From: Decina, Anita
To: Hummel, Lindsey; Kreke, Thomas; IDEM OLQ Solid Waste Permits Submittals
Cc: Chalhoub, Robert; Warfield, Jenny
Subject: RE: 15 Day Notification Solid Waste Processing Facility
Date: Tuesday, June 25, 2024 3:01:56 PM
Attachments: Crystal Clean Indy IDEM Requirement F3_complete package_with attachments.pdf

Good afternoon,

Please find attached our submittal fulfilling the compliance schedule requirement F3 of the solid waste permit renewal dated April 26, 2024.

Thank you,
Anita

Anita Decina
Vice President, Operational, Safety & Environmental Excellence

Crystal Clean, LLC
O: 847-783-5924 | C: 630-688-3303
2000 Center Drive, Suite East C300
Hoffman Estates, IL 60192

June 25, 2024

Thomas Kreke, Chief, Solid Waste Permits Section
Lindsey Hummel, Permit Manager
Office of Land Quality
Indiana Department of Environmental Management
100 N. Senate Avenue
Indianapolis, IN 46204

RE: **Compliance Schedule Requirement F3**
Approval of Solid Waste Permit Renewal, April 26, 2024; SW Program ID 49-60; Crystal Clean Indianapolis Solid Waste Processing Facility at 3970 West 10th Street, Indianapolis, Marion County, IN 46222

Dear Mr. Kreke and Ms. Hummel:

Crystal Clean, LLC (Crystal Clean) is submitting the attached materials to fulfil the compliance schedule Requirement F3 in the approval of the solid waste permit renewal issued by Indiana Department of Environmental Management (IDEM) on April 26, 2024.

Requirement F3 states: "Within 60 days after receiving this approval and prior to beginning construction/installation of Tanks 56 and 57, the permittee must submit the PE Stamped Calculations referenced in the tank quote on page 37 of the April 5, 2024 (VFC #83621658) submittal, certified by an Indiana-registered Professional Engineer to IDEM for approval."

Along with this cover letter, Crystal Clean is submitting the following materials to address the Compliance Schedule Requirement F3:

- Regarding F3, Attachment 1 is provided and includes the PE Stamped Calculations for Tanks 56 and 57 by Precision Tank as referenced in the tank quote on page 37 of the April 5, 2024 submittal. Attachment 1 by Precision Tank provides calculations for the tank design and takes into consideration the tank dimensions, contents, and specifications. Attachment 1 includes the following calculations and aspects:
    - Tank Design Data taken from design drawing
    - Shell Thickness for Internal Liquid Pressure - Methodology and Results
    - Self-Supported Roof Design - Methodology and Results
    - Wind Design, Seismic Design, and Shell Buckling Check - Methodology and Results
    - Foundation and Maximum Anchor Bolt Loads - Methodology and Results
    - Applicable appendices and references
    - Indiana PE Stamp on page 4

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The letter and attachments herein provide information that address the requirements of F3. Crystal Clean requests a response letter acknowledging completion of Requirement F3. Crystal Clean is available to further discuss with IDEM if needed. I can be contacted at 847-783-5924 and Anita.Decina@Crystal-Clean.com.

Thank you for your collaboration on this solid waste processing facility permit renewal.

Sincerely,

Anita Decina
Vice President, Operational, Safety & Environmental Excellence

Cc: Glenn Casbourne, Vice President of Engineering & Re-Refinery Operations
Robert Chalhoub, Crystal Clean, Re-Refinery Manager
Andrew Burdett, Crystal Clean, Health/Safety/Security/Environmental Manager
Kimberly Klein, Crystal Clean
Jennifer Warfield, Tetra Tech

Attachments –
Attachment 1: PE Stamped Calculations for Tanks 56 and 57

ATTACHMENT 1 - PE STAMPED CALCULATIONS FOR TANKS 56 AND 57

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TAMPA TANK FLORIDA STRUCTURAL STEEL

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Calculation Report for Shop Fabricated UL-142 Tank

Introduction:

This calculation report is provided to confirm the acceptability of the shell, bottom, and roof of a 12 ft dia. by 42 ft tall UL-142 carbon steel tank design. Additionally, this report provides wind and seismic calculations, shell buckling checks, and the maximum anchor bolt loads. While the UL-142 Standard provides tables and standards to follow, it lacks stress equations or a table of allowable stresses. Therefore, the calculations in this report are supplemented with methodologies and allowable stresses sourced from API 650 13th Edition, ASME Section VIII Division 1 2023 Edition, and AISC 360.

Tank Design Data taken from design drawing:

1. Product specific gravity:
    a. 1.0 at full shell height
2. Design Pressure, Vacuum, and Design Temperature:
    a. Atmospheric pressure at 120°F
    b. 1" W.C. vacuum design pressure
3. Wind speed design:
    a. ASCE 7-10, Rick Category III-IV, 120 mph, Exposure C
4. Seismic design:
    a. ASCE 7-10, Ss=16.8%, S1=8.9%, TL=12s

Shell Thickness for Internal Liquid Pressure - Methodology and Results:

API 650 13th Edition and ASME Section VIII Division 1 2023 Edition are utilized to determine acceptability of the shell thicknesses. For A36 carbon steel, the allowable stresses being considered for steel are 21,000 psi (API 650) and 16,600 psi (ASME), and the tank has a joint efficiency of 70% from drawings provided. The lowest shell course of each plate thickness is examined.

1. ASME Section VIII Division 1 Analysis of the 1st Shell Course:
    a. The design thickness of the 1st shell course is calculated to be a minimum of 0.1131 inches.
    b. The estimated maximum stress in the ¼" shell plate, according to ASME Section VIII Division 1 Section UG-21(c)(1), is 7,516 psi.
    c. As 7,516 psi is less than 16,600 psi, the 1st shell course thickness is deemed acceptable and in compliance with the UL-142 and ASME Section VIII Division 1 Standards.

2. ASME Section VIII Division 1 Analysis of the 5th Shell Course:
    a. The design thickness of the 5th shell course is calculated to be a minimum of 0.0698 inches.
    b. The estimated maximum stress in the ¼" shell plate, according to ASME Section VIII Division 1 Section UG-21(c)(1), is 3,229 psi.
    c. As 3,229 psi is less than 16,600 psi, the 5th shell course thickness is deemed acceptable and in compliance with the UL-142 and ASME Section VIII Division 1 Standards.
3. API 650 Analysis of the 1st Shell Course:
    a. The design thickness of the 1st shell course is calculated to be a minimum of 0.087 inches.
    b. The estimated maximum stress in the ¼" shell plate, according to API 650 Section A.4.1, is 7,310 psi.
    c. As 7,310 psi is less than 21,000 psi, the 1st shell course thickness is deemed acceptable and in compliance with the UL-142 and API 650 Standards.
4. API 650 Analysis of the 5th Shell Course:
    a. The design thickness of the 5th shell course is calculated to be a minimum of 0.0361 inches.
    b. The estimated maximum stress in the ¼" shell plate, according to API 650 Section A.4.1, is 3,031 psi.
    c. As 3,031 psi is less than 21,000 psi, the 5th shell course thickness is deemed acceptable and in compliance with the UL-142 and API 650 Standards.

Self-Supported Roof Design - Methodology and Results:

The tank roof is engineered as a 2:12 self-supported cone roof, adhering to UL-142 Section 15.3 and Table 15.1. As UL-142 provides limited guidance on tank roof structural acceptability, additional tank codes are consulted.

A key requirement of the API 650 Standard is for the tank cone roof to be walkable by personnel and equipment. A further API 650 requirement is a rim angle at the top of the shell, a structural member not required by the UL-142 Standard. API 650 Section 5.10.2.8 permits alternate roofs designs, therefore the design loads and load combinations provided in API 650 are used with the software RISA 3D to calculate the maximum stress in the roof and shell plates in accordance with AISC 360. This stress is then compared to the allowable stress provided in the API 650 Standard to determine acceptability.

1. Design Loading:
    a. The maximum design loading for the roof load combinations provided in API 650 5.2.2(e)(1) & API 650 5.2.2(e)(1) is 36.6484 psf and includes:
        i. A minimum live load of 20 psf
        ii. A ground snow load of 29 psf
        iii. Loading due to vacuum pressure

2. Modeling:
    a. The 1/4" thick A36 cone roof, the 3/16" thick A36 upper shell course, and a 10” vent nozzle neck at roof center are modeled in RISA, with the loading applied to the horizontal projected area of the roof.
3. Stress Analysis:
    a. The maximum stress in the roof plate is calculated to be 1,082 psi, while the maximum stress in the shell plate is calculated to be 770 psi.
    b. As both stress values are less than 21,000 psi, the cone roof thickness and slope are deemed acceptable and in compliance with UL-142 and API 650 Standards.

Wind Design, Seismic Design, and Shell Buckling Check - Methodology and Results:

The wind speed design, seismic design, shell buckling checks, and anchor bolt loading are calculated using the API 650 Standard. The design wind speed of 120 mph, obtained from the design data table on the drawing, corresponds to ASCE 7-10, Risk Category III-IV, for zip code 46241. Consequently, the wind pressure applied on the shell is calculated using API 650 Section 5.2.1(k):

1. The design wind pressure according to API 650 5.9.6.1 is calculated at 23.86 psf.

To check for shell buckling due to wind pressure, the need for an intermediate wind girder is evaluated using API 650 Section 5.9.6:

1. The maximum allowable height of an unstiffened shell is calculated at 331.5 ft using the diameter, shell thickness, and design wind pressure.
2. The total transposed width of the tank shell is calculated at 29.7 ft using the width and thickness of each shell course.
3. As 29.7 ft is less than 331.5 ft, the tank does not require an intermediate wind girder for wind shell buckling.

Seismic design of the tank is based on API 650 Annex E:

1. The maximum longitudinal shell compression stress at the bottom of the shell is calculated to be 2,660 psi according to API 650 Section E.6.2.2.1-1b.
2. The maximum allowable compression stress in the shell is 6,789 psi according to API 650 Section E.6.2.2.3.
3. As 2,660 psi is less than 6,789 psi, the stress level is deemed acceptable.

Foundation and Maximum Anchor Bolt Loads - Methodology and Results:

Foundation loads and anchor bolt loads are calculated using the methodology provided API 650 Section 5.12 and API 650 Table 5.20b. Maximum net uplift for both wind and seismic loads are divided by the number of anchor bolts to estimate the maximum load per anchor. Seismic anchor loading governs the design of the anchors for this tank.

1. The maximum anchor bolt load due to seismic is calculated to be 9,157 lbs. per anchor bolt.
2. The maximum foundation loading at the top of the foundation is determined to be 2,632 psf.

Conclusions:

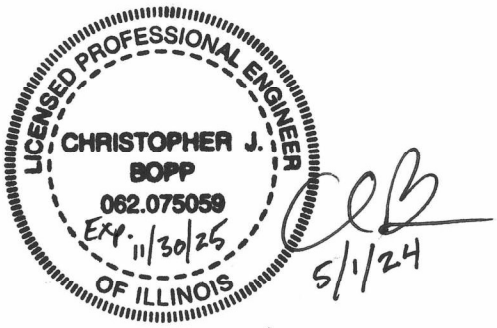
The design of two (2) 12 ft diameter by 42 ft tall carbon steel tanks were evaluated by the engineer to determine conformance and acceptability to the UL-142 Standard. Additionally, an analysis and comparison was conducted with other national standards, incorporating allowable stresses and calculations. No deficiencies were found in the design of these tanks, and they are deemed to meet the requirements of the UL-142 Standard and demonstrate compliance with relevant national standards.

Appendices:

1. Appendix 1 – Shell Thickness Calculations in accordance with ASME Section VIII Division 1
2. Appendix 2 – Shell Thickness Calculations in accordance with API 650
3. Appendix 3 – Self-Supported Roof Design in accordance with AISC 360
4. Appendix 4 – Wind Design, Seismic Design, and Shell Buckling Calculations in accordance with API 650
5. Appendix 5 – Foundation and Maximum Anchor Bolt Loading

References:

1. HERITAGE CRYSTAL CLEAN #182352 TK-56 4.26
2. HERITAGE CRYSTAL CLEAN #182352 TK-57 4.26
3. HERITAGE CRYSTAL CLEAN #182352 DETAIL 4.26
4. API 650 13th Edition
5. ASME Section VIII Division 1 2023 Edition
6. RISA 3D v.22.0.0 (AISC 360)
7. ASCE 7-22



Rich Skarvan

Digitally signed by Rich Skarvan
DN: cn=Rich Skarvan, o=Superior Engineering, ou, email=rdskarvan@supereng.com, c=US
Date: 2024.05.31 10:19:07 -05'00'

signed 5/30/2024
exp. 7/31/2024

The calculations and analysis presented in this report were conducted by Christopher J. Bopp, Illinois PE 062.075059, a professional engineer with over 7 years of experience in the design of API 650, ASME Section VIII Division 1, and UL-142 storage tanks.

Appendix 1

Shell Thickness Calculations in accordance with ASME Section VIII Division 1 – 2023 Edition

Cylinder #1

ASME Section VIII Division 1, 2023 Edition				
Component		Cylinder		
Material		SA-36 (II-D p. 12, ln. 19)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**
Internal		0.04	120	-20
External		0.04	120	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		18.19	504	1
Test horizontal		5.2	144	1
Dimensions				
Inner Diameter		144"		
Length		72"		
Nominal Thickness		0.25"		
Corrosion	**Inner**	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)	**Capacity (US gal)**	
New		2,308.47	5,076.16	
Corroded		2,308.47	5,076.16	
Radiography				
Longitudinal seam		None UW-11(c) Type 1		
Top Circumferential seam		None UW-11(c) Type 1		
Bottom Circumferential seam		None UW-11(c) Type 1		

Results Summary	
Governing condition	Internal pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.1131"
Design thickness due to external pressure (t_e)	0.0699"
Design thickness due to combined loadings + corrosion	0.0504"
Maximum allowable working pressure (MAWP)	22.07 psi
Maximum allowable pressure (MAP)	40.26 psi
Maximum allowable external pressure (MAEP)	0.86 psi
Rated MDMT	-55 °F

UCS-66 Material Toughness Requirements	
Governing thickness, t_g =	0.25"
Exemption temperature from Fig UCS-66 Curve A =	18°F
$t_r = \frac{18.25 \cdot 72}{16{,}600 \cdot 0.7 - 0.6 \cdot 18.25} =$	0.1132"
Stress ratio $= \frac{t_r \cdot E^*}{t_n - c} = \frac{0.1132 \cdot 0.8}{0.25 - 0} =$	0.3622
Stress ratio longitudinal $= \frac{1{,}079 \cdot 0.8}{16{,}600 \cdot 0.7} =$	0.0743
Reduction in MDMT, T_R from Fig UCS-66.1 =	125.9°F
$MDMT = \max[MDMT - T_R, -55] = \max[18 - 125.9, -55] =$	-55°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 120 °F) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{18.23 \cdot 72}{16{,}600 \cdot 0.70 - 0.60 \cdot 18.23} + 0 = 0.1131"$$

Maximum allowable working pressure, (at 120 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{16{,}600 \cdot 0.70 \cdot 0.25}{72 + 0.60 \cdot 0.25} - 18.19 = 22.07 \text{ psi}$$

Maximum allowable pressure, (at 70 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{16{,}600 \cdot 0.70 \cdot 0.25}{72 + 0.60 \cdot 0.25} = 40.26 \text{ psi}$$

External Pressure, (Corroded & at 120 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{518}{144.5} = 3.5848$$

$$\frac{D_o}{t} = \frac{144.5}{0.0699} = 2068.3453$$

Experimental basin formula

$$P_a = \left[2.42 \cdot \frac{E}{(1-\mu^2)^{0.75}}\right] \cdot \frac{\frac{(t/D_o)^{2.50}}{L/D_o - 0.45 \cdot (t/D_o)^{0.50}}}{3} = \left[2.42 \cdot \frac{29000000}{(1-0.30^2)^{0.75}}\right] \cdot \frac{\frac{(0.0699/144.5)^{2.50}}{518/144.5 - 0.45 \cdot (0.0699/144.5)^{0.50}}}{3} = 0.04 \text{ psi}$$

Design thickness for external pressure P_a = 0.04 psi

$$t_a = t + \text{Corrosion} = 0.0699 + 0 = 0.0699"$$

Maximum Allowable External Pressure, (Corroded & at 120 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{518}{144.5} = 3.5848$$

$$\frac{D_o}{t} = \frac{144.5}{0.25} = 578.0000$$

From table G: $A = 0.000026$

From table CS-2: $B = 374.3814 \text{ psi}$

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o/t)} = \frac{4 \cdot 374.38}{3 \cdot (144.5/0.25)} = 0.86 \text{ psi}$$

% Extreme fiber elongation - UCS-79(d)

$$EFE = \left(\frac{50 \cdot t}{R_f}\right) \cdot \left(1 - \frac{R_f}{R_o}\right) = \left(\frac{50 \cdot 0.25}{72.125}\right) \cdot \left(1 - \frac{72.125}{\infty}\right) = 0.1733\,\%$$

The extreme fiber elongation does not exceed 5%.

