if(x>y,y,x)$
$\nu := 0.33$	Poisson's ratio	$maxx(x,y) := if(x>y,x,y)$

$K := 316\cdot ksi$ Water bulk modulus, Mark's Standard Handbook, 9th Ed., Table 3.3.2

$\sigma_{ys} := 30\cdot ksi$	Shell yield stress
$\sigma_{us} := 75\cdot ksi$	Shell ultimate stress
$\sigma_{yb} := 30\cdot ksi$	Bottom plate yield stress
$\sigma_{ub} := 75\cdot ksi$	Bottom plate ultimate stress
$\gamma_f := 62.4\cdot pcf$	Fluid weight
$\gamma_s := 490\cdot pcf$	Shell weight

$$\rho_f := \frac{\gamma_f}{g}$$

$$\rho_s := \frac{\gamma_s}{g}$$

$$I_b := \frac{t_b^3}{12\cdot\left(1-\nu^2\right)} \qquad I_b = 0.000616\cdot in^3$$

$A_v := 0.10\cdot g$ 2/3 ZPA of ground spectra

$Scale := 2.58$ Spectral acceleration scale factor. Assumed, must iterate so that the demand M_{sh} is close to the capacity M_{sc}, (factor of safety = 1.0)

Weight Summary

$W_H := \pi \cdot R \cdot \sqrt{R^2 + H_d^2} \cdot t_h \cdot \gamma_s$ $\qquad W_H = 10 \cdot kip$

$X_H := H_s + \frac{H_d}{2}$ $\qquad X_H = 534 \cdot in$

$W_s := \pi \cdot 2 \cdot R \cdot t_a \cdot H_s \cdot \gamma_s$ $\qquad W_s = 46 \cdot kip$

$X_s := \frac{H_s}{2}$

$W_w := \pi \cdot R^2 \cdot H \cdot \gamma_f$ $\qquad W_w = 2927 \cdot kip$

Impulsive Mode

$\frac{t_a}{R} = 0.0009$ $\qquad \frac{H}{R} = 1.867$

$C_{WI} := 0.09$ Frequency coefficient from Haroun and Housner (1981)

$C_{LI} := C_{WI} \cdot \sqrt{\frac{0.127 \cdot \rho_s}{\rho_f}}$ $\qquad C_{LI} = 0.09$

$f_I := \frac{C_{LI}}{2 \cdot \pi \cdot H} \cdot \sqrt{\frac{E_s}{\rho_s}}$

$f_I = 6.268 \cdot Hz$ $\qquad 0.8 \cdot f_I = 5.014 \cdot Hz$ $\qquad 1.2 \cdot f_I = 7.521 \cdot Hz$

$S_{AI} := 0.24 \cdot g$ From IP3 SSE Ground Spectra 5% Damping, x (5/4)^0.5 to estimate 4% damping

$S_{AI} := Scale \cdot S_{AI}$ $\qquad S_{AI} = 0.619 \cdot g$

$$W_I := \begin{cases} \left(1 - 0.436 \cdot \frac{R}{H}\right) \cdot W_w & \text{if } \frac{H}{R} \geq 1.5 \\ (0.764 \cdot W_w) & \text{if } \frac{H}{R} < 1.5 \end{cases}$$

$W_I = 2244 \cdot kip$

$$X_I := \begin{cases} \left[\left(0.5 - 0.188 \cdot \frac{R}{H}\right) \cdot H\right] & \text{if } \frac{H}{R} \geq 1.5 \\ \left(0.304 \cdot H \cdot \frac{W_w}{W_I}\right) & \text{if } \frac{H}{R} < 1.5 \end{cases}$$

$X_I = 178.9 \cdot in$

$V_l := \frac{S_{Al}}{g} \cdot (W_H + W_s + W_l)$ $\qquad V_l = 1424 \cdot kip$

$M_l := \frac{S_{Al}}{g} \cdot (W_H \cdot X_H + W_s \cdot X_s + W_l \cdot X_l)$ $\qquad M_l = 21570 \cdot kip \cdot ft$

Sloshing Mode

$f_c := \sqrt{\frac{1.5 \cdot \frac{ft}{sec^2}}{R} \cdot \tanh\left[1.835 \cdot \left(\frac{H}{R}\right)\right]}$ $\qquad f_c = 0.274 \cdot Hz$