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = \frac{W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{15,815.3}{2 \cdot \pi \cdot 72.125} + \frac{1,343,409}{\pi \cdot 72.125^{\,2}} = 117.1017 \text{ lb/in}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = \frac{117.1017}{0.04 \cdot 144.5} = 22.5109$$

$$n = 4$$

$$m = \frac{1.23}{\left(\frac{L}{D_o}\right)^2} = \frac{1.23}{\left(\frac{518}{144.5}\right)^2} = 0.0957$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{4^2 - 1 + 0.0957 + 0.0957 \cdot 22.5109}{4^2 - 1 + 0.0957} = 1.1427$$

$$RatioP_e \cdot P_e \le \text{MAEP}$$

$$(1.1427 \cdot 0.04 = 0.04) \le 0.86$$

Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{1.02 \cdot 15,815.3}{2 \cdot \pi \cdot 72.125} + \frac{5,583,706}{\pi \cdot 72.125^{\,2}} = 377.4242 \text{ lb/in}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = \frac{377.4242}{0.04 \cdot 144.5} = 72.5537$$

$$n = 4$$

$$m = \frac{1.23}{\left(\frac{L}{D_o}\right)^2} = \frac{1.23}{\left(\frac{518}{144.5}\right)^2} = 0.0957$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{4^2 - 1 + 0.0957 + 0.0957 \cdot 72.5537}{4^2 - 1 + 0.0957} = 1.46$$

$$RatioP_e \cdot P_e \le \text{MAEP}$$

$$(1.46 \cdot 0.04 = 0.05) \le 0.86$$

Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c					
Operating, Hot & Corroded	0.04	16,600	6,260	120	0	Wind	0.0045	0.0154
						Seismic	0.0232	0.0501
Operating, Hot & New	0.04	16,600	6,260	120	0	Wind	0.0045	0.0154
						Seismic	0.0232	0.0501
Hot Shut Down, Corroded	0	16,600	6,260	120	0	Wind	0.0044	0.0156
						Seismic	0.0231	0.0502
Hot Shut Down, New	0	16,600	6,260	120	0	Wind	0.0044	0.0156
						Seismic	0.0231	0.0502
Empty, Corroded	0	16,600	6,260	70	0	Wind	0.0044	0.0156
						Seismic	0.0004	0.007
Empty, New	0	16,600	6,260	70	0	Wind	0.0044	0.0156
						Seismic	0.0004	0.007
Vacuum	-0.04	16,600	6,260	120	0	Wind	0.0043	0.0158
						Seismic	0.023	0.0504
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	16,600	6,260	120	0	Weight	0.0056	0.0056

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{72.25/0.25} = 0.000433$$

$$B = 6{,}260 \quad \text{psi}$$

$$S = \frac{16{,}600}{1.00} = 16{,}600 \quad \text{psi}$$

$$S_{cHC} = \min(B, S) = \underline{6{,}260 \text{ psi}}$$

Allowable Compressive Stress, Hot and New- S_{cHN}

$$S_c HN = S_c HC = \underline{6{,}260 \text{ psi}}$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{72.25/0.25} = 0.000433$$

$$B = 6{,}260 \quad \text{psi}$$

$$S = \frac{16{,}600}{1.00} = 16{,}600 \quad \text{psi}$$

$$S_{cCN} = \min(B, S) = \underline{6{,}260 \text{ psi}}$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

$$S_c\mathbb{C} = S_c CN = \underline{6{,}260 \text{ psi}}$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{72.25/0.25} = 0.000433$$

$$B = 6{,}260 \quad \text{psi}$$

$$S = \frac{16{,}600}{1.00} = 16{,}600 \quad \text{psi}$$

$$S_{cVC} = \min(B, S) = \underline{6{,}260 \text{ psi}}$$

Operating, Hot & Corroded, Wind, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 + 0.40 \cdot |0.04|}$

$= 0.0001"$

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{1{,}343{,}409}{\pi \cdot 72.125^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

$= 0.0059"$

$t_w = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.60*15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

$= 0.0015"$

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0.0001+0.0059-(0.0015)$

$= 0.0045"$

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 6{,}259.52 \cdot 1.20 + 0.40 \cdot |0.04|}$

$= 0.0002"$

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{1{,}343{,}409}{\pi \cdot 72.125^{\ 2} \cdot 6{,}259.52 \cdot 1.20}$

$= 0.0109"$

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 6{,}259.52 \cdot 1.20}$

$= 0.0046"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0109+(0.0046)-(0.0002)$

$= 0.0154"$

Maximum allowable working pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

$$= \frac{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 \cdot (0.25 - 0.0059 + (0.0015))}{72 - 0.40 \cdot (0.25 - 0.0059 + (0.0015))}$$

= 95.26 psi

Operating, Hot & New, Wind, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 + 0.40 \cdot |0.04|}$

$= 0.0001"$

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{1{,}343{,}409}{\pi \cdot 72.125^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

$= 0.0059"$

$t_w = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.60*15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

$= 0.0015"$

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0.0001+0.0059-(0.0015)$

$= 0.0045"$

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 6{,}259.52 \cdot 1.20 + 0.40 \cdot |0.04|}$

$= 0.0002"$

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{1{,}343{,}409}{\pi \cdot 72.125^{\ 2} \cdot 6{,}259.52 \cdot 1.20}$

$= 0.0109"$

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 6{,}259.52 \cdot 1.20}$

$= 0.0046"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0109+(0.0046)-(0.0002)$

$= 0.0154"$

Maximum allowable working pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

$$= \frac{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 \cdot (0.25 - 0.0059 + (0.0015))}{72 - 0.40 \cdot (0.25 - 0.0059 + (0.0015))}$$

= 95.26 psi

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p = 0" (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$$ (bending)

$$= \frac{1{,}343{,}409}{\pi \cdot 72.125^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$$

= 0.0059"

$$t_w = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$$ (Weight)

$$= \frac{0.60*15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$$

= 0.0015"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.0059 - (0.0015)$

= 0.0044"

$$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$$ (bending)

$$= \frac{1{,}343{,}409}{\pi \cdot 72.125^{\ 2} \cdot 6{,}259.52 \cdot 1.20}$$

= 0.0109"

$$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$$ (Weight)

$$= \frac{15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 6{,}259.52 \cdot 1.20}$$

= 0.0046"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0109 + (0.0046) - (0)$

= 0.0156"

Hot Shut Down, New, Wind, Bottom Seam

t_p = 0" (Pressure)

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

= $\frac{1,343,409}{\pi \cdot 72.125^{\ 2} \cdot 16,600 \cdot 1.20 \cdot 0.70}$

= 0.0059"

t_w = $\frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

= $\frac{0.60*15,815.3}{2 \cdot \pi \cdot 72.125 \cdot 16,600 \cdot 1.20 \cdot 0.70}$

= 0.0015"

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $0 + 0.0059 - (0.0015)$

= 0.0044"

t_{mc} = $\frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

= $\frac{1,343,409}{\pi \cdot 72.125^{\ 2} \cdot 6,259.52 \cdot 1.20}$

= 0.0109"

$t_{w\,c}$ = $\frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

= $\frac{15,815.3}{2 \cdot \pi \cdot 72.125 \cdot 6,259.52 \cdot 1.20}$

= 0.0046"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.0109 + (0.0046) - (0)$

= 0.0156"

Empty, Corroded, Wind, Bottom Seam

t_p = 0" (Pressure)

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

= $\frac{1,343,409}{\pi \cdot 72.125^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0059"

t_w = $\frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

= $\frac{0.60*15,815.3}{2 \cdot \pi \cdot 72.125 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0015"

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $0 + 0.0059 - (0.0015)$

= 0.0044"

t_{mc} = $\frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

= $\frac{1,343,409}{\pi \cdot 72.125^{\ 2} \cdot 6{,}259.52 \cdot 1.20}$

= 0.0109"

$t_{w\,c}$ = $\frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

= $\frac{15,815.3}{2 \cdot \pi \cdot 72.125 \cdot 6{,}259.52 \cdot 1.20}$

= 0.0046"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.0109 + (0.0046) - (0)$

= 0.0156"

Empty, New, Wind, Bottom Seam

t_p = 0" (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{1,343,409}{\pi \cdot 72.125^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0059"

$t_w = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.60*15,815.3}{2 \cdot \pi \cdot 72.125 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0015"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.0059 - (0.0015)$

= 0.0044"

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{1,343,409}{\pi \cdot 72.125^{\ 2} \cdot 6{,}259.52 \cdot 1.20}$

= 0.0109"

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{15,815.3}{2 \cdot \pi \cdot 72.125 \cdot 6{,}259.52 \cdot 1.20}$

= 0.0046"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0109 + (0.0046) - (0)$

= 0.0156"

Vacuum, Wind, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{-0.04 \cdot 72}{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 + 0.40 \cdot |0.04|}$

= -0.0001"

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{1{,}343{,}409}{\pi \cdot 72.125^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0059"

$t_w = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.60*15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0015"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= -0.0001 + 0.0059 - (0.0015)$

= 0.0043"

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{-0.04 \cdot 72}{2 \cdot 6{,}259.52 \cdot 1.20 + 0.40 \cdot |0.04|}$

$= -0.0002$ "

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{1{,}343{,}409}{\pi \cdot 72.125^{\ 2} \cdot 6{,}259.52 \cdot 1.20}$

= 0.0109"

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 6{,}259.52 \cdot 1.20}$

= 0.0046"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0109 + (0.0046) - (-0.0002)$

= 0.0158"

Maximum Allowable External Pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$$

$$= \frac{2 \cdot 6{,}259.52 \cdot 1.20 \cdot (0.25 - 0.0109 - 0.0046)}{72 - 0.40 \cdot (0.25 - 0.0109 - 0.0046)}$$

= 48.97 psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Bottom Seam

t_p = 0" (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$$ (bending)

$$= \frac{0}{\pi \cdot 72.125^{\ 2} \cdot 6{,}259.52 \cdot 1.00}$$

= 0"

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$$ (Weight)

$$= \frac{15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 6{,}259.52 \cdot 1.00}$$

= 0.0056"

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0 - (0.0056)|$

= 0.0056"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0 + (0.0056) - (0)$

= 0.0056"

Operating, Hot & Corroded, Seismic, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 + 0.40 \cdot |0.04|}$

= 0.0001"

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{5{,}583{,}706}{\pi \cdot 72.125^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0245"

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.58*15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0014"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0.0001 + 0.0245 - (0.0014)$

= 0.0232"

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 6{,}259.52 \cdot 1.20 + 0.40 \cdot |0.04|}$

= 0.0002"

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{5{,}583{,}706}{\pi \cdot 72.125^{\ 2} \cdot 6{,}259.52 \cdot 1.20}$

= 0.0455"

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{1.02*15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 6{,}259.52 \cdot 1.20}$

= 0.0048"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0455 + (0.0048) - (0.0002)$

= 0.0501"

Maximum allowable working pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

$$= \frac{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 \cdot (0.25 - 0.0245 + (0.0014))}{72 - 0.40 \cdot (0.25 - 0.0245 + (0.0014))}$$

= 88.01 psi

Operating, Hot & New, Seismic, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 + 0.40 \cdot |0.04|}$

$= 0.0001"$

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{5{,}583{,}706}{\pi \cdot 72.125^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

$= 0.0245"$

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.58*15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

$= 0.0014"$

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0.0001+0.0245 - (0.0014)$

$= 0.0232"$

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 6{,}259.52 \cdot 1.20 + 0.40 \cdot |0.04|}$

$= 0.0002"$

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{5{,}583{,}706}{\pi \cdot 72.125^{\ 2} \cdot 6{,}259.52 \cdot 1.20}$

$= 0.0455"$

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{1.02*15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 6{,}259.52 \cdot 1.20}$

$= 0.0048"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0455+(0.0048) - (0.0002)$

$= 0.0501"$

Maximum allowable working pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

$$= \frac{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 \cdot (0.25 - 0.0245 + (0.0014))}{72 - 0.40 \cdot (0.25 - 0.0245 + (0.0014))}$$

= 88.01 psi

Hot Shut Down, Corroded, Seismic, Bottom Seam

t_p = 0" (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$$ (bending)

$$= \frac{5{,}583{,}706}{\pi \cdot 72.125^{\,2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$$

= 0.0245"

$$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$$ (Weight)

$$= \frac{0.58{*}15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$$

= 0.0014"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.0245 - (0.0014)$

= 0.0231"

$$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$$ (bending)

$$= \frac{5{,}583{,}706}{\pi \cdot 72.125^{\,2} \cdot 6{,}259.52 \cdot 1.20}$$

= 0.0455"

$$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$$ (Weight)

$$= \frac{1.02{*}15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 6{,}259.52 \cdot 1.20}$$

= 0.0048"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0455 + (0.0048) - (0)$

= 0.0502"

Hot Shut Down, New, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

= $\frac{5,583,706}{\pi \cdot 72.125^{\ 2} \cdot 16,600 \cdot 1.20 \cdot 0.70}$

= 0.0245"

t_w = $\frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

= $\frac{0.58*15,815.3}{2 \cdot \pi \cdot 72.125 \cdot 16,600 \cdot 1.20 \cdot 0.70}$

= 0.0014"

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $0 + 0.0245 - (0.0014)$

= 0.0231"

t_{mc} = $\frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

= $\frac{5,583,706}{\pi \cdot 72.125^{\ 2} \cdot 6,259.52 \cdot 1.20}$

= 0.0455"

$t_{w\,c}$ = $\frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

= $\frac{1.02*15,815.3}{2 \cdot \pi \cdot 72.125 \cdot 6,259.52 \cdot 1.20}$

= 0.0048"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.0455 + (0.0048) - (0)$

= 0.0502"

Empty, Corroded, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

= $\frac{280,420}{\pi \cdot 72.125^{\ 2} \cdot 6,259.52 \cdot 1.20}$

= 0.0023"

t_w = $(0.6 - 0.14 \cdot S_{DS}) \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

= $\frac{0.58*15,815.3}{2 \cdot \pi \cdot 72.125 \cdot 6,259.52 \cdot 1.20}$

= 0.0027"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)

= $|0 + 0.0023 - (0.0027)|$

= 0.0004"

$t_{w\,c}$ = $\frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

= $\frac{1.02*15,815.3}{2 \cdot \pi \cdot 72.125 \cdot 6,259.52 \cdot 1.20}$

= 0.0048"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.0023+(0.0048) - (0)$

= 0.007"

Empty, New, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

= $\frac{280,420}{\pi \cdot 72.125^{\ 2} \cdot 6,259.52 \cdot 1.20}$

= 0.0023"

t_w = $(0.6 - 0.14 \cdot S_{DS}) \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

= $\frac{0.58*15,815.3}{2 \cdot \pi \cdot 72.125 \cdot 6,259.52 \cdot 1.20}$

= 0.0027"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)

= $|0 + 0.0023 - (0.0027)|$

= 0.0004"

$t_{w\,c}$ = $\frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

= $\frac{1.02*15,815.3}{2 \cdot \pi \cdot 72.125 \cdot 6,259.52 \cdot 1.20}$

= 0.0048"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.0023+(0.0048) - (0)$

= 0.007"

Vacuum, Seismic, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{-0.04 \cdot 72}{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 + 0.40 \cdot |0.04|}$

= -0.0001"

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{5{,}583{,}706}{\pi \cdot 72.125^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0245"

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.58*15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0014"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= -0.0001 + 0.0245 - (0.0014)$

= 0.023"

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{-0.04 \cdot 72}{2 \cdot 6{,}259.52 \cdot 1.20 + 0.40 \cdot |0.04|}$

$= -0.0002$ "

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{5{,}583{,}706}{\pi \cdot 72.125^{\ 2} \cdot 6{,}259.52 \cdot 1.20}$

= 0.0455"

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{1.02*15{,}815.3}{2 \cdot \pi \cdot 72.125 \cdot 6{,}259.52 \cdot 1.20}$

= 0.0048"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0455 + (0.0048) - (-0.0002)$

= 0.0504"

Maximum Allowable External Pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$$

$$= \frac{2 \cdot 6{,}259.52 \cdot 1.20 \cdot (0.25 - 0.0455 - 0.0048)}{72 - 0.40 \cdot (0.25 - 0.0455 - 0.0048)}$$

= 41.72 psi

Cylinder #5

ASME Section VIII Division 1, 2023 Edition				
Component		Cylinder		
Material		SA-36 (II-D p. 12, In. 19)		
Impact Tested	**Normalized**	**Fine Grain Practice**	**PWHT**	**Maximize MDMT/ No MAWP**
No	No	No	No	No
		Design Pressure (psi)	**Design Temperature (°F)**	**Design MDMT (°F)**
Internal		0.04	120	-20
External		0.04	120	
Static Liquid Head				
Condition		**P_s (psi)**	**H_s (in)**	**SG**
Operating		7.8	216	1
Test horizontal		5.2	144	1
Dimensions				
Inner Diameter		144"		
Length		72"		
Nominal Thickness		0.1875"		
Corrosion	**Inner**	0"		
	Outer	0"		
Weight and Capacity				
		Weight (lb)	**Capacity (US gal)**	
New		1,730.6	5,076.16	
Corroded		1,730.6	5,076.16	
Radiography				
Longitudinal seam		None UW-11(c) Type 1		
Top Circumferential seam		None UW-11(c) Type 1		
Bottom Circumferential seam		None UW-11(c) Type 1		

Results Summary	
Governing condition	External pressure
Minimum thickness per UG-16	0.0625" + 0" = 0.0625"
Design thickness due to internal pressure (t)	0.0486"
Design thickness due to external pressure (t_e)	0.0698"
Design thickness due to combined loadings + corrosion	0.0172"
Maximum allowable working pressure (MAWP)	22.42 psi
Maximum allowable pressure (MAP)	30.21 psi
Maximum allowable external pressure (MAEP)	0.43 psi
Rated MDMT	-155 °F

UCS-66 Material Toughness Requirements	
$t_r = \frac{7.86 \cdot 72}{16{,}600 \cdot 0.7 - 0.6 \cdot 7.86} =$	0.0487"
Stress ratio $= \frac{t_r \cdot E^*}{t_n - c} = \frac{0.0487 \cdot 0.8}{0.1875 - 0} =$	0.2078
Stress ratio longitudinal $= \frac{331 \cdot 0.8}{16{,}600 \cdot 0.7} =$	0.0228
Stress ratio ≤ 0.35, MDMT per UCS-66(b)(3) =	-155°F
Material is exempt from impact testing at the Design MDMT of -20°F.	

Design thickness, (at 120 °F) UG-27(c)(1)

$$t = \frac{P \cdot R}{S \cdot E - 0.60 \cdot P} + \text{Corrosion} = \frac{7.83 \cdot 72}{16{,}600 \cdot 0.70 - 0.60 \cdot 7.83} + 0 = 0.0486"$$

Maximum allowable working pressure, (at 120 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} - P_s = \frac{16{,}600 \cdot 0.70 \cdot 0.1875}{72 + 0.60 \cdot 0.1875} - 7.8 = 22.42 \text{ psi}$$

Maximum allowable pressure, (at 70 °F) UG-27(c)(1)

$$P = \frac{S \cdot E \cdot t}{R + 0.60 \cdot t} = \frac{16{,}600 \cdot 0.70 \cdot 0.1875}{72 + 0.60 \cdot 0.1875} = 30.21 \text{ psi}$$

External Pressure, (Corroded & at 120 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{518}{144.375} = 3.5879$$

$$\frac{D_o}{t} = \frac{144.375}{0.0698} = 2068.3453$$

Experimental basin formula

$$P_a = \left[2.42 \cdot \frac{E}{\left(1 - \mu^2\right)^{0.75}} \right] \cdot \frac{(t/D_o)^{2.50}}{\frac{L/D_o - 0.45 \cdot (t/D_o)^{0.50}}{3}} = \left[2.42 \cdot \frac{29000000}{\left(1 - 0.30^{\,2}\right)^{0.75}} \right] \cdot \frac{(0.0698/144.375)^{2.50}}{\frac{518/144.375 - 0.45 \cdot (0.0698/144.375)^{0.50}}{3}} = 0.04 \text{ psi}$$

Design thickness for external pressure P_a = 0.04 psi

$$t_a = t + \text{Corrosion} = 0.0698 + 0 = 0.0698"$$

Maximum Allowable External Pressure, (Corroded & at 120 °F) UG-28(c)

$$\frac{L}{D_o} = \frac{518}{144.375} = 3.5879$$

$$\frac{D_o}{t} = \frac{144.375}{0.1875} = 770.0000$$

From table G: $A = 0.000017$

From table CS-2: $B = 245.6286$ psi

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o / t)} = \frac{4 \cdot 245.63}{3 \cdot (144.375 / 0.1875)} = 0.43 \text{ psi}$$

% Extreme fiber elongation - UCS-79(d)

$$EFE = \left(\frac{50 \cdot t}{R_f} \right) \cdot \left(1 - \frac{R_f}{R_o} \right) = \left(\frac{50 \cdot 0.1875}{72.0938} \right) \cdot \left(1 - \frac{72.0938}{\infty} \right) = 0.13 \, \%$$

The extreme fiber elongation does not exceed 5%.

External Pressure + Weight + Wind Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = \frac{W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{6,581.4}{2 \cdot \pi \cdot 72.0938} + \frac{267,647}{\pi \cdot 72.0938^{\,2}} = 30.9206 \;\; \text{lb/in}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = \frac{30.9206}{0.04 \cdot 144.375} = 5.9491$$

$$n = 5$$

$$m = \frac{1.23}{\left(\frac{L}{D_o} \right)^2} = \frac{1.23}{\left(\frac{518}{144.375} \right)^2} = 0.0955$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{5^2 - 1 + 0.0955 + 0.0955 \cdot 5.9491}{5^2 - 1 + 0.0955} = 1.0236$$

$$RatioP_e \cdot P_e \le \text{MAEP}$$

$$(1.0236 \cdot 0.04 = 0.04) \le 0.43$$

Cylinder design thickness is satisfactory.

External Pressure + Weight + Seismic Loading Check (Bergman, ASME paper 54-A-104)

$$P_v = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m} + \frac{M}{\pi \cdot R_m^2} = \frac{1.02 \cdot 6,581.4}{2 \cdot \pi \cdot 72.0938} + \frac{1,317,314}{\pi \cdot 72.0938^{\,2}} = 95.5632 \;\; \text{lb/in}$$

$$\alpha = \frac{P_v}{P_e \cdot D_o} = \frac{95.5632}{0.04 \cdot 144.375} = 18.3864$$

$$n = 5$$

$$m = \frac{1.23}{\left(\frac{L}{D_o} \right)^2} = \frac{1.23}{\left(\frac{518}{144.375} \right)^2} = 0.0955$$

$$RatioP_e = \frac{n^2 - 1 + m + m \cdot \alpha}{n^2 - 1 + m} = \frac{5^2 - 1 + 0.0955 + 0.0955 \cdot 18.3864}{5^2 - 1 + 0.0955} = 1.0729$$

$$RatioP_e \cdot P_e \le \text{MAEP}$$

$$(1.0729 \cdot 0.04 = 0.04) \le 0.43$$

Cylinder design thickness is satisfactory.

Thickness Required Due to Pressure + External Loads								
Condition	Pressure P (psi)	Allowable Stress Before UG-23 Stress Increase (psi)		Temperature (°F)	Corrosion C (in)	Load	Req'd Thk Due to Tension (in)	Req'd Thk Due to Compression (in)
		S_t	S_c					
Operating, Hot & Corroded	0.04	16,600	4,705	120	0	Wind	0.0006	0.0052
						Seismic	0.0053	0.0167
Operating, Hot & New	0.04	16,600	4,705	120	0	Wind	0.0006	0.0052
						Seismic	0.0053	0.0167
Hot Shut Down, Corroded	0	16,600	4,705	120	0	Wind	0.0006	0.0055
						Seismic	0.0052	0.0169
Hot Shut Down, New	0	16,600	4,705	120	0	Wind	0.0006	0.0055
						Seismic	0.0052	0.0169
Empty, Corroded	0	16,600	4,705	70	0	Wind	0.0006	0.0055
						Seismic	0.0007	0.0035
Empty, New	0	16,600	4,705	70	0	Wind	0.0006	0.0055
						Seismic	0.0007	0.0035
Vacuum	-0.04	16,600	4,705	120	0	Wind	0.0005	0.0057
						Seismic	0.0051	0.0172
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	0	16,600	4,705	120	0	Weight	0.0031	0.0031

Allowable Compressive Stress, Hot and Corroded- S_{cHC}, (table CS-2)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{72.1875/0.1875} = 0.000325$$

$$B = 4{,}705 \quad \text{psi}$$

$$S = \frac{16{,}600}{1.00} = 16{,}600 \quad \text{psi}$$

$$S_{cHC} = \min(B, S) = 4{,}705 \text{ psi}$$

Allowable Compressive Stress, Hot and New- S_{cHN}

$$S_c HN = S_c HC = 4{,}705 \text{ psi}$$

Allowable Compressive Stress, Cold and New- S_{cCN}, (table CS-2)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{72.1875/0.1875} = 0.000325$$

$$B = 4{,}705 \quad \text{psi}$$

$$S = \frac{16{,}600}{1.00} = 16{,}600 \quad \text{psi}$$

$$S_{cCN} = \min(B, S) = 4{,}705 \text{ psi}$$

Allowable Compressive Stress, Cold and Corroded- S_{cCC}

$$S_c\mathbb{C} = S_c CN = 4{,}705 \text{ psi}$$

Allowable Compressive Stress, Vacuum and Corroded- S_{cVC}, (table CS-2)

$$A = \frac{0.125}{R_o/t} = \frac{0.125}{72.1875/0.1875} = 0.000325$$

$$B = 4{,}705 \quad \text{psi}$$

$$S = \frac{16{,}600}{1.00} = 16{,}600 \quad \text{psi}$$

$$S_{cVC} = \min(B, S) = 4{,}705 \text{ psi}$$

Operating, Hot & Corroded, Wind, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 + 0.40 \cdot |0.04|}$

$= 0.0001"$

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{267{,}647}{\pi \cdot 72.0938^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

$= 0.0012"$

$t_w = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.60*6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

$= 0.0006"$

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0.0001+0.0012 - (0.0006)$

$= 0.0006"$

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 4{,}705.04 \cdot 1.20 + 0.40 \cdot |0.04|}$

$= 0.0002"$

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{267{,}647}{\pi \cdot 72.0938^{\ 2} \cdot 4{,}705.04 \cdot 1.20}$

$= 0.0029"$

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.20}$

$= 0.0026"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0029+(0.0026) - (0.0002)$

$= 0.0052"$

Maximum allowable working pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

$$= \frac{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 \cdot (0.1875 - 0.0012 + (0.0006))}{72 - 0.40 \cdot (0.1875 - 0.0012 + (0.0006))}$$

= 72.49 psi

Operating, Hot & New, Wind, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 + 0.40 \cdot |0.04|}$

$= 0.0001"$

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{267{,}647}{\pi \cdot 72.0938^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

$= 0.0012"$

$t_w = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.60*6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

$= 0.0006"$

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0.0001+0.0012 - (0.0006)$

$= 0.0006"$

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 4{,}705.04 \cdot 1.20 + 0.40 \cdot |0.04|}$

$= 0.0002"$

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{267{,}647}{\pi \cdot 72.0938^{\ 2} \cdot 4{,}705.04 \cdot 1.20}$

$= 0.0029"$

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.20}$

$= 0.0026"$

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0029+(0.0026) - (0.0002)$

$= 0.0052"$

Maximum allowable working pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

$$= \frac{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 \cdot (0.1875 - 0.0012 + (0.0006))}{72 - 0.40 \cdot (0.1875 - 0.0012 + (0.0006))}$$

= 72.49 psi

Hot Shut Down, Corroded, Wind, Bottom Seam

t_p = 0" (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{267{,}647}{\pi \cdot 72.0938^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0012"

$t_w = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.60*6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0006"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.0012 - (0.0006)$

= 0.0006"

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{267{,}647}{\pi \cdot 72.0938^{\ 2} \cdot 4{,}705.04 \cdot 1.20}$

= 0.0029"

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.20}$

= 0.0026"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0029 + (0.0026) - (0)$

= 0.0055"

Hot Shut Down, New, Wind, Bottom Seam

t_p = 0" (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{267,647}{\pi \cdot 72.0938^{\ 2} \cdot 16,600 \cdot 1.20 \cdot 0.70}$

= 0.0012"

$t_w = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.60*6,581.4}{2 \cdot \pi \cdot 72.0938 \cdot 16,600 \cdot 1.20 \cdot 0.70}$

= 0.0006"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.0012 - (0.0006)$

= 0.0006"

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{267,647}{\pi \cdot 72.0938^{\ 2} \cdot 4,705.04 \cdot 1.20}$

= 0.0029"

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{6,581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4,705.04 \cdot 1.20}$

= 0.0026"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0029 + (0.0026) - (0)$

= 0.0055"

Empty, Corroded, Wind, Bottom Seam

t_p = 0" (Pressure)

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

= $\frac{267,647}{\pi \cdot 72.0938^{\ 2} \cdot 16,600 \cdot 1.20 \cdot 0.70}$

= 0.0012"

t_w = $\frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

= $\frac{0.60*6,581.4}{2 \cdot \pi \cdot 72.0938 \cdot 16,600 \cdot 1.20 \cdot 0.70}$

= 0.0006"

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $0 + 0.0012 - (0.0006)$

= 0.0006"

t_{mc} = $\frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

= $\frac{267,647}{\pi \cdot 72.0938^{\ 2} \cdot 4,705.04 \cdot 1.20}$

= 0.0029"

$t_{w\,c}$ = $\frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

= $\frac{6,581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4,705.04 \cdot 1.20}$

= 0.0026"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.0029 + (0.0026) - (0)$

= 0.0055"

Empty, New, Wind, Bottom Seam

t_p = 0" (Pressure)

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{267,647}{\pi \cdot 72.0938^{\ 2} \cdot 16,600 \cdot 1.20 \cdot 0.70}$

= 0.0012"

$t_w = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.60*6,581.4}{2 \cdot \pi \cdot 72.0938 \cdot 16,600 \cdot 1.20 \cdot 0.70}$

= 0.0006"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.0012 - (0.0006)$

= 0.0006"

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{267,647}{\pi \cdot 72.0938^{\ 2} \cdot 4,705.04 \cdot 1.20}$

= 0.0029"

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{6,581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4,705.04 \cdot 1.20}$

= 0.0026"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0029 + (0.0026) - (0)$

= 0.0055"

Vacuum, Wind, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{-0.04 \cdot 72}{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 + 0.40 \cdot |0.04|}$

= -0.0001"

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{267{,}647}{\pi \cdot 72.0938^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0012"

$t_w = \frac{0.6 \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.60*6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0006"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= -0.0001 + 0.0012 - (0.0006)$

= 0.0005"

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{-0.04 \cdot 72}{2 \cdot 4{,}705.04 \cdot 1.20 + 0.40 \cdot |0.04|}$

$= -0.0002$ "

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{267{,}647}{\pi \cdot 72.0938^{\ 2} \cdot 4{,}705.04 \cdot 1.20}$

= 0.0029"

$t_{w\,c} = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.20}$

= 0.0026"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0029 + (0.0026) - (-0.0002)$

= 0.0057"

Maximum Allowable External Pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$$

$$= \frac{2 \cdot 4{,}705.04 \cdot 1.20 \cdot (0.1875 - 0.0029 - 0.0026)}{72 - 0.40 \cdot (0.1875 - 0.0029 - 0.0026)}$$

= 28.58 psi

Hot Shut Down, Corroded, Weight & Eccentric Moments Only, Bottom Seam

t_p = 0" (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$$ (bending)

$$= \frac{0}{\pi \cdot 72.0938^{\ 2} \cdot 4{,}705.04 \cdot 1.00}$$

= 0"

$$t_w = \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$$ (Weight)

$$= \frac{6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.00}$$

= 0.0031"

$t_t = |t_p + t_m - t_w|$ (total, net compressive)

$= |0 + 0 - (0.0031)|$

= 0.0031"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0 + (0.0031) - (0)$

= 0.0031"

Operating, Hot & Corroded, Seismic, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 + 0.40 \cdot |0.04|}$

= 0.0001"

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{1{,}317{,}314}{\pi \cdot 72.0938^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0058"

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.58*6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0006"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0.0001 + 0.0058 - (0.0006)$

= 0.0053"

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 4{,}705.04 \cdot 1.20 + 0.40 \cdot |0.04|}$

= 0.0002"

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{1{,}317{,}314}{\pi \cdot 72.0938^{\ 2} \cdot 4{,}705.04 \cdot 1.20}$

= 0.0143"

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{1.02*6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.20}$

= 0.0026"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0143 + (0.0026) - (0.0002)$

= 0.0167"

Maximum allowable working pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

$$= \frac{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 \cdot (0.1875 - 0.0058 + (0.0006))}{72 - 0.40 \cdot (0.1875 - 0.0058 + (0.0006))}$$

= 70.69 psi

Operating, Hot & New, Seismic, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 + 0.40 \cdot |0.04|}$

= 0.0001"

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{1{,}317{,}314}{\pi \cdot 72.0938^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0058"

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.58*6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0006"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0.0001 + 0.0058 - (0.0006)$

= 0.0053"

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{0.04 \cdot 72}{2 \cdot 4{,}705.04 \cdot 1.20 + 0.40 \cdot |0.04|}$

= 0.0002"

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{1{,}317{,}314}{\pi \cdot 72.0938^{\ 2} \cdot 4{,}705.04 \cdot 1.20}$

= 0.0143"

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{1.02*6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.20}$

= 0.0026"

$t_c = t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

$= 0.0143 + (0.0026) - (0.0002)$

= 0.0167"

Maximum allowable working pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_t \cdot K_s \cdot E_c \cdot (t - t_m + t_w)}{R - 0.40 \cdot (t - t_m + t_w)}$$

$$= \frac{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 \cdot (0.1875 - 0.0058 + (0.0006))}{72 - 0.40 \cdot (0.1875 - 0.0058 + (0.0006))}$$

= 70.69 psi

Hot Shut Down, Corroded, Seismic, Bottom Seam

t_p = 0" (Pressure)

$$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$$ (bending)

$$= \frac{1{,}317{,}314}{\pi \cdot 72.0938^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$$

= 0.0058"

$$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$$ (Weight)

$$= \frac{0.58{*}6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$$

= 0.0006"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= 0 + 0.0058 - (0.0006)$

= 0.0052"

$$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$$ (bending)

$$= \frac{1{,}317{,}314}{\pi \cdot 72.0938^{\ 2} \cdot 4{,}705.04 \cdot 1.20}$$

= 0.0143"

$$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$$ (Weight)

$$= \frac{1.02{*}6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.20}$$

= 0.0026"