$S_{Ac} := 0.100 \cdot g$ IP3 SSE Ground Spectra @ 0.5% Damping at 0.5 Hz

$S_{Ac} := Scale \cdot S_{Ac}$ $\qquad S_{Ac} = 0.258 \cdot g$

$W_c := 0.46 \cdot \frac{R}{H} \cdot \tanh\left[1.835 \cdot \left(\frac{H}{R}\right)\right] \cdot W_w$ $\qquad W_c = 720 \cdot kip$

$X_c := \left(1 - \frac{\cosh\left(1.835 \cdot \frac{H}{R}\right) - 1}{1.835 \cdot \frac{H}{R} \cdot \sinh\left(1.835 \cdot \frac{H}{R}\right)}\right) \cdot H$ $\qquad X_c = 325.5 \cdot in$

$V_c := \frac{S_{Ac}}{g} \cdot W_c$ $\qquad V_c = 186 \cdot kip$

$M_c := \frac{S_{Ac}}{g} \cdot W_c \cdot X_c$ $\qquad M_c = 5037 \cdot kip \cdot ft$

Vertical Mode

$f_v := \frac{1}{4 \cdot H} \cdot \left[\rho_f \cdot \left(\frac{2 \cdot R}{t_s \cdot E_s} + \frac{1}{K}\right)\right]^{-\frac{1}{2}}$

$f_v = 7.288 \cdot Hz$ $\qquad 0.8 \cdot f_v = 5.831 \cdot Hz$ $\qquad 1.2 \cdot f_v = 8.746 \cdot Hz$

$S_{Av} := 0.15 \cdot g$ 2/3 Horizontal, 5% Damping x (5/4)^0.5 to estimate 4% damping

$S_{Av} := Scale \cdot S_{Av}$ $\qquad S_{Av} = 0.387 \cdot g$

Demand

$SRSS(x,y) := \sqrt{x^2 + y^2}$

$V_{sh} := SRSS(V_l, V_c)$ $\qquad V_{sh} = 1436 \cdot kip$

$M_{sh} := SRSS(M_l, M_c)$ $\qquad M_{sh} = 22150 \cdot kip \cdot ft$

Pressures

$y := (H - 198 \cdot in), H .. H$

$P_{st}(y) := \gamma_f \cdot y$ $\qquad P_i := \dfrac{W_l \cdot X_l \cdot \dfrac{S_{Al}}{g}}{1.36 \cdot R \cdot H^2}$ $\qquad P_i = 3.794 \cdot psi$

$$P_c(y) := \frac{0.267 \cdot W_w \cdot \dfrac{S_{Ac}}{g}}{R \cdot H} \cdot \frac{\cosh\left[1.835 \cdot \left(\dfrac{H-y}{R}\right)\right]}{\cosh\left[1.835 \cdot \left(\dfrac{H}{R}\right)\right]}$$

$P_v(y) := 0.8 \cdot \gamma_f \cdot H \cdot \dfrac{S_{Av}}{g} \cdot \cos\left(\dfrac{\pi}{2} \cdot \dfrac{H-y}{H}\right)$ $\qquad P_{sh}(y) := SRSS(P_i, P_c(y))$

$P_{sm}(y) := SRSS(P_{sh}(y), P_v(y))$

$\frac{y}{in}$	$\frac{P_{st}(y)}{psi}$	$\frac{P_c(y)}{psi}$	$\frac{P_v(y)}{psi}$	$\frac{P_{sh}(y)}{psi}$	$\frac{P_{sm}(y)}{psi}$
250	9.028	0.29	3.849	3.805	5.412
448	16.178	0.122	5.009	3.796	6.284

$P_{cp} := P_{st}(H) + P_{sh}(H) + 0.4 \cdot P_v(H)$ $\qquad P_{cp} = 21.977 \cdot psi$

$P_{cm} := P_{st}(H) + P_{sh}(H) - 0.4 \cdot P_v(H)$ $\qquad P_{cm} = 17.97 \cdot psi$

$P_{tm} := P_{st}(H) - P_{sh}(H) - 0.4 \cdot P_v(H)$ $\qquad P_{tm} = 10.379 \cdot psi$

$P_a := P_{st}(H) - 0.4 \cdot P_v(H)$ $\qquad P_a = 14.174 \cdot psi$

Elephant Foot Buckling

$S_1 := \frac{R}{400 \cdot t_s}$ $\qquad S_1 = 2.105$

$\sigma_{ye} := \sigma_{ys}$ $\qquad \sigma_{ye} = 30 \cdot ksi$

$$\sigma_p := \frac{0.6 \cdot E_s}{\left(\frac{R}{t_s}\right)} \cdot \left[1 - \left(\frac{P_{cp} \cdot R}{\sigma_{ye} \cdot t_s}\right)^2\right] \cdot \left(1 - \frac{1}{1.12 + S_1^{1.5}}\right) \cdot \left(\frac{S_1 + \frac{\sigma_{ye}}{36 \cdot ksi}}{S_1 + 1}\right)$$