$t_c = t_{mc} + t_{uc} - t_{pc}$ (total required, compressive)

$= 0.0143 + (0.0026) - (0)$

= 0.0169"

Hot Shut Down, New, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

= $\frac{1,317,314}{\pi \cdot 72.0938^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0058"

t_w = $\frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

= $\frac{0.58*6,581.4}{2 \cdot \pi \cdot 72.0938 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0006"

t_t = $t_p + t_m - t_w$ (total required, tensile)

= $0 + 0.0058 - (0.0006)$

= 0.0052"

t_{mc} = $\frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

= $\frac{1,317,314}{\pi \cdot 72.0938^{\ 2} \cdot 4{,}705.04 \cdot 1.20}$

= 0.0143"

$t_{w\,c}$ = $\frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

= $\frac{1.02*6,581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.20}$

= 0.0026"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.0143 + (0.0026) - (0)$

= 0.0169"

Empty, Corroded, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

= $\frac{76,570}{\pi \cdot 72.0938^{\ 2} \cdot 4{,}705.04 \cdot 1.20}$

= 0.0008"

t_w = $(0.6 - 0.14 \cdot S_{DS}) \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

= $\frac{0.58*6,581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.20}$

= 0.0015"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)

= $|0 + 0.0008 - (0.0015)|$

= 0.0007"

$t_{w\,c}$ = $\frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

= $\frac{1.02*6,581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.20}$

= 0.0026"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.0008 + (0.0026) - (0)$

= 0.0035"

Empty, New, Seismic, Bottom Seam

t_p = 0" (Pressure)

t_m = $\frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

= $\frac{76,570}{\pi \cdot 72.0938^{\ 2} \cdot 4{,}705.04 \cdot 1.20}$

= 0.0008"

t_w = $(0.6 - 0.14 \cdot S_{DS}) \cdot \frac{W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

= $\frac{0.58*6,581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.20}$

= 0.0015"

t_t = $|t_p + t_m - t_w|$ (total, net compressive)

= $|0 + 0.0008 - (0.0015)|$

= 0.0007"

$t_{w\,c}$ = $\frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

= $\frac{1.02*6,581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.20}$

= 0.0026"

t_c = $t_{mc} + t_{wc} - t_{pc}$ (total required, compressive)

= $0.0008+(0.0026) - (0)$

= 0.0035"

Vacuum, Seismic, Bottom Seam

$t_p = \frac{P \cdot R}{2 \cdot S_t \cdot K_s \cdot E_c + 0.40 \cdot |P|}$ (Pressure)

$= \frac{-0.04 \cdot 72}{2 \cdot 16{,}600 \cdot 1.20 \cdot 0.70 + 0.40 \cdot |0.04|}$

= -0.0001"

$t_m = \frac{M}{\pi \cdot R_m^2 \cdot S_t \cdot K_s \cdot E_c}$ (bending)

$= \frac{1{,}317{,}314}{\pi \cdot 72.0938^{\ 2} \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0058"

$t_w = \frac{(0.6 - 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_t \cdot K_s \cdot E_c}$ (Weight)

$= \frac{0.58*6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 16{,}600 \cdot 1.20 \cdot 0.70}$

= 0.0006"

$t_t = t_p + t_m - t_w$ (total required, tensile)

$= -0.0001 + 0.0058 - (0.0006)$

= 0.0051"

$t_{pc} = \frac{P \cdot R}{2 \cdot S_c \cdot K_s + 0.40 \cdot |P|}$ (Pressure)

$= \frac{-0.04 \cdot 72}{2 \cdot 4{,}705.04 \cdot 1.20 + 0.40 \cdot |0.04|}$

$= -0.0002$ "

$t_{mc} = \frac{M}{\pi \cdot R_m^2 \cdot S_c \cdot K_s}$ (bending)

$= \frac{1{,}317{,}314}{\pi \cdot 72.0938^{\ 2} \cdot 4{,}705.04 \cdot 1.20}$

= 0.0143"

$t_{w\,c} = \frac{(1 + 0.14 \cdot S_{DS}) \cdot W}{2 \cdot \pi \cdot R_m \cdot S_c \cdot K_s}$ (Weight)

$= \frac{1.02*6{,}581.4}{2 \cdot \pi \cdot 72.0938 \cdot 4{,}705.04 \cdot 1.20}$

= 0.0026"

$t_c = t_{mc} + t_{uc} - t_{pc}$ (total required, compressive)

$= 0.0143 + (0.0026) - (-0.0002)$

= 0.0172"

Maximum Allowable External Pressure, Longitudinal Stress

$$P = \frac{2 \cdot S_c \cdot K_s \cdot (t - t_{mc} - t_{wc})}{R - 0.40 \cdot (t - t_{mc} - t_{wc})}$$

$$= \frac{2 \cdot 4{,}705.04 \cdot 1.20 \cdot (0.1875 - 0.0143 - 0.0026)}{72 - 0.40 \cdot (0.1875 - 0.0143 - 0.0026)}$$

= 26.78 psi

Appendix 2

Shell Thickness Calculations in accordance with API 650 – 13th Edition

Design Data

Tank Diameter	12'- 0.0000" (Inside)
Tank Height	42'- 0.0000"
High Liquid Level	42'- 0.0000"
Normal Liquid Level	42'- 0.0000"
Low Liquid Level	0'- 0.0000"
Total Capacity	35,531 gallons
	846 barrels
Working Capacity	35,531 gallons
	846 barrels
Design Standard	API-650 13th Edition, Annex J, E
Design Metal Temperature	25 °F
Operating Temperature	100 °F
Design Temperature	120 °F
Roof Live Load	20.00 psf
Ground Snow Load	29.00 psf
Roof Design Snow Load (0.84 x Ground Snow Load)	24.36 psf
Additional Roof Loads	0.00 psf
Wind:	
Velocity per ASCE 7-10 Figure 26.5-1B	120 mph
Risk Category	III
Exposure	C
Seismic:	
Site Class	D
Importance Factor	1.00
Use Group	I
Ss Value	16.80 %
S1 Value	8.90 %
Vertical Acceleration	0.08 g
Transitional Period (TL)	12

Specific Gravity	1.0000
Internal Pressure (Design).....	Atmospheric
(Operating).....	Atmospheric
Combination Factor.....	0.40
External Pressure (Design).....	1.00 inches of water
(Operating).....	Atmospheric
Combination Factor.....	0.40

Corrosion Allowance:

Bottom	0.0000 in
Shell Courses 1 - 1	0.0000 in
Courses 2 - 2	0.0000 in
Courses 3 - 7	0.0000 in
Roof	0.0000 in
Anchor Bolts	0.0000 in
Anchor Chairs	0.0000 in

All Calculations are to be in the Corroded Condition

Shell

Shell Course 01: 0.2500 in (A36) PL x 72.0000 in wide (weight: 2,309 lbs)

Shell Course 02: 0.2500 in (A36) PL x 72.0000 in wide (weight: 2,309 lbs)

Shell Course 03: 0.2500 in (A36) PL x 72.0000 in wide (weight: 2,309 lbs)

Shell Course 04: 0.2500 in (A36) PL x 72.0000 in wide (weight: 2,309 lbs)

Shell Course 05: 0.1875 in (A36) PL x 72.0000 in wide (weight: 1,732 lbs)

Shell Course 06: 0.1875 in (A36) PL x 72.0000 in wide (weight: 1,732 lbs)

Shell Course 07: 0.1875 in (A36) PL x 72.0000 in wide (weight: 1,732 lbs)

Shell Design

Per A.4.1

$$t = \frac{2.6\ (H - 1.0)D\ G}{SE} + CA$$

where
Diameter (D) = 12.0000 ft
Design Specific Gravity (G) = 1.0000
Joint Efficiency (E) = 0.70

Shell Course 01

Material Grade: A36 Shell Height: 6.0000 ft

Allowable Stress per A.4.1 (S) = 21000.0000 psi

H = 42.0000 ft

Corrosion Allowance (CA): 0.0000 in

$$t = \frac{(2.6)(42.0000 - 1.0)(12.0000)(1.0000)}{(21000.0000)(0.7000)} + 0.0000 = 0.0870 \text{ in}$$

(Per J.3.3 - min. t = 0.2360 in)
Actual t = 0.2500 in

Shell Course 02

Material Grade: A36 Shell Height: 6.0000 ft

Allowable Stress per A.4.1 (S) = 21000.0000 psi

H = 36.0000 ft

Corrosion Allowance (CA): 0.0000 in

$$t = \frac{(2.6)(36.0000 - 1.0)(12.0000)(1.0000)}{(21000.0000)(0.7000)} + 0.0000 = 0.0743 \text{ in}$$

(Per J.3.3 - min. t = 0.2360 in)
Actual t = 0.2500 in

Shell Course 03

Material Grade: A36 Shell Height: 6.0000 ft

Allowable Stress per A.4.1 (S) = 21000.0000 psi

H = 30.0000 ft

Corrosion Allowance (CA): 0.0000 in

$$t = \frac{(2.6)(30.0000 - 1.0)(12.0000)(1.0000)}{(21000.0000)(0.7000)} + 0.0000 = 0.0616 \text{ in}$$

(Per J.3.3 - min. t = 0.2360 in)
Actual t = 0.2500 in

Shell Course 04

Material Grade: A36 Shell Height: 6.0000 ft

Allowable Stress per A.4.1 (S) = 21000.0000 psi

H = 24.0000 ft

Corrosion Allowance (CA): 0.0000 in

$$t = \frac{(2.6)(24.0000 - 1.0)(12.0000)(1.0000)}{(21000.0000)(0.7000)} + 0.0000 = 0.0488 \text{ in}$$

(Per J.3.3 - min. t = 0.2360 in)
Actual t = 0.2500 in

Shell Course 05

Material Grade: A36 Shell Height: 6.0000 ft

Allowable Stress per A.4.1 (S) = 21000.0000 psi

H = 18.0000 ft

Corrosion Allowance (CA): 0.0000 in

$$t = \frac{(2.6)(18.0000 - 1.0)(12.0000)(1.0000)}{(21000.0000)(0.7000)} + 0.0000 = 0.0361 \text{ in}$$

(Per J.3.3 - min. t = 0.2360 in)
Actual t = 0.1875 in

Shell Course 5 actual thickness is less than the minimum thickness required by the standard.

Shell Course 06

Material Grade: A36 Shell Height: 6.0000 ft

Allowable Stress per A.4.1 (S) = 21000.0000 psi

H = 12.0000 ft

Corrosion Allowance (CA): 0.0000 in

$$t = \frac{(2.6)(12.0000 - 1.0)(12.0000)(1.0000)}{(21000.0000)(0.7000)} + 0.0000 = 0.0233 \text{ in}$$

(Per J.3.3 - min. t = 0.2360 in)
Actual t = 0.1875 in

Shell Course 6 actual thickness is less than the minimum thickness required by the standard.

Shell Course 07

Material Grade: A36 Shell Height: 6.0000 ft

Allowable Stress per A.4.1 (S) = 21000.0000 psi

H = 6.0000 ft

Corrosion Allowance (CA): 0.0000 in

$$t = \frac{(2.6)(6.0000 - 1.0)(12.0000)(1.0000)}{(21000.0000)(0.7000)} + 0.0000 = 0.0106 \text{ in}$$

(Per J.3.3 - min. t = 0.2360 in)
Actual t = 0.1875 in

Shell Course 7 actual thickness is less than the minimum thickness required by the standard.

Appendix 3

Self-Supported Roof Design Calculations in accordance with AISC 360

Plate Surface Loads (BLC 2 : Gravity Load per API)

	Plate Label	Direction	Magnitude [psf, F]
1	P192	Y	-36.648
2	P188	Y	-36.648
3	P187	Y	-36.648
4	P186	Y	-36.648
5	P181	Y	-36.648
6	P180	Y	-36.648
7	P179	Y	-36.648
8	P177	Y	-36.648
9	P176	Y	-36.648
10	P175	Y	-36.648
11	P173	Y	-36.648
12	P172	Y	-36.648
13	P171	Y	-36.648
14	P170	Y	-36.648
15	P166	Y	-36.648
16	P165	Y	-36.648
17	P164	Y	-36.648
18	P163	Y	-36.648
19	P162	Y	-36.648
20	P161	Y	-36.648
21	P160	Y	-36.648
22	P152	Y	-36.648
23	P151	Y	-36.648
24	P150	Y	-36.648
25	P149	Y	-36.648
26	P148	Y	-36.648
27	P147	Y	-36.648
28	P146	Y	-36.648
29	P145	Y	-36.648
30	P143	Y	-36.648
31	P140	Y	-36.648
32	P139	Y	-36.648
33	P135	Y	-36.648
34	P134	Y	-36.648
35	P133	Y	-36.648
36	P132	Y	-36.648
37	P131	Y	-36.648
38	P130	Y	-36.648
39	P94	Y	-36.648
40	P93	Y	-36.648
41	P92	Y	-36.648
42	P88	Y	-36.648
43	P85	Y	-36.648
44	P81	Y	-36.648
45	P78	Y	-36.648
46	P75	Y	-36.648
47	P71	Y	-36.648
48	P70	Y	-36.648
49	P69	Y	-36.648
50	P66	Y	-36.648
51	P65	Y	-36.648
52	P64	Y	-36.648
53	P59	Y	-36.648
54	P58	Y	-36.648
55	P55	Y	-36.648

Plate Surface Loads (BLC 2 : Gravity Load per API) (Continued)

	Plate Label	Direction	Magnitude [psf, F]
56	P54	Y	-36.648
57	P52	Y	-36.648
58	P48	Y	-36.648
59	P47	Y	-36.648
60	P43	Y	-36.648
61	P42	Y	-36.648
62	P37	Y	-36.648
63	P34	Y	-36.648
64	P33	Y	-36.648
65	P30	Y	-36.648
66	P27	Y	-36.648
67	P26	Y	-36.648
68	P23	Y	-36.648
69	P17	Y	-36.648
70	P12	Y	-36.648
71	P8	Y	-36.648
72	P5	Y	-36.648
73	P4	Y	-36.648
74	P3	Y	-36.648
75	P2	Y	-36.648
76	P99	Y	-36.648
77	P100	Y	-36.648
78	P101	Y	-36.648
79	P103	Y	-36.648
80	P104	Y	-36.648
81	P106	Y	-36.648
82	P107	Y	-36.648
83	P109	Y	-36.648
84	P112	Y	-36.648
85	P115	Y	-36.648
86	P118	Y	-36.648
87	P119	Y	-36.648
88	P121	Y	-36.648
89	P124	Y	-36.648
90	P128	Y	-36.648
91	P191	Y	-36.648
92	P189	Y	-36.648
93	P185	Y	-36.648
94	P184	Y	-36.648
95	P183	Y	-36.648
96	P182	Y	-36.648
97	P168	Y	-36.648
98	P159	Y	-36.648
99	P158	Y	-36.648
100	P156	Y	-36.648
101	P142	Y	-36.648
102	P129	Y	-36.648
103	P127	Y	-36.648
104	P125	Y	-36.648
105	P123	Y	-36.648
106	P120	Y	-36.648
107	P114	Y	-36.648
108	P157	Y	-36.648
109	P113	Y	-36.648
110	P111	Y	-36.648

Plate Surface Loads (BLC 2 : Gravity Load per API) (Continued)

	Plate Label	Direction	Magnitude [psf, F]
111	P136	Y	-36.648
112	P110	Y	-36.648
113	P108	Y	-36.648
114	P102	Y	-36.648
115	P98	Y	-36.648
116	P96	Y	-36.648
117	P95	Y	-36.648
118	P122	Y	-36.648
119	P90	Y	-36.648
120	P86	Y	-36.648
121	P141	Y	-36.648
122	P84	Y	-36.648
123	P82	Y	-36.648
124	P80	Y	-36.648
125	P91	Y	-36.648
126	P77	Y	-36.648
127	P76	Y	-36.648
128	P74	Y	-36.648
129	P72	Y	-36.648
130	P68	Y	-36.648
131	P79	Y	-36.648
132	P126	Y	-36.648
133	P67	Y	-36.648
134	P73	Y	-36.648
135	P178	Y	-36.648
136	P63	Y	-36.648
137	P190	Y	-36.648
138	P62	Y	-36.648
139	P87	Y	-36.648
140	P61	Y	-36.648
141	P60	Y	-36.648
142	P138	Y	-36.648
143	P57	Y	-36.648
144	P153	Y	-36.648
145	P154	Y	-36.648
146	P56	Y	-36.648
147	P167	Y	-36.648
148	P53	Y	-36.648
149	P83	Y	-36.648
150	P169	Y	-36.648
151	P51	Y	-36.648
152	P46	Y	-36.648
153	P174	Y	-36.648
154	P45	Y	-36.648
155	P50	Y	-36.648
156	P44	Y	-36.648
157	P41	Y	-36.648
158	P40	Y	-36.648
159	P39	Y	-36.648
160	P155	Y	-36.648
161	P38	Y	-36.648
162	P36	Y	-36.648
163	P32	Y	-36.648
164	P31	Y	-36.648
165	P144	Y	-36.648

Plate Surface Loads (BLC 2 : Gravity Load per API) (Continued)