$\sigma_p = 8989 \cdot psi$

$C_{Be} := \sigma_p \cdot t_s$ $\qquad C_{Be} = 2562 \cdot \frac{lb}{in}$

Diamond Shape Buckling

$\phi := \frac{1}{16} \cdot \sqrt{\frac{R}{t_s}}$ $\qquad \phi = 1.814$

$\gamma := 1 - 0.73 \cdot \left(1 - e^{-\phi}\right)$ $\qquad \gamma = 0.389$ $\qquad \frac{P_{cm}}{E_s} \cdot \left(\frac{R}{t_s}\right)^2 = 0.45$

$\Delta\gamma := 0.19$ Manually from Figure Figure 6 of NASA SP-8007 based on Pc-

$$\sigma_{cb} := (0.6 \cdot \gamma + \Delta\gamma) \cdot \frac{E_s}{\left(\frac{R}{t_s}\right)}$$

$C_{Bd} := \sigma_{cb} \cdot t_s$ $\qquad C_{Bd} = 4055 \cdot \frac{lb}{in}$

$C_B := 0.72 \cdot \text{minx}\left(C_{Be}, C_{Bd}\right)$ $\qquad C_B = 1844 \cdot \frac{lb}{in}$

Fluid Hold Down Force

$P := P_{st}(H) - 0.09 \cdot P_{sh}(H) - 0.4 \cdot P_v(H)$ Average pressure for fluid hold-down calculation

$P = 13.833 \cdot psi$

$\kappa := \sqrt{\frac{R}{t_s} \cdot \sqrt{3 \cdot \left(1 - \nu^2\right)}}$ $\kappa = 37.11$

$K := \frac{E_s \cdot t_s^{\,3}}{12 \cdot \left(1 - \nu^2\right)}$ $K = 5105 \cdot lb \cdot ft$

$K_s := \frac{2 \cdot K \cdot \kappa}{R}$ $K_s = 18944 \cdot lb$

$M_F := \frac{R \cdot t_s}{\sqrt{12 \cdot \left(1 - \nu^2\right)}} \cdot \left(1 - \frac{R}{H \cdot \kappa}\right) \cdot P$ $M_F = 285 \cdot lb$

$L := 1 \cdot in, 2 \cdot in .. 30 \cdot in$

$F(L) := 1 + \frac{K_s \cdot L}{2 \cdot E_s \cdot I_b}$

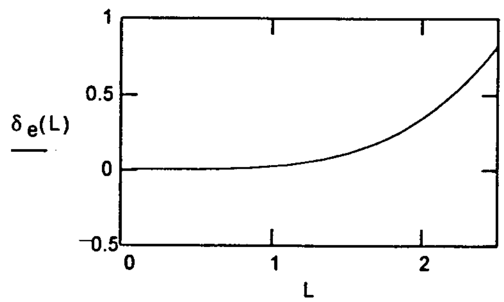
$T_e(L) := \left[\frac{L}{2} + \frac{1}{F(L)} \cdot \left(\frac{K_s \cdot L^2}{12 \cdot E_s \cdot I_b} + \frac{M_F}{P \cdot L}\right)\right] \cdot P$

$M_e(L) := \left(\frac{1}{F(L)}\right) \cdot \left(\frac{K_s \cdot L^3}{12 \cdot E_s \cdot I_b} + \frac{M_F}{P}\right) \cdot P$

$\delta_e(L) := \left[\frac{L^4}{24} - \frac{1}{F(L)} \cdot \left(\frac{K_s \cdot L^5}{72 \cdot E_s \cdot I_b} + \frac{M_F}{P} \cdot \frac{L^2}{6}\right)\right] \cdot \frac{P}{E_s \cdot I_b}$