	Plate Label	Direction	Magnitude [psf, F]
166	P28	Y	-36.648
167	P25	Y	-36.648
168	P29	Y	-36.648
169	P24	Y	-36.648
170	P35	Y	-36.648
171	P22	Y	-36.648
172	P117	Y	-36.648
173	P21	Y	-36.648
174	P116	Y	-36.648
175	P20	Y	-36.648
176	P19	Y	-36.648
177	P137	Y	-36.648
178	P18	Y	-36.648
179	P97	Y	-36.648
180	P16	Y	-36.648
181	P15	Y	-36.648
182	P89	Y	-36.648
183	P14	Y	-36.648
184	P13	Y	-36.648
185	P11	Y	-36.648
186	P49	Y	-36.648
187	P10	Y	-36.648
188	P9	Y	-36.648
189	P7	Y	-36.648
190	P6	Y	-36.648
191	P105	Y	-36.648
192	P1	Y	-36.648

Basic Load Cases

	BLC Description	Category	Y Gravity	Surface(Plate/Wall)
1	Self Weight	DL	-1	
2	Gravity Load per API	DL		192

Load Combinations

	Description	Solve	P-Delta	BLC	Factor	BLC	Factor
1	Deflection 1	Yes	Y	1	1	2	1

Load Combination Design

	Description	Service	Hot Rolled	Cold Formed	Wood	Concrete	Masonry	Aluminum	Stainless	Connection
1	Deflection 1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Node Reactions

	LC	Node Label	X [lb]	Y [lb]	Z [lb]	MX [lb-ft]	MY [lb-ft]	MZ [lb-ft]
1	1	N425	25.168	218.663	0	0	0	-10.461
2	1	N445	-17.796	218.663	17.796	7.397	0	7.397
3	1	N439	-23.252	218.663	-9.631	-4.003	0	9.665
4	1	N446	-13.982	218.663	20.926	8.698	0	5.812
5	1	N419	9.631	218.663	23.252	9.665	0	-4.003
6	1	N418	4.91	218.663	24.684	10.26	0	-2.041
7	1	N448	-4.91	218.663	24.684	10.26	0	2.041

Node Reactions (Continued)

	LC	Node Label	X [lb]	Y [lb]	Z [lb]	MX [lb-ft]	MY [lb-ft]	MZ [lb-ft]
8	1	N436	-13.982	218.663	-20.926	-8.698	0	5.812
9	1	N441	-25.168	218.663	0	0	0	10.461
10	1	N422	20.926	218.663	13.982	5.812	0	-8.698
11	1	N432	4.91	218.663	-24.684	-10.26	0	-2.041
12	1	N420	13.982	218.663	20.926	8.698	0	-5.812
13	1	N426	24.684	218.663	-4.91	-2.041	0	-10.26
14	1	N428	20.926	218.663	-13.982	-5.812	0	-8.698
15	1	N430	13.982	218.663	-20.926	-8.698	0	-5.812
16	1	N434	-4.91	218.663	-24.684	-10.26	0	2.041
17	1	N438	-20.926	218.663	-13.982	-5.812	0	8.698
18	1	N444	-20.926	218.663	13.982	5.812	0	8.698
19	1	N424	24.684	218.663	4.91	2.041	0	-10.26
20	1	N437	-17.796	218.663	-17.796	-7.397	0	7.397
21	1	N442	-24.684	218.663	4.91	2.041	0	10.26
22	1	N447	-9.631	218.663	23.252	9.665	0	4.003
23	1	N423	23.252	218.663	9.631	4.003	0	-9.665
24	1	N431	9.631	218.663	-23.252	-9.665	0	-4.003
25	1	N443	-23.252	218.663	9.631	4.003	0	9.665
26	1	N421	17.796	218.663	17.796	7.397	0	-7.397
27	1	N435	-9.631	218.663	-23.252	-9.665	0	4.003
28	1	N427	23.252	218.663	-9.631	-4.003	0	-9.665
29	1	N417	0	218.663	25.168	10.461	0	0
30	1	N429	17.796	218.663	-17.796	-7.397	0	-7.397
31	1	N440	-24.684	218.663	-4.91	-2.041	0	10.26
32	1	N433	0	218.663	-25.168	-10.461	0	0
33	1	Totals:	0	6997.207	0			
34	1	COG (in):	X: 0	Y: -5.419	Z: 0			

Plate Principal Stresses

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
1	1	P1	T	763.712	380.422	191.645	0	661.396
2			B	565.484	-681.718	623.601	0	1081.671
3	1	P2	T	763.712	380.422	191.645	0	661.396
4			B	565.484	-681.718	623.601	0	1081.671
5	1	P3	T	763.712	380.422	191.645	0	661.396
6			B	565.484	-681.718	623.601	0	1081.671
7	1	P4	T	763.712	380.422	191.645	0	661.396
8			B	565.484	-681.718	623.601	0	1081.671
9	1	P5	T	763.712	380.422	191.645	0	661.396
10			B	565.484	-681.718	623.601	0	1081.671
11	1	P6	T	763.712	380.422	191.645	0	661.396
12			B	565.484	-681.718	623.601	0	1081.671
13	1	P7	T	763.712	380.422	191.645	0	661.396
14			B	565.484	-681.718	623.601	0	1081.671
15	1	P8	T	763.712	380.422	191.645	0	661.396
16			B	565.484	-681.718	623.601	0	1081.671
17	1	P9	T	763.712	380.422	191.645	0	661.396
18			B	565.484	-681.718	623.601	0	1081.671
19	1	P10	T	763.712	380.422	191.645	0	661.396
20			B	565.484	-681.718	623.601	0	1081.671
21	1	P11	T	763.712	380.422	191.645	0	661.396
22			B	565.484	-681.718	623.601	0	1081.671
23	1	P12	T	763.712	380.422	191.645	0	661.396
24			B	565.484	-681.718	623.601	0	1081.671
25	1	P13	T	763.712	380.422	191.645	0	661.396

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
26			B	565.484	-681.718	623.601	0	1081.671
27	1	P14	T	763.712	380.422	191.645	0	661.396
28			B	565.484	-681.718	623.601	0	1081.671
29	1	P15	T	763.712	380.422	191.645	0	661.396
30			B	565.484	-681.718	623.601	0	1081.671
31	1	P16	T	763.712	380.422	191.645	0	661.396
32			B	565.484	-681.718	623.601	0	1081.671
33	1	P17	T	763.712	380.422	191.645	0	661.396
34			B	565.484	-681.718	623.601	0	1081.671
35	1	P18	T	763.712	380.422	191.645	0	661.396
36			B	565.484	-681.718	623.601	0	1081.671
37	1	P19	T	763.712	380.422	191.645	0	661.396
38			B	565.484	-681.718	623.601	0	1081.671
39	1	P20	T	763.712	380.422	191.645	0	661.396
40			B	565.484	-681.718	623.601	0	1081.671
41	1	P21	T	763.712	380.422	191.645	0	661.396
42			B	565.484	-681.718	623.601	0	1081.671
43	1	P22	T	763.712	380.422	191.645	0	661.396
44			B	565.484	-681.718	623.601	0	1081.671
45	1	P23	T	763.712	380.422	191.645	0	661.396
46			B	565.484	-681.718	623.601	0	1081.671
47	1	P24	T	763.712	380.422	191.645	0	661.396
48			B	565.484	-681.718	623.601	0	1081.671
49	1	P25	T	763.712	380.422	191.645	0	661.396
50			B	565.484	-681.718	623.601	0	1081.671
51	1	P26	T	763.712	380.422	191.645	0	661.396
52			B	565.484	-681.718	623.601	0	1081.671
53	1	P27	T	763.712	380.422	191.645	0	661.396
54			B	565.484	-681.718	623.601	0	1081.671
55	1	P28	T	763.712	380.422	191.645	0	661.396
56			B	565.484	-681.718	623.601	0	1081.671
57	1	P29	T	763.712	380.422	191.645	0	661.396
58			B	565.484	-681.718	623.601	0	1081.671
59	1	P30	T	763.712	380.422	191.645	0	661.396
60			B	565.484	-681.718	623.601	0	1081.671
61	1	P31	T	763.712	380.422	191.645	0	661.396
62			B	565.484	-681.718	623.601	0	1081.671
63	1	P32	T	763.712	380.422	191.645	0	661.396
64			B	565.484	-681.718	623.601	0	1081.671
65	1	P33	T	-454.981	-1039.935	292.477	0	902.952
66			B	610.735	134.438	238.148	1.571	555.846
67	1	P34	T	-454.981	-1039.935	292.477	0	902.952
68			B	610.735	134.438	238.148	1.571	555.846
69	1	P35	T	-454.981	-1039.935	292.477	0	902.952
70			B	610.735	134.438	238.148	1.571	555.846
71	1	P36	T	-454.981	-1039.935	292.477	0	902.952
72			B	610.735	134.438	238.148	1.571	555.846
73	1	P37	T	-454.981	-1039.935	292.477	0	902.952
74			B	610.735	134.438	238.148	1.571	555.846
75	1	P38	T	-454.981	-1039.935	292.477	0	902.952
76			B	610.735	134.438	238.148	1.571	555.846
77	1	P39	T	-454.981	-1039.935	292.477	0	902.952
78			B	610.735	134.438	238.148	1.571	555.846
79	1	P40	T	-454.981	-1039.935	292.477	0	902.952
80			B	610.735	134.438	238.148	1.571	555.846

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
81	1	P41	T	-454.981	-1039.935	292.477	0	902.952
82			B	610.735	134.438	238.148	1.571	555.846
83	1	P42	T	-454.981	-1039.935	292.477	0	902.952
84			B	610.735	134.438	238.148	1.571	555.846
85	1	P43	T	-454.981	-1039.935	292.477	0	902.952
86			B	610.735	134.438	238.148	1.571	555.846
87	1	P44	T	-454.981	-1039.935	292.477	0	902.952
88			B	610.735	134.438	238.148	1.571	555.846
89	1	P45	T	-454.981	-1039.935	292.477	0	902.952
90			B	610.735	134.438	238.148	1.571	555.846
91	1	P46	T	-454.981	-1039.935	292.477	0	902.952
92			B	610.735	134.438	238.148	1.571	555.846
93	1	P47	T	-454.981	-1039.935	292.477	0	902.952
94			B	610.735	134.438	238.148	1.571	555.846
95	1	P48	T	-454.981	-1039.935	292.477	0	902.952
96			B	610.735	134.438	238.148	1.571	555.846
97	1	P49	T	-454.981	-1039.935	292.477	0	902.952
98			B	610.735	134.438	238.148	1.571	555.846
99	1	P50	T	-454.981	-1039.935	292.477	0	902.952
100			B	610.735	134.438	238.148	1.571	555.846
101	1	P51	T	-454.981	-1039.935	292.477	0	902.952
102			B	610.735	134.438	238.148	1.571	555.846
103	1	P52	T	-454.981	-1039.935	292.477	0	902.952
104			B	610.735	134.438	238.148	1.571	555.846
105	1	P53	T	-454.981	-1039.935	292.477	0	902.952
106			B	610.735	134.438	238.148	1.571	555.846
107	1	P54	T	-454.981	-1039.935	292.477	0	902.952
108			B	610.735	134.438	238.148	1.571	555.846
109	1	P55	T	-454.981	-1039.935	292.477	0	902.952
110			B	610.735	134.438	238.148	1.571	555.846
111	1	P56	T	-454.981	-1039.935	292.477	0	902.952
112			B	610.735	134.438	238.148	1.571	555.846
113	1	P57	T	-454.981	-1039.935	292.477	0	902.952
114			B	610.735	134.438	238.148	1.571	555.846
115	1	P58	T	-454.981	-1039.935	292.477	0	902.952
116			B	610.735	134.438	238.148	1.571	555.846
117	1	P59	T	-454.981	-1039.935	292.477	0	902.952
118			B	610.735	134.438	238.148	1.571	555.846
119	1	P60	T	-454.981	-1039.935	292.477	0	902.952
120			B	610.735	134.438	238.148	1.571	555.846
121	1	P61	T	-454.981	-1039.935	292.477	0	902.952
122			B	610.735	134.438	238.148	1.571	555.846
123	1	P62	T	-454.981	-1039.935	292.477	0	902.952
124			B	610.735	134.438	238.148	1.571	555.846
125	1	P63	T	-454.981	-1039.935	292.477	0	902.952
126			B	610.735	134.438	238.148	1.571	555.846
127	1	P64	T	-454.981	-1039.935	292.477	0	902.952
128			B	610.735	134.438	238.148	1.571	555.846
129	1	P65	T	-157.76	-431.548	136.894	1.571	378.208
130			B	-157.76	-471.931	157.085	1.571	416.119
131	1	P66	T	-157.76	-431.548	136.894	1.571	378.208
132			B	-157.76	-471.931	157.085	1.571	416.119
133	1	P67	T	-157.76	-431.548	136.894	1.571	378.208
134			B	-157.76	-471.931	157.085	1.571	416.119
135	1	P68	T	-157.76	-431.548	136.894	1.571	378.208

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
136			B	-157.76	-471.931	157.085	1.571	416.119
137	1	P69	T	-157.76	-431.548	136.894	1.571	378.208
138			B	-157.76	-471.931	157.085	1.571	416.119
139	1	P70	T	-157.76	-431.548	136.894	1.571	378.208
140			B	-157.76	-471.931	157.085	1.571	416.119
141	1	P71	T	-157.76	-431.548	136.894	1.571	378.208
142			B	-157.76	-471.931	157.085	1.571	416.119
143	1	P72	T	-157.76	-431.548	136.894	1.571	378.208
144			B	-157.76	-471.931	157.085	1.571	416.119
145	1	P73	T	-157.76	-431.548	136.894	1.571	378.208
146			B	-157.76	-471.931	157.085	1.571	416.119
147	1	P74	T	-157.76	-431.548	136.894	1.571	378.208
148			B	-157.76	-471.931	157.085	1.571	416.119
149	1	P75	T	-157.76	-431.548	136.894	1.571	378.208
150			B	-157.76	-471.931	157.085	1.571	416.119
151	1	P76	T	-157.76	-431.548	136.894	1.571	378.208
152			B	-157.76	-471.931	157.085	1.571	416.119
153	1	P77	T	-157.76	-431.548	136.894	1.571	378.208
154			B	-157.76	-471.931	157.085	1.571	416.119
155	1	P78	T	-157.76	-431.548	136.894	1.571	378.208
156			B	-157.76	-471.931	157.085	1.571	416.119
157	1	P79	T	-157.76	-431.548	136.894	1.571	378.208
158			B	-157.76	-471.931	157.085	1.571	416.119
159	1	P80	T	-157.76	-431.548	136.894	1.571	378.208
160			B	-157.76	-471.931	157.085	1.571	416.119
161	1	P81	T	-157.76	-431.548	136.894	1.571	378.208
162			B	-157.76	-471.931	157.085	1.571	416.119
163	1	P82	T	-157.76	-431.548	136.894	1.571	378.208
164			B	-157.76	-471.931	157.085	1.571	416.119
165	1	P83	T	-157.76	-431.548	136.894	1.571	378.208
166			B	-157.76	-471.931	157.085	1.571	416.119
167	1	P84	T	-157.76	-431.548	136.894	1.571	378.208
168			B	-157.76	-471.931	157.085	1.571	416.119
169	1	P85	T	-157.76	-431.548	136.894	1.571	378.208
170			B	-157.76	-471.931	157.085	1.571	416.119
171	1	P86	T	-157.76	-431.548	136.894	1.571	378.208
172			B	-157.76	-471.931	157.085	1.571	416.119
173	1	P87	T	-157.76	-431.548	136.894	1.571	378.208
174			B	-157.76	-471.931	157.085	1.571	416.119
175	1	P88	T	-157.76	-431.548	136.894	1.571	378.208
176			B	-157.76	-471.931	157.085	1.571	416.119
177	1	P89	T	-157.76	-431.548	136.894	1.571	378.208
178			B	-157.76	-471.931	157.085	1.571	416.119
179	1	P90	T	-157.76	-431.548	136.894	1.571	378.208
180			B	-157.76	-471.931	157.085	1.571	416.119
181	1	P91	T	-157.76	-431.548	136.894	1.571	378.208
182			B	-157.76	-471.931	157.085	1.571	416.119
183	1	P92	T	-157.76	-431.548	136.894	1.571	378.208
184			B	-157.76	-471.931	157.085	1.571	416.119
185	1	P93	T	-157.76	-431.548	136.894	1.571	378.208
186			B	-157.76	-471.931	157.085	1.571	416.119
187	1	P94	T	-157.76	-431.548	136.894	1.571	378.208
188			B	-157.76	-471.931	157.085	1.571	416.119
189	1	P95	T	-157.76	-431.548	136.894	1.571	378.208
190			B	-157.76	-471.931	157.085	1.571	416.119

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
191	1	P96	T	-157.76	-431.548	136.894	1.571	378.208
192			B	-157.76	-471.931	157.085	1.571	416.119
193	1	P97	T	10.916	-197.038	103.977	1.571	202.717
194			B	-227.382	-289.832	31.225	1.571	264.202
195	1	P98	T	10.916	-197.038	103.977	1.571	202.717
196			B	-227.382	-289.832	31.225	1.571	264.202
197	1	P99	T	10.916	-197.038	103.977	1.571	202.717
198			B	-227.382	-289.832	31.225	1.571	264.202
199	1	P100	T	10.916	-197.038	103.977	1.571	202.717
200			B	-227.382	-289.832	31.225	1.571	264.202
201	1	P101	T	10.916	-197.038	103.977	1.571	202.717
202			B	-227.382	-289.832	31.225	1.571	264.202
203	1	P102	T	10.916	-197.038	103.977	1.571	202.717
204			B	-227.382	-289.832	31.225	1.571	264.202
205	1	P103	T	10.916	-197.038	103.977	1.571	202.717
206			B	-227.382	-289.832	31.225	1.571	264.202
207	1	P104	T	10.916	-197.038	103.977	1.571	202.717
208			B	-227.382	-289.832	31.225	1.571	264.202
209	1	P105	T	10.916	-197.038	103.977	1.571	202.717
210			B	-227.382	-289.832	31.225	1.571	264.202
211	1	P106	T	10.916	-197.038	103.977	1.571	202.717
212			B	-227.382	-289.832	31.225	1.571	264.202
213	1	P107	T	10.916	-197.038	103.977	1.571	202.717
214			B	-227.382	-289.832	31.225	1.571	264.202
215	1	P108	T	10.916	-197.038	103.977	1.571	202.717
216			B	-227.382	-289.832	31.225	1.571	264.202
217	1	P109	T	10.916	-197.038	103.977	1.571	202.717
218			B	-227.382	-289.832	31.225	1.571	264.202
219	1	P110	T	10.916	-197.038	103.977	1.571	202.717
220			B	-227.382	-289.832	31.225	1.571	264.202
221	1	P111	T	10.916	-197.038	103.977	1.571	202.717
222			B	-227.382	-289.832	31.225	1.571	264.202
223	1	P112	T	10.916	-197.038	103.977	1.571	202.717
224			B	-227.382	-289.832	31.225	1.571	264.202
225	1	P113	T	10.916	-197.038	103.977	1.571	202.717
226			B	-227.382	-289.832	31.225	1.571	264.202
227	1	P114	T	10.916	-197.038	103.977	1.571	202.717
228			B	-227.382	-289.832	31.225	1.571	264.202
229	1	P115	T	10.916	-197.038	103.977	1.571	202.717
230			B	-227.382	-289.832	31.225	1.571	264.202
231	1	P116	T	10.916	-197.038	103.977	1.571	202.717
232			B	-227.382	-289.832	31.225	1.571	264.202
233	1	P117	T	10.916	-197.038	103.977	1.571	202.717
234			B	-227.382	-289.832	31.225	1.571	264.202
235	1	P118	T	10.916	-197.038	103.977	1.571	202.717
236			B	-227.382	-289.832	31.225	1.571	264.202
237	1	P119	T	10.916	-197.038	103.977	1.571	202.717
238			B	-227.382	-289.832	31.225	1.571	264.202
239	1	P120	T	10.916	-197.038	103.977	1.571	202.717
240			B	-227.382	-289.832	31.225	1.571	264.202
241	1	P121	T	10.916	-197.038	103.977	1.571	202.717
242			B	-227.382	-289.832	31.225	1.571	264.202
243	1	P122	T	10.916	-197.038	103.977	1.571	202.717
244			B	-227.382	-289.832	31.225	1.571	264.202
245	1	P123	T	10.916	-197.038	103.977	1.571	202.717

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
246			B	-227.382	-289.832	31.225	1.571	264.202
247	1	P124	T	10.916	-197.038	103.977	1.571	202.717
248			B	-227.382	-289.832	31.225	1.571	264.202
249	1	P125	T	10.916	-197.038	103.977	1.571	202.717
250			B	-227.382	-289.832	31.225	1.571	264.202
251	1	P126	T	10.916	-197.038	103.977	1.571	202.717
252			B	-227.382	-289.832	31.225	1.571	264.202
253	1	P127	T	10.916	-197.038	103.977	1.571	202.717
254			B	-227.382	-289.832	31.225	1.571	264.202
255	1	P128	T	10.916	-197.038	103.977	1.571	202.717
256			B	-227.382	-289.832	31.225	1.571	264.202
257	1	P129	T	-118.097	-154.264	18.084	1.571	139.736
258			B	-38.154	-154.264	58.055	1.571	139.167
259	1	P130	T	-118.097	-154.264	18.084	1.571	139.736
260			B	-38.154	-154.264	58.055	1.571	139.167
261	1	P131	T	-118.097	-154.264	18.084	1.571	139.736
262			B	-38.154	-154.264	58.055	1.571	139.167
263	1	P132	T	-118.097	-154.264	18.084	1.571	139.736
264			B	-38.154	-154.264	58.055	1.571	139.167
265	1	P133	T	-118.097	-154.264	18.084	1.571	139.736
266			B	-38.154	-154.264	58.055	1.571	139.167
267	1	P134	T	-118.097	-154.264	18.084	1.571	139.736
268			B	-38.154	-154.264	58.055	1.571	139.167
269	1	P135	T	-118.097	-154.264	18.084	1.571	139.736
270			B	-38.154	-154.264	58.055	1.571	139.167
271	1	P136	T	-118.097	-154.264	18.084	1.571	139.736
272			B	-38.154	-154.264	58.055	1.571	139.167
273	1	P137	T	-118.097	-154.264	18.084	1.571	139.736
274			B	-38.154	-154.264	58.055	1.571	139.167
275	1	P138	T	-118.097	-154.264	18.084	1.571	139.736
276			B	-38.154	-154.264	58.055	1.571	139.167
277	1	P139	T	-118.097	-154.264	18.084	1.571	139.736
278			B	-38.154	-154.264	58.055	1.571	139.167
279	1	P140	T	-118.097	-154.264	18.084	1.571	139.736
280			B	-38.154	-154.264	58.055	1.571	139.167
281	1	P141	T	-118.097	-154.264	18.084	1.571	139.736
282			B	-38.154	-154.264	58.055	1.571	139.167
283	1	P142	T	-118.097	-154.264	18.084	1.571	139.736
284			B	-38.154	-154.264	58.055	1.571	139.167
285	1	P143	T	-118.097	-154.264	18.084	1.571	139.736
286			B	-38.154	-154.264	58.055	1.571	139.167
287	1	P144	T	-118.097	-154.264	18.084	1.571	139.736
288			B	-38.154	-154.264	58.055	1.571	139.167
289	1	P145	T	-118.097	-154.264	18.084	1.571	139.736
290			B	-38.154	-154.264	58.055	1.571	139.167
291	1	P146	T	-118.097	-154.264	18.084	1.571	139.736
292			B	-38.154	-154.264	58.055	1.571	139.167
293	1	P147	T	-118.097	-154.264	18.084	1.571	139.736
294			B	-38.154	-154.264	58.055	1.571	139.167
295	1	P148	T	-118.097	-154.264	18.084	1.571	139.736
296			B	-38.154	-154.264	58.055	1.571	139.167
297	1	P149	T	-118.097	-154.264	18.084	1.571	139.736
298			B	-38.154	-154.264	58.055	1.571	139.167
299	1	P150	T	-118.097	-154.264	18.084	1.571	139.736
300			B	-38.154	-154.264	58.055	1.571	139.167

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
301	1	P151	T	-118.097	-154.264	18.084	1.571	139.736
302			B	-38.154	-154.264	58.055	1.571	139.167
303	1	P152	T	-118.097	-154.264	18.084	1.571	139.736
304			B	-38.154	-154.264	58.055	1.571	139.167
305	1	P153	T	-118.097	-154.264	18.084	1.571	139.736
306			B	-38.154	-154.264	58.055	1.571	139.167
307	1	P154	T	-118.097	-154.264	18.084	1.571	139.736
308			B	-38.154	-154.264	58.055	1.571	139.167
309	1	P155	T	-118.097	-154.264	18.084	1.571	139.736
310			B	-38.154	-154.264	58.055	1.571	139.167
311	1	P156	T	-118.097	-154.264	18.084	1.571	139.736
312			B	-38.154	-154.264	58.055	1.571	139.167
313	1	P157	T	-118.097	-154.264	18.084	1.571	139.736
314			B	-38.154	-154.264	58.055	1.571	139.167
315	1	P158	T	-118.097	-154.264	18.084	1.571	139.736
316			B	-38.154	-154.264	58.055	1.571	139.167
317	1	P159	T	-118.097	-154.264	18.084	1.571	139.736
318			B	-38.154	-154.264	58.055	1.571	139.167
319	1	P160	T	-118.097	-154.264	18.084	1.571	139.736
320			B	-38.154	-154.264	58.055	1.571	139.167
321	1	P161	T	-9.514	-85.272	37.879	1.571	80.936
322			B	-70.812	-118.43	23.809	1.571	103.217
323	1	P162	T	-9.514	-85.272	37.879	1.571	80.936
324			B	-70.812	-118.43	23.809	1.571	103.217
325	1	P163	T	-9.514	-85.272	37.879	1.571	80.936
326			B	-70.812	-118.43	23.809	1.571	103.217
327	1	P164	T	-9.514	-85.272	37.879	1.571	80.936
328			B	-70.812	-118.43	23.809	1.571	103.217
329	1	P165	T	-9.514	-85.272	37.879	1.571	80.936
330			B	-70.812	-118.43	23.809	1.571	103.217
331	1	P166	T	-9.514	-85.272	37.879	1.571	80.936
332			B	-70.812	-118.43	23.809	1.571	103.217
333	1	P167	T	-9.514	-85.272	37.879	1.571	80.936
334			B	-70.812	-118.43	23.809	1.571	103.217
335	1	P168	T	-9.514	-85.272	37.879	1.571	80.936
336			B	-70.812	-118.43	23.809	1.571	103.217
337	1	P169	T	-9.514	-85.272	37.879	1.571	80.936
338			B	-70.812	-118.43	23.809	1.571	103.217
339	1	P170	T	-9.514	-85.272	37.879	1.571	80.936
340			B	-70.812	-118.43	23.809	1.571	103.217
341	1	P171	T	-9.514	-85.272	37.879	1.571	80.936
342			B	-70.812	-118.43	23.809	1.571	103.217
343	1	P172	T	-9.514	-85.272	37.879	1.571	80.936
344			B	-70.812	-118.43	23.809	1.571	103.217
345	1	P173	T	-9.514	-85.272	37.879	1.571	80.936
346			B	-70.812	-118.43	23.809	1.571	103.217
347	1	P174	T	-9.514	-85.272	37.879	1.571	80.936
348			B	-70.812	-118.43	23.809	1.571	103.217
349	1	P175	T	-9.514	-85.272	37.879	1.571	80.936
350			B	-70.812	-118.43	23.809	1.571	103.217
351	1	P176	T	-9.514	-85.272	37.879	1.571	80.936
352			B	-70.812	-118.43	23.809	1.571	103.217
353	1	P177	T	-9.514	-85.272	37.879	1.571	80.936
354			B	-70.812	-118.43	23.809	1.571	103.217
355	1	P178	T	-9.514	-85.272	37.879	1.571	80.936

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
356			B	-70.812	-118.43	23.809	1.571	103.217
357	1	P179	T	-9.514	-85.272	37.879	1.571	80.936
358			B	-70.812	-118.43	23.809	1.571	103.217
359	1	P180	T	-9.514	-85.272	37.879	1.571	80.936
360			B	-70.812	-118.43	23.809	1.571	103.217
361	1	P181	T	-9.514	-85.272	37.879	1.571	80.936
362			B	-70.812	-118.43	23.809	1.571	103.217
363	1	P182	T	-9.514	-85.272	37.879	1.571	80.936
364			B	-70.812	-118.43	23.809	1.571	103.217
365	1	P183	T	-9.514	-85.272	37.879	1.571	80.936
366			B	-70.812	-118.43	23.809	1.571	103.217
367	1	P184	T	-9.514	-85.272	37.879	1.571	80.936
368			B	-70.812	-118.43	23.809	1.571	103.217
369	1	P185	T	-9.514	-85.272	37.879	1.571	80.936
370			B	-70.812	-118.43	23.809	1.571	103.217
371	1	P186	T	-9.514	-85.272	37.879	1.571	80.936
372			B	-70.812	-118.43	23.809	1.571	103.217
373	1	P187	T	-9.514	-85.272	37.879	1.571	80.936
374			B	-70.812	-118.43	23.809	1.571	103.217
375	1	P188	T	-9.514	-85.272	37.879	1.571	80.936
376			B	-70.812	-118.43	23.809	1.571	103.217
377	1	P189	T	-9.514	-85.272	37.879	1.571	80.936
378			B	-70.812	-118.43	23.809	1.571	103.217
379	1	P190	T	-9.514	-85.272	37.879	1.571	80.936
380			B	-70.812	-118.43	23.809	1.571	103.217
381	1	P191	T	-9.514	-85.272	37.879	1.571	80.936
382			B	-70.812	-118.43	23.809	1.571	103.217
383	1	P192	T	-9.514	-85.272	37.879	1.571	80.936
384			B	-70.812	-118.43	23.809	1.571	103.217
385	1	P193	T	520.789	-362.501	441.645	0	769.035
386			B	699.945	234.683	232.631	0	617.036
387	1	P194	T	520.789	-362.501	441.645	0	769.035
388			B	699.945	234.683	232.631	0	617.036
389	1	P195	T	520.789	-362.501	441.645	0	769.035
390			B	699.945	234.683	232.631	0	617.036
391	1	P196	T	520.789	-362.501	441.645	0	769.035
392			B	699.945	234.683	232.631	0	617.036
393	1	P197	T	520.789	-362.501	441.645	0	769.035
394			B	699.945	234.683	232.631	0	617.036
395	1	P198	T	520.789	-362.501	441.645	0	769.035
396			B	699.945	234.683	232.631	0	617.036
397	1	P199	T	520.789	-362.501	441.645	0	769.035
398			B	699.945	234.683	232.631	0	617.036
399	1	P200	T	520.789	-362.501	441.645	0	769.035
400			B	699.945	234.683	232.631	0	617.036
401	1	P201	T	520.789	-362.501	441.645	0	769.035
402			B	699.945	234.683	232.631	0	617.036
403	1	P202	T	520.789	-362.501	441.645	0	769.035
404			B	699.945	234.683	232.631	0	617.036
405	1	P203	T	520.789	-362.501	441.645	0	769.035
406			B	699.945	234.683	232.631	0	617.036
407	1	P204	T	520.789	-362.501	441.645	0	769.035
408			B	699.945	234.683	232.631	0	617.036
409	1	P205	T	520.789	-362.501	441.645	0	769.035
410			B	699.945	234.683	232.631	0	617.036

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
411	1	P206	T	520.789	-362.501	441.645	0	769.035
412			B	699.945	234.683	232.631	0	617.036
413	1	P207	T	520.789	-362.501	441.645	0	769.035
414			B	699.945	234.683	232.631	0	617.036
415	1	P208	T	520.789	-362.501	441.645	0	769.035
416			B	699.945	234.683	232.631	0	617.036
417	1	P209	T	520.789	-362.501	441.645	0	769.035
418			B	699.945	234.683	232.631	0	617.036
419	1	P210	T	520.789	-362.501	441.645	0	769.035
420			B	699.945	234.683	232.631	0	617.036
421	1	P211	T	520.789	-362.501	441.645	0	769.035
422			B	699.945	234.683	232.631	0	617.036
423	1	P212	T	520.789	-362.501	441.645	0	769.035
424			B	699.945	234.683	232.631	0	617.036
425	1	P213	T	520.789	-362.501	441.645	0	769.035
426			B	699.945	234.683	232.631	0	617.036
427	1	P214	T	520.789	-362.501	441.645	0	769.035
428			B	699.945	234.683	232.631	0	617.036
429	1	P215	T	520.789	-362.501	441.645	0	769.035
430			B	699.945	234.683	232.631	0	617.036
431	1	P216	T	520.789	-362.501	441.645	0	769.035
432			B	699.945	234.683	232.631	0	617.036
433	1	P217	T	520.789	-362.501	441.645	0	769.035
434			B	699.945	234.683	232.631	0	617.036
435	1	P218	T	520.789	-362.501	441.645	0	769.035
436			B	699.945	234.683	232.631	0	617.036
437	1	P219	T	520.789	-362.501	441.645	0	769.035
438			B	699.945	234.683	232.631	0	617.036
439	1	P220	T	520.789	-362.501	441.645	0	769.035
440			B	699.945	234.683	232.631	0	617.036
441	1	P221	T	520.789	-362.501	441.645	0	769.035
442			B	699.945	234.683	232.631	0	617.036
443	1	P222	T	520.789	-362.501	441.645	0	769.035
444			B	699.945	234.683	232.631	0	617.036
445	1	P223	T	520.789	-362.501	441.645	0	769.035
446			B	699.945	234.683	232.631	0	617.036
447	1	P224	T	520.789	-362.501	441.645	0	769.035
448			B	699.945	234.683	232.631	0	617.036
449	1	P225	T	284.432	42.774	120.829	1.571	265.64
450			B	-168.272	-419.056	125.392	0	365.251
451	1	P226	T	284.432	42.774	120.829	1.571	265.64
452			B	-168.272	-419.056	125.392	0	365.251
453	1	P227	T	284.432	42.774	120.829	1.571	265.64
454			B	-168.272	-419.056	125.392	0	365.251
455	1	P228	T	284.432	42.774	120.829	1.571	265.64
456			B	-168.272	-419.056	125.392	0	365.251
457	1	P229	T	284.432	42.774	120.829	1.571	265.64
458			B	-168.272	-419.056	125.392	0	365.251
459	1	P230	T	284.432	42.774	120.829	1.571	265.64
460			B	-168.272	-419.056	125.392	0	365.251
461	1	P231	T	284.432	42.774	120.829	1.571	265.64
462			B	-168.272	-419.056	125.392	0	365.251
463	1	P232	T	284.432	42.774	120.829	1.571	265.64
464			B	-168.272	-419.056	125.392	0	365.251
465	1	P233	T	284.432	42.774	120.829	1.571	265.64