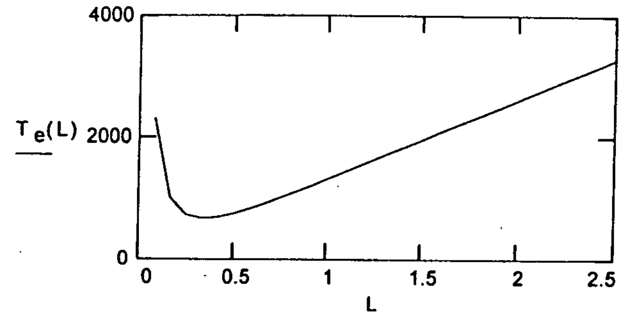
$M_{pb} := \text{minx}\left(\sigma_{us} \cdot \frac{t_s^{\,2}}{4}, \sigma_{ub} \cdot \frac{t_b^{\,2}}{4}\right)$ $M_{pb} = 0.659 \cdot \frac{kip \cdot in}{in}$

$F_H := \frac{\sigma_{ye} \cdot t_s}{2 \cdot \kappa} + \frac{M_{pb} \cdot \kappa}{R}$ $F_H = 0.217 \cdot \frac{kip}{in}$



$T_m(L) := \sqrt{4 \cdot M_{pb} \cdot P} \cdot \sqrt{1 + \frac{F_H \cdot \delta_e(L)}{2 \cdot M_{pb}}}$

$\frac{L}{in}$	$\frac{\delta_e(L)}{in}$	$\frac{T_e(L)}{\left(\frac{lb}{in}\right)}$	$\frac{T_m(L)}{\left(\frac{lb}{in}\right)}$
1	-0.002	192.544	190.952
2	-0.005	84.588	190.902
3	-0.008	61.192	190.857
4	-0.009	56.456	190.835
5	-0.008	58.359	190.857
6	-0.002	63.245	190.947
7	0.01	69.677	191.131
8	0.029	76.994	191.44
9	0.059	84.854	191.91
10	0.102	93.068	192.577
11	0.16	101.521	193.482
12	0.237	110.143	194.669
13	0.335	118.886	196.184
14	0.459	127.721	198.071
15	0.612	136.624	200.379
16	0.799	145.581	203.152
17	1.023	154.579	206.436
18	1.289	163.611	210.272
19	1.602	172.67	214.699
20	1.967	181.751	219.751
21	2.39	190.849	225.457
22	2.876	199.963	231.844
23	3.432	209.09	238.931
24	4.063	218.227	246.733
25	4.775	227.373	255.26
26	5.577	236.528	264.519
27	6.473	245.688	274.512
28	7.473	254.855	285.238
29	8.583	264.027	296.693
30	9.81	273.204	308.873



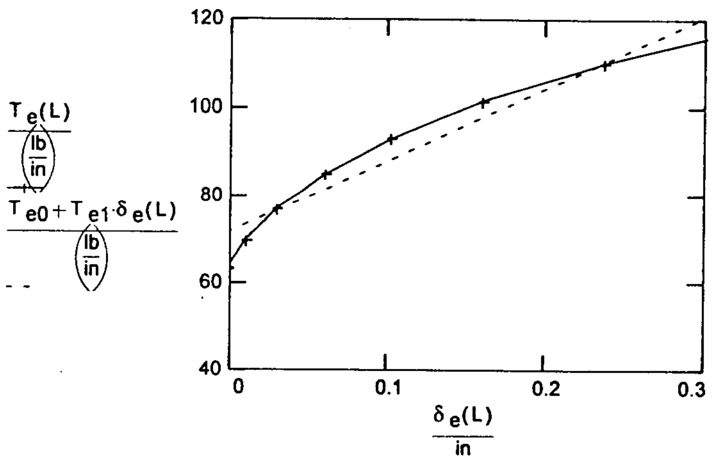
$i := 0..35$

$\delta_i := \delta_e(0.2 \cdot i \cdot in + 6 \cdot in)$

$T_i := T_e(0.2 \cdot i \cdot in + 6 \cdot in)$

$T_{e0} := \text{intercept}(\delta, T)$ $\quad T_{e0} = 71.777 \cdot \frac{lb}{in}$

$T_{e1} := \text{slope}(\delta, T)$ $\quad T_{e1} = 162.8 \cdot \frac{lb}{in^2}$



$h_a := 28 \cdot in$

$\delta_{e0} := 0.01 \cdot (h_a)$ $\quad \delta_{e0} = 0.28 \cdot in$

$h_c := 10 \cdot in$ Assumed, not sensitive

$\Delta T_e := T_{e1} \cdot \delta_{e0}$

$W_{te} := (W_H + W_s) \cdot \left(1 - 0.4 \cdot \frac{Scale \cdot A_v}{g}\right)$ $\quad W_{te} = 50 \cdot kip$

$C_1(\beta) := \frac{1 + \cos(\beta)}{\sin(\beta) + (\pi - \beta) \cdot \cos(\beta)}$

$C_2(\beta) := \frac{\sin(\beta) \cdot \cos(\beta) + \pi - \beta}{1 + \cos(\beta)}$

$C_3(\beta) := \frac{\sin(\beta) - \beta \cdot \cos(\beta)}{\sin(\beta) + (\pi - \beta) \cdot \cos(\beta)} \cdot \frac{1 + \cos(\beta)}{1 - \cos(\beta)}$

$C_4(\beta) := \frac{\beta - \sin(\beta) \cdot \cos(\beta)}{1 - \cos(\beta)}$

$\beta 1 := 1.64$ Initial Guess

$N_b := 24$

$i := 1, 2 .. N_b$

$A_b := 3.14 \cdot in^2$

$\alpha_i := i \cdot \frac{360}{N_b} \cdot deg$

$T_{BC} := 55.7 \cdot kip$

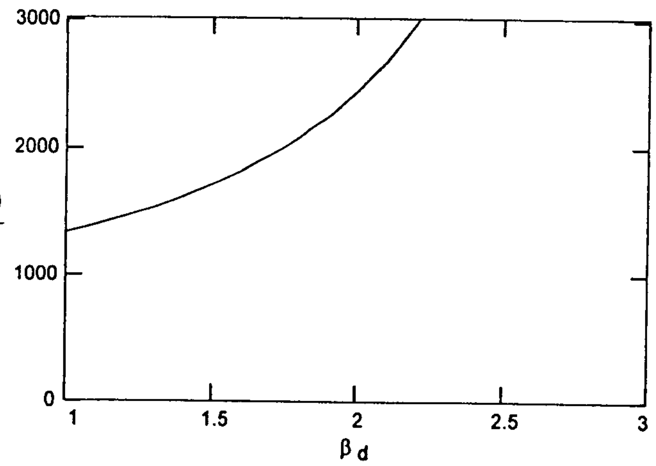
$\delta_{e_i} := \delta_{e0} \cdot \frac{\cos(\alpha_i) - \cos(\beta 1)}{1 - \cos(\beta 1)}$

$K_b := \frac{A_b \cdot E_s}{h_a}$

$T_{b_i} := maxx\left(minx\left(\delta_{e_i} \cdot K_b, T_{BC}\right), 0 \cdot kip\right)$

$\beta_d := 1.0, 1.1 .. 3$

$$\frac{\left(\frac{W_{te} + \sum_i T_{b_i}}{2 \cdot R} + T_{e0} \cdot \beta_d\right) \cdot C_1(\beta_d) + \Delta T_e \cdot C_3(\beta_d)}{\left(\frac{lb}{in}\right)}$$



$$\beta := \text{root}\left[\left(\frac{W_{te} + \sum_i T_{b_i}}{2 \cdot R} + T_{e0} \cdot \beta 1\right) \cdot C_1(\beta 1) + \Delta T_e \cdot C_3(\beta 1) - \text{minx}\left[\frac{E_s \cdot t_s \cdot \left(\delta_{e0} \cdot \frac{1 + \cos(\beta 1)}{1 - \cos(\beta 1)}\right)}{h_c}, C_B\right], \beta 1\right]$$

$\beta = 1.634$

$$\delta_c := \delta_{e0} \cdot \frac{1 + \cos(\beta)}{1 - \cos(\beta)}$$

$$C_m := \text{minx}\left(\frac{E_s \cdot t_s \cdot \delta_c}{h_c}, C_B\right) \qquad C_m = 1844 \cdot \frac{\text{lb}}{\text{in}}$$

$$M_{sc} := C_m \cdot C_2(\beta) \cdot R^2 + \sum_i T_{b_i} \cdot R \cdot \cos(\alpha_i) + T_{e0} \cdot R^2 \cdot 2 \cdot \sin(\beta) + \Delta T_e \cdot C_4(\beta) \cdot R^2$$

$M_{sc} = 23148 \cdot \text{kip} \cdot \text{ft}$

$COF := 0.55$

$W_{ve} := W_{te} + P_a \cdot \pi \cdot R^2$

$V_{sc} := COF \cdot W_{ve}$ $\qquad V_{sc} = 1438 \cdot \text{kip}$

$$\text{Factor\_of\_Safety} := \text{minx}\left(\frac{M_{sc}}{M_{sh}}, \frac{V_{sc}}{V_{sh}}\right) \qquad \text{Factor\_of\_Safety} = 1.002$$

Capacity: $S_{AI} = 0.619 \cdot g$