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
466			B	-168.272	-419.056	125.392	0	365.251
467	1	P234	T	284.432	42.774	120.829	1.571	265.64
468			B	-168.272	-419.056	125.392	0	365.251
469	1	P235	T	284.432	42.774	120.829	1.571	265.64
470			B	-168.272	-419.056	125.392	0	365.251
471	1	P236	T	284.432	42.774	120.829	1.571	265.64
472			B	-168.272	-419.056	125.392	0	365.251
473	1	P237	T	284.432	42.774	120.829	1.571	265.64
474			B	-168.272	-419.056	125.392	0	365.251
475	1	P238	T	284.432	42.774	120.829	1.571	265.64
476			B	-168.272	-419.056	125.392	0	365.251
477	1	P239	T	284.432	42.774	120.829	1.571	265.64
478			B	-168.272	-419.056	125.392	0	365.251
479	1	P240	T	284.432	42.774	120.829	1.571	265.64
480			B	-168.272	-419.056	125.392	0	365.251
481	1	P241	T	284.432	42.774	120.829	1.571	265.64
482			B	-168.272	-419.056	125.392	0	365.251
483	1	P242	T	284.432	42.774	120.829	1.571	265.64
484			B	-168.272	-419.056	125.392	0	365.251
485	1	P243	T	284.432	42.774	120.829	1.571	265.64
486			B	-168.272	-419.056	125.392	0	365.251
487	1	P244	T	284.432	42.774	120.829	1.571	265.64
488			B	-168.272	-419.056	125.392	0	365.251
489	1	P245	T	284.432	42.774	120.829	1.571	265.64
490			B	-168.272	-419.056	125.392	0	365.251
491	1	P246	T	284.432	42.774	120.829	1.571	265.64
492			B	-168.272	-419.056	125.392	0	365.251
493	1	P247	T	284.432	42.774	120.829	1.571	265.64
494			B	-168.272	-419.056	125.392	0	365.251
495	1	P248	T	284.432	42.774	120.829	1.571	265.64
496			B	-168.272	-419.056	125.392	0	365.251
497	1	P249	T	284.432	42.774	120.829	1.571	265.64
498			B	-168.272	-419.056	125.392	0	365.251
499	1	P250	T	284.432	42.774	120.829	1.571	265.64
500			B	-168.272	-419.056	125.392	0	365.251
501	1	P251	T	284.432	42.774	120.829	1.571	265.64
502			B	-168.272	-419.056	125.392	0	365.251
503	1	P252	T	284.432	42.774	120.829	1.571	265.64
504			B	-168.272	-419.056	125.392	0	365.251
505	1	P253	T	284.432	42.774	120.829	1.571	265.64
506			B	-168.272	-419.056	125.392	0	365.251
507	1	P254	T	284.432	42.774	120.829	1.571	265.64
508			B	-168.272	-419.056	125.392	0	365.251
509	1	P255	T	284.432	42.774	120.829	1.571	265.64
510			B	-168.272	-419.056	125.392	0	365.251
511	1	P256	T	284.432	42.774	120.829	1.571	265.64
512			B	-168.272	-419.056	125.392	0	365.251
513	1	P257	T	-91.264	-327.975	118.355	0	293.197
514			B	186.545	63.092	61.727	1.571	164.348
515	1	P258	T	-91.264	-327.975	118.355	0	293.197
516			B	186.545	63.092	61.727	1.571	164.348
517	1	P259	T	-91.264	-327.975	118.355	0	293.197
518			B	186.545	63.092	61.727	1.571	164.348
519	1	P260	T	-91.264	-327.975	118.355	0	293.197
520			B	186.545	63.092	61.727	1.571	164.348

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
521	1	P261	T	-91.264	-327.975	118.355	0	293.197
522			B	186.545	63.092	61.727	1.571	164.348
523	1	P262	T	-91.264	-327.975	118.355	0	293.197
524			B	186.545	63.092	61.727	1.571	164.348
525	1	P263	T	-91.264	-327.975	118.355	0	293.197
526			B	186.545	63.092	61.727	1.571	164.348
527	1	P264	T	-91.264	-327.975	118.355	0	293.197
528			B	186.545	63.092	61.727	1.571	164.348
529	1	P265	T	-91.264	-327.975	118.355	0	293.197
530			B	186.545	63.092	61.727	1.571	164.348
531	1	P266	T	-91.264	-327.975	118.355	0	293.197
532			B	186.545	63.092	61.727	1.571	164.348
533	1	P267	T	-91.264	-327.975	118.355	0	293.197
534			B	186.545	63.092	61.727	1.571	164.348
535	1	P268	T	-91.264	-327.975	118.355	0	293.197
536			B	186.545	63.092	61.727	1.571	164.348
537	1	P269	T	-91.264	-327.975	118.355	0	293.197
538			B	186.545	63.092	61.727	1.571	164.348
539	1	P270	T	-91.264	-327.975	118.355	0	293.197
540			B	186.545	63.092	61.727	1.571	164.348
541	1	P271	T	-91.264	-327.975	118.355	0	293.197
542			B	186.545	63.092	61.727	1.571	164.348
543	1	P272	T	-91.264	-327.975	118.355	0	293.197
544			B	186.545	63.092	61.727	1.571	164.348
545	1	P273	T	-91.264	-327.975	118.355	0	293.197
546			B	186.545	63.092	61.727	1.571	164.348
547	1	P274	T	-91.264	-327.975	118.355	0	293.197
548			B	186.545	63.092	61.727	1.571	164.348
549	1	P275	T	-91.264	-327.975	118.355	0	293.197
550			B	186.545	63.092	61.727	1.571	164.348
551	1	P276	T	-91.264	-327.975	118.355	0	293.197
552			B	186.545	63.092	61.727	1.571	164.348
553	1	P277	T	-91.264	-327.975	118.355	0	293.197
554			B	186.545	63.092	61.727	1.571	164.348
555	1	P278	T	-91.264	-327.975	118.355	0	293.197
556			B	186.545	63.092	61.727	1.571	164.348
557	1	P279	T	-91.264	-327.975	118.355	0	293.197
558			B	186.545	63.092	61.727	1.571	164.348
559	1	P280	T	-91.264	-327.975	118.355	0	293.197
560			B	186.545	63.092	61.727	1.571	164.348
561	1	P281	T	-91.264	-327.975	118.355	0	293.197
562			B	186.545	63.092	61.727	1.571	164.348
563	1	P282	T	-91.264	-327.975	118.355	0	293.197
564			B	186.545	63.092	61.727	1.571	164.348
565	1	P283	T	-91.264	-327.975	118.355	0	293.197
566			B	186.545	63.092	61.727	1.571	164.348
567	1	P284	T	-91.264	-327.975	118.355	0	293.197
568			B	186.545	63.092	61.727	1.571	164.348
569	1	P285	T	-91.264	-327.975	118.355	0	293.197
570			B	186.545	63.092	61.727	1.571	164.348
571	1	P286	T	-91.264	-327.975	118.355	0	293.197
572			B	186.545	63.092	61.727	1.571	164.348
573	1	P287	T	-91.264	-327.975	118.355	0	293.197
574			B	186.545	63.092	61.727	1.571	164.348
575	1	P288	T	-91.264	-327.975	118.355	0	293.197

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
576			B	186.545	63.092	61.727	1.571	164.348
577	1	P289	T	85.585	66.044	9.771	1.571	77.681
578			B	-29.778	-233.821	102.021	0	220.445
579	1	P290	T	85.585	66.044	9.771	1.571	77.681
580			B	-29.778	-233.821	102.021	0	220.445
581	1	P291	T	85.585	66.044	9.771	1.571	77.681
582			B	-29.778	-233.821	102.021	0	220.445
583	1	P292	T	85.585	66.044	9.771	1.571	77.681
584			B	-29.778	-233.821	102.021	0	220.445
585	1	P293	T	85.585	66.044	9.771	1.571	77.681
586			B	-29.778	-233.821	102.021	0	220.445
587	1	P294	T	85.585	66.044	9.771	1.571	77.681
588			B	-29.778	-233.821	102.021	0	220.445
589	1	P295	T	85.585	66.044	9.771	1.571	77.681
590			B	-29.778	-233.821	102.021	0	220.445
591	1	P296	T	85.585	66.044	9.771	1.571	77.681
592			B	-29.778	-233.821	102.021	0	220.445
593	1	P297	T	85.585	66.044	9.771	1.571	77.681
594			B	-29.778	-233.821	102.021	0	220.445
595	1	P298	T	85.585	66.044	9.771	1.571	77.681
596			B	-29.778	-233.821	102.021	0	220.445
597	1	P299	T	85.585	66.044	9.771	1.571	77.681
598			B	-29.778	-233.821	102.021	0	220.445
599	1	P300	T	85.585	66.044	9.771	1.571	77.681
600			B	-29.778	-233.821	102.021	0	220.445
601	1	P301	T	85.585	66.044	9.771	1.571	77.681
602			B	-29.778	-233.821	102.021	0	220.445
603	1	P302	T	85.585	66.044	9.771	1.571	77.681
604			B	-29.778	-233.821	102.021	0	220.445
605	1	P303	T	85.585	66.044	9.771	1.571	77.681
606			B	-29.778	-233.821	102.021	0	220.445
607	1	P304	T	85.585	66.044	9.771	1.571	77.681
608			B	-29.778	-233.821	102.021	0	220.445
609	1	P305	T	85.585	66.044	9.771	1.571	77.681
610			B	-29.778	-233.821	102.021	0	220.445
611	1	P306	T	85.585	66.044	9.771	1.571	77.681
612			B	-29.778	-233.821	102.021	0	220.445
613	1	P307	T	85.585	66.044	9.771	1.571	77.681
614			B	-29.778	-233.821	102.021	0	220.445
615	1	P308	T	85.585	66.044	9.771	1.571	77.681
616			B	-29.778	-233.821	102.021	0	220.445
617	1	P309	T	85.585	66.044	9.771	1.571	77.681
618			B	-29.778	-233.821	102.021	0	220.445
619	1	P310	T	85.585	66.044	9.771	1.571	77.681
620			B	-29.778	-233.821	102.021	0	220.445
621	1	P311	T	85.585	66.044	9.771	1.571	77.681
622			B	-29.778	-233.821	102.021	0	220.445
623	1	P312	T	85.585	66.044	9.771	1.571	77.681
624			B	-29.778	-233.821	102.021	0	220.445
625	1	P313	T	85.585	66.044	9.771	1.571	77.681
626			B	-29.778	-233.821	102.021	0	220.445
627	1	P314	T	85.585	66.044	9.771	1.571	77.681
628			B	-29.778	-233.821	102.021	0	220.445
629	1	P315	T	85.585	66.044	9.771	1.571	77.681
630			B	-29.778	-233.821	102.021	0	220.445

Plate Principal Stresses (Continued)

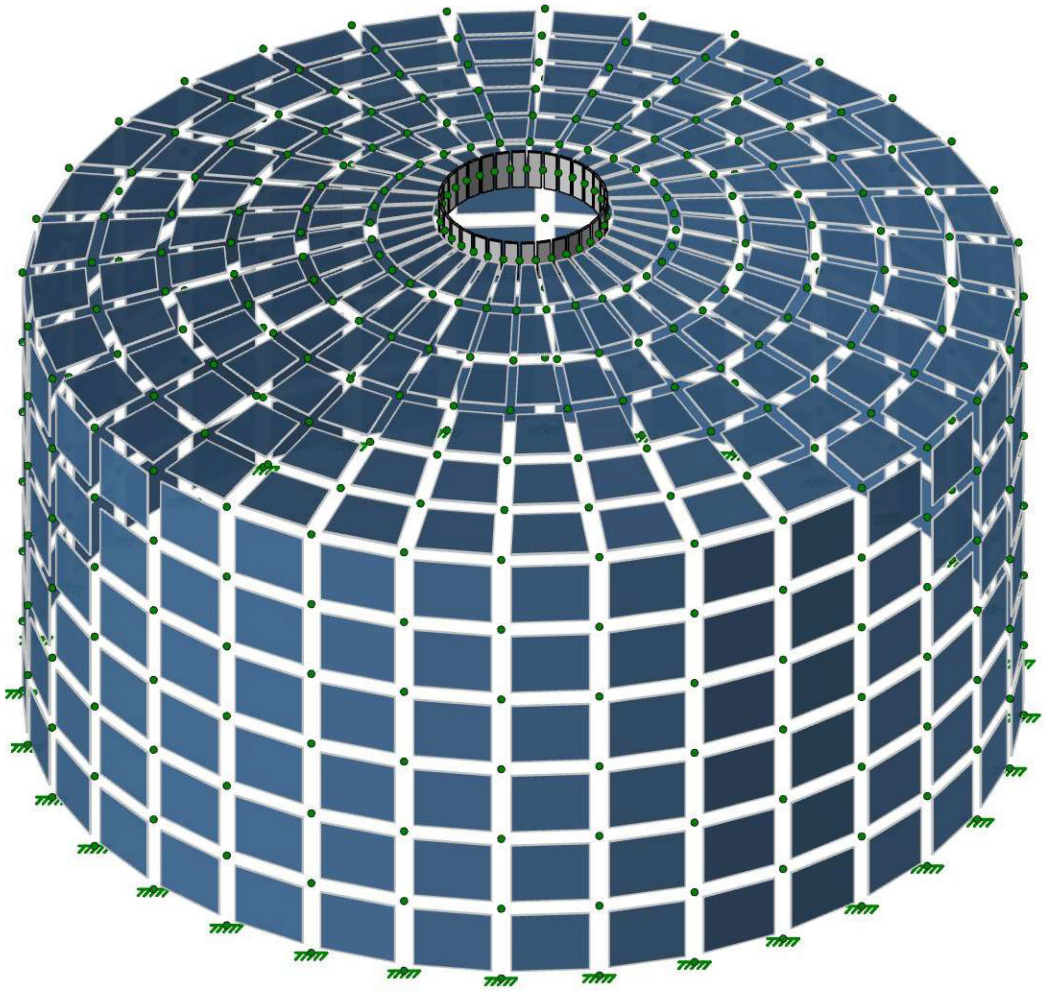
	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
631	1	P316	T	85.585	66.044	9.771	1.571	77.681
632			B	-29.778	-233.821	102.021	0	220.445
633	1	P317	T	85.585	66.044	9.771	1.571	77.681
634			B	-29.778	-233.821	102.021	0	220.445
635	1	P318	T	85.585	66.044	9.771	1.571	77.681
636			B	-29.778	-233.821	102.021	0	220.445
637	1	P319	T	85.585	66.044	9.771	1.571	77.681
638			B	-29.778	-233.821	102.021	0	220.445
639	1	P320	T	85.585	66.044	9.771	1.571	77.681
640			B	-29.778	-233.821	102.021	0	220.445
641	1	P321	T	-42.497	-154.18	55.841	0	137.932
642			B	3.498	-0.861	2.18	0	3.999
643	1	P322	T	-42.497	-154.18	55.841	0	137.932
644			B	3.498	-0.861	2.18	0	3.999
645	1	P323	T	-42.497	-154.18	55.841	0	137.932
646			B	3.498	-0.861	2.18	0	3.999
647	1	P324	T	-42.497	-154.18	55.841	0	137.932
648			B	3.498	-0.861	2.18	0	3.999
649	1	P325	T	-42.497	-154.18	55.841	0	137.932
650			B	3.498	-0.861	2.18	0	3.999
651	1	P326	T	-42.497	-154.18	55.841	0	137.932
652			B	3.498	-0.861	2.18	0	3.999
653	1	P327	T	-42.497	-154.18	55.841	0	137.932
654			B	3.498	-0.861	2.18	0	3.999
655	1	P328	T	-42.497	-154.18	55.841	0	137.932
656			B	3.498	-0.861	2.18	0	3.999
657	1	P329	T	-42.497	-154.18	55.841	0	137.932
658			B	3.498	-0.861	2.18	0	3.999
659	1	P330	T	-42.497	-154.18	55.841	0	137.932
660			B	3.498	-0.861	2.18	0	3.999
661	1	P331	T	-42.497	-154.18	55.841	0	137.932
662			B	3.498	-0.861	2.18	0	3.999
663	1	P332	T	-42.497	-154.18	55.841	0	137.932
664			B	3.498	-0.861	2.18	0	3.999
665	1	P333	T	-42.497	-154.18	55.841	0	137.932
666			B	3.498	-0.861	2.18	0	3.999
667	1	P334	T	-42.497	-154.18	55.841	0	137.932
668			B	3.498	-0.861	2.18	0	3.999
669	1	P335	T	-42.497	-154.18	55.841	0	137.932
670			B	3.498	-0.861	2.18	0	3.999
671	1	P336	T	-42.497	-154.18	55.841	0	137.932
672			B	3.498	-0.861	2.18	0	3.999
673	1	P337	T	-42.497	-154.18	55.841	0	137.932
674			B	3.498	-0.861	2.18	0	3.999
675	1	P338	T	-42.497	-154.18	55.841	0	137.932
676			B	3.498	-0.861	2.18	0	3.999
677	1	P339	T	-42.497	-154.18	55.841	0	137.932
678			B	3.498	-0.861	2.18	0	3.999
679	1	P340	T	-42.497	-154.18	55.841	0	137.932
680			B	3.498	-0.861	2.18	0	3.999
681	1	P341	T	-42.497	-154.18	55.841	0	137.932
682			B	3.498	-0.861	2.18	0	3.999
683	1	P342	T	-42.497	-154.18	55.841	0	137.932
684			B	3.498	-0.861	2.18	0	3.999
685	1	P343	T	-42.497	-154.18	55.841	0	137.932

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
686			B	3.498	-0.861	2.18	0	3.999
687	1	P344	T	-42.497	-154.18	55.841	0	137.932
688			B	3.498	-0.861	2.18	0	3.999
689	1	P345	T	-42.497	-154.18	55.841	0	137.932
690			B	3.498	-0.861	2.18	0	3.999
691	1	P346	T	-42.497	-154.18	55.841	0	137.932
692			B	3.498	-0.861	2.18	0	3.999
693	1	P347	T	-42.497	-154.18	55.841	0	137.932
694			B	3.498	-0.861	2.18	0	3.999
695	1	P348	T	-42.497	-154.18	55.841	0	137.932
696			B	3.498	-0.861	2.18	0	3.999
697	1	P349	T	-42.497	-154.18	55.841	0	137.932
698			B	3.498	-0.861	2.18	0	3.999
699	1	P350	T	-42.497	-154.18	55.841	0	137.932
700			B	3.498	-0.861	2.18	0	3.999
701	1	P351	T	-42.497	-154.18	55.841	0	137.932
702			B	3.498	-0.861	2.18	0	3.999
703	1	P352	T	-42.497	-154.18	55.841	0	137.932
704			B	3.498	-0.861	2.18	0	3.999
705	1	P353	T	68.449	-61.461	64.955	0	112.559
706			B	68.449	-100.386	84.417	0	147.085
707	1	P354	T	68.449	-61.461	64.955	0	112.559
708			B	68.449	-100.386	84.417	0	147.085
709	1	P355	T	68.449	-61.461	64.955	0	112.559
710			B	68.449	-100.386	84.417	0	147.085
711	1	P356	T	68.449	-61.461	64.955	0	112.559
712			B	68.449	-100.386	84.417	0	147.085
713	1	P357	T	68.449	-61.461	64.955	0	112.559
714			B	68.449	-100.386	84.417	0	147.085
715	1	P358	T	68.449	-61.461	64.955	0	112.559
716			B	68.449	-100.386	84.417	0	147.085
717	1	P359	T	68.449	-61.461	64.955	0	112.559
718			B	68.449	-100.386	84.417	0	147.085
719	1	P360	T	68.449	-61.461	64.955	0	112.559
720			B	68.449	-100.386	84.417	0	147.085
721	1	P361	T	68.449	-61.461	64.955	0	112.559
722			B	68.449	-100.386	84.417	0	147.085
723	1	P362	T	68.449	-61.461	64.955	0	112.559
724			B	68.449	-100.386	84.417	0	147.085
725	1	P363	T	68.449	-61.461	64.955	0	112.559
726			B	68.449	-100.386	84.417	0	147.085
727	1	P364	T	68.449	-61.461	64.955	0	112.559
728			B	68.449	-100.386	84.417	0	147.085
729	1	P365	T	68.449	-61.461	64.955	0	112.559
730			B	68.449	-100.386	84.417	0	147.085
731	1	P366	T	68.449	-61.461	64.955	0	112.559
732			B	68.449	-100.386	84.417	0	147.085
733	1	P367	T	68.449	-61.461	64.955	0	112.559
734			B	68.449	-100.386	84.417	0	147.085
735	1	P368	T	68.449	-61.461	64.955	0	112.559
736			B	68.449	-100.386	84.417	0	147.085
737	1	P369	T	68.449	-61.461	64.955	0	112.559
738			B	68.449	-100.386	84.417	0	147.085
739	1	P370	T	68.449	-61.461	64.955	0	112.559
740			B	68.449	-100.386	84.417	0	147.085

Plate Principal Stresses (Continued)

	LC	Plate Label	Loc	Sigma1[psi]	Sigma2[psi]	Tau Max[psi]	Angle[rad]	Von Mises[psi]
741	1	P371	T	68.449	-61.461	64.955	0	112.559
742			B	68.449	-100.386	84.417	0	147.085
743	1	P372	T	68.449	-61.461	64.955	0	112.559
744			B	68.449	-100.386	84.417	0	147.085
745	1	P373	T	68.449	-61.461	64.955	0	112.559
746			B	68.449	-100.386	84.417	0	147.085
747	1	P374	T	68.449	-61.461	64.955	0	112.559
748			B	68.449	-100.386	84.417	0	147.085
749	1	P375	T	68.449	-61.461	64.955	0	112.559
750			B	68.449	-100.386	84.417	0	147.085
751	1	P376	T	68.449	-61.461	64.955	0	112.559
752			B	68.449	-100.386	84.417	0	147.085
753	1	P377	T	68.449	-61.461	64.955	0	112.559
754			B	68.449	-100.386	84.417	0	147.085
755	1	P378	T	68.449	-61.461	64.955	0	112.559
756			B	68.449	-100.386	84.417	0	147.085
757	1	P379	T	68.449	-61.461	64.955	0	112.559
758			B	68.449	-100.386	84.417	0	147.085
759	1	P380	T	68.449	-61.461	64.955	0	112.559
760			B	68.449	-100.386	84.417	0	147.085
761	1	P381	T	68.449	-61.461	64.955	0	112.559
762			B	68.449	-100.386	84.417	0	147.085
763	1	P382	T	68.449	-61.461	64.955	0	112.559
764			B	68.449	-100.386	84.417	0	147.085
765	1	P383	T	68.449	-61.461	64.955	0	112.559
766			B	68.449	-100.386	84.417	0	147.085
767	1	P384	T	68.449	-61.461	64.955	0	112.559
768			B	68.449	-100.386	84.417	0	147.085



Loads: BLC 1, Self Weight

IRISA A NEMETSCHEK COMPANY	<Licensed Company>		SK-2
	cbopp		Apr 30, 2024 at 02:26 PM
			tank roof.r3d

Appendix 4

Wind Design, Seismic Design, and Shell Buckling Calculations in accordance with API 650

Wind Calculations

Wind Velocity per ASCE 7-10 Figure 26.5-1B = 120 mph
Tank diameter (D) = 12.0000 ft
Thinnest shell course thickness (t) = 0.1875 in

Exposure C

Risk Category = III

Calculation are in the corroded condition

Per 5.2.1 (k)(1)(b), wind loads are based on ASCE 7-10.

For Shell:
Centroid of shell Cs = 21.0000 ft
z = Cs but not less than 15.00 ft
z = 21.0000 ft from bottom of tank
Per ASCE7, zg = 900.00 ft
α = 9.50
Kz = 2.01(21.00/900.00)^(2/9.50) = 0.911

Kd = 0.95
Kzt = 1.00

h/D = 42.00/12.00 = 3.50

Per 5.2.1(k)(1)(b), V = (0.78)(120) = 93.60 mph

$q_z = 0.00256K_zK_{zt}K_dV^2$ =
$(0.00256)(0.911)(1.00)(0.95)(93.60)^2 = 19.41$ lbf/ft²

Cf = 0.50 +[(0.60 - 0.50)/(7.00 - 1.00)](3.50 - 1.00) = 0.5417

G = 0.85
$P_w = q_zGC_f = (19.41)(0.85)(0.5417) = 8.9388$ lbf/ft²
but not less than 10.0000 lbf/ft²
= 10.0000 lbf/ft²

For Roof:
Top of roof Cs = 43.00 ft
z = Cs but not less than 15.00 ft
z = 43.00 ft from bottom of tank
Per ASCE7, zg = 900.00 ft
α = 9.50
Kz = 2.01(43.00/900.00)^(2/9.50) = 1.060

Kd = 0.85
Kzt = 1.00
V = 93.60 mph

$q_z = 0.00256 K_z K_{zt} K_d V^2 =$
$(0.00256)(1.060)(1.00)(0.85)(93.60)^2 = 20.1999$ lbf/ft²

$GC_p = 0.90$
$U_w = q_z GC_p = (20.1999)(0.90) = 18.1799$ lbf/ft²

$P_{wr} = q_z GC_f = (20.1999)(0.85)(0.5417) = 9.3004$ lbf/ft²
but not less than 10.0000 lbf/ft²
= 10.00 lbf/ft²

V = 93.60 mph

Per 5.9.6.1: $P_{wv} = 31.00(V/120)^2 = 31.00(93.60/120)^2 = 18.86$ lbf/ft²
$P_{wd} = P_{wv} + 5.00 = 23.86$ lbf/ft²

$H_1 = 600000.00t[\sqrt{(t/D)^3}](36.00/P_{wd}) =$
$(600000.00)(0.1875)[\sqrt{(0.1875 / 12.0000)^3}](36.00/23.86) = 331.5182$ ft

Per 5.9.6.2: $t_{uniform} = t = 0.1875$ in

For each shell course, $W_{tr} = W \sqrt{\left(\frac{t_{uniform}}{t_{actual}}\right)^5}$

(Shell courses are numbered from bottom to top)

Shell Course	W (ft)	T_{actual} (in)	W_{tr} (ft)
7	6.0000	0.1875	6.0000
6	6.0000	0.1875	6.0000
5	6.0000	0.1875	6.0000
4	6.0000	0.2500	2.9228
3	6.0000	0.2500	2.9228
2	6.0000	0.2500	2.9228
1	6.0000	0.2500	2.9228
		Total Transposed Width:	29.6913

Overturning moment:
Total vertical height (H) = 42.0000 ft

Overturning Moment (Mw) = $(P_w D H^2/2 + U_w \pi D^3/8) =$
$= [(10.0000)(12.0000)(42.0000)^2/2 + (18.1799)(\pi)(12.0000)^3/8] = 118176.5886$ ft-lbs

Overturning moment:
Total shell vertical height (H) = 42.0000 ft

Overturning Moment (M_{ws}) = ($P_{wD}H^2/2$)
= [(10.0000)(12.0000)(42.0000)^2/2] = 105840.0000 ft-lbs

Tank does not contain internal pressure. Therefore, MPi = 0

Check for tank stability without anchors per 5.11.2
Weight of shell (D_{LS}) = 14434.0474 lbs
M_{DL} = D_{LS} * D/2 = 14434.0474 * 12.0000 / 2 = 86604.2847 ft-lbs
Weight of roof (D_{LR}) = 1170.6518 lbs
M_{DLR} = D_{LR} * D/2 = 1170.6518 * 12.0000 / 2 = 7023.9106 ft-lbs

Bottom thickness used (tb-CA) = 0.2500 - 0.0000 but shall not exceed
bottom shell course corroded thickness of 0.2500 in = 0.2500 in
Bottom material yield strength (F_{by}) = 36000.0000 psi
G = lesser of 0.70 or product specific gravity = 0.7000

w_L = 4.6700tb $\sqrt{(F_{by}H)}$ =
(4.6700)(0.2500)$\sqrt{(36000.0000 * 42.0000)}$ = 1435.5978 lbf/ft

not to exceed 0.450HD = 0.450 * 42.0000 * 12.0000 = 226.8000 lbf/ft
therefore, w_L = 226.8000 lbf/ft

M_F = $w_L(\pi)D^2/2$ = (226.8000)(π)(12.0000)^2/2 = 51300.9514 ft-lbs

For tank to be stable: 0.6Mw + Mpi < M_{DL}/1.5 + M_{DLR}
and Mw + 0.40Mpi < (M_{DL} + M_F)/2 + M_{DLR}
0.6Mw + Mpi = (0.6)(118176.5886) + (0.0000) = 70905.9532 ft-lbs
M_{DL}/1.5 + M_{DLR} = 86604.2847/1.5 + 7023.9106 = 64760.1004 ft-lbs

Mw + 0.40Mpi = 118176.5886 + (0.40)(0.0000) = 118176.5886 ft-lbs
(M_{DL} + M_F)/2 + M_{DLR} = (86604.2847 + 51300.9514)/2 + 7023.9106
= 75976.5287 ft-lbs

For tank to be stable: M_{ws} + 0.40Mpi < M_{DL}/1.5 + M_{DLR}

M_{ws} + 0.40Mpi = (105840.0000) + (0.40)(0.0000) = 105840.0000 ft-lbs
M_{DL}/1.5 + M_{DLR} = 86604.2847/1.5 + 7023.9106 = 64760.1004 ft-lbs

Anchorage of the tank for wind is required

Weights

	New (lbf)	Corroded (lbf)
Product:	296405.4970	296405.4970
Total Shell Plates:	14434.0474	14434.0474
Total Bottom Plates:	1219.7661	1219.7661
Total Roof Plates:	1170.6518	1170.6518
Total Live Load:	2261.9467	2261.9467
Total Snow Load:	2755.0511	2755.0511
Total Additional Dead Load:	0.0000	0.0000
Shell Insulation:	0.0000	0.0000
Roof Insulation:	0.0000	0.0000
Total Rafters:	0.0000	0.0000
Total Roof and Framing:	1170.6518	1170.6518
Total Shell Appurtenances:	0.0000	0.0000
Total Roof Appurtenances:	0.0000	0.0000
Total Roof Appurtenances acting on Shell	0.0000	0.0000
Live Load acting on Shell:	2261.9467	2261.9467
Snow Load acting on Shell:	2755.0511	2755.0511
Total of Roof acting on Shell:	1170.6518	1170.6518
Total of Roof Structural acting on Shell:	0.0000	0.0000
Total Compression Ring and Shell Stiffener	0.0000	0.0000

Seismic Calculations

Tank is mechanically anchored. The tank shall be shimmed and grouted per E.7.1.

Tank diameter (D): 12.0000 ft
Product Height (H): 42.0000 ft
Specific Gravity (G): 1.0000

Tank is mechanically anchored

Mapped spectral response acceleration (S_S): 0.1680 g
Mapped spectral response acceleration (S_1): 0.0890 g
Mapped spectral response acceleration (S_0) = 0.4Ss = (0.4)(0.1680) = 0.0672 g
Mapped spectral response acceleration (S_P) = 0.8S_1 = (0.8)(0.0890) = 0.0712 g

Site Class per E.4.4 : D
Seismic Use Group per E.3.1 : I

From Table E-1, Fa = 1.6000
From Table E-2, Fv = 2.4000
From Table E-5, I = 1.0000
From Table E-4, Rwi = 4.0000
From Table E-4, Rwc = 2.0000

Scaling factor per E.2, Q = 2/3

S_{DS} = QFaSs = (2/3)(1.6000)(0.1680) = 0.1792
S_{D1} = QFvS_1 = (2/3)(2.4000)(0.0890) = 0.1424

Per E.6.1.3, Av = 0.47SDS
Vertical earthquake acceleration coefficient (Av): 0.0842 g

E.4.5.2 Convective (Sloshing) Period

E.4.5.2-c:

$$K_s = \frac{0.578}{\sqrt{\tanh\left(\frac{3.68H}{D}\right)}} = \frac{0.578}{\sqrt{\tanh\left(\frac{(3.68)(42.0000)}{12.0000}\right)}} = 0.5780$$

Per E4.5.2-b: $T_c = 1.0K_s\sqrt{D} = (1.0)(0.5780)\sqrt{12.0000} = 2.0023$

E.4.6.1 Spectral Acceleration Coefficients

Impulsive spectral acceleration parameter:

Per E.4.6.1-1:

$$A_i = S_{DS}\left(\frac{I}{Rwi}\right) = 0.1792\left(\frac{1.00}{4.0000}\right) = 0.0448$$

However, per E.4.6.1-2, $A_i \geq 0.0070$
Therefore, $A_i = 0.0448$

Convective spectral acceleration parameter:

$T_L = 12.0000$
$K = 1.5$

$T_c \leq T_L$, Per E.4.6.1-4

$$A_c = KS_{D1}\left(\frac{1}{T_c}\right)\left(\frac{I}{R_{wc}}\right) = (1.5)(0.1424)\left(\frac{1}{2.0023}\right)\left(\frac{1.00}{2.0000}\right) = 0.0533$$

However, $A_c \leq A_i$
Therefore, $A_c = 0.0448$

Per E.6.1.1

$D/H = 12.0000/42.0000 = 0.2857$

Weights:
$W_s = 14434$ lbs
$W_f = 1220$ lbs
W_r = Roof weight + 10% of snow = 1446 lbs
$W_P = 296405$ lbs

$D/H < 1.333$

Per E.6.1.1-2, $W_i = (1.0 - 0.218D/H)W_P = (1.0 - 0.218 * 0.2857)(296405)$
$= 277944$ lbs

Per E.6.1.1-3, $W_c = 0.230D/H \tanh(3.67H/D)W_P =$
$(0.230)(0.2857)[\tanh(3.67/0.2857)](296405) = 19478$ lbs

Per E.6.1-2, $V_i = A_i(W_s + W_r + W_f + W_i) =$
$(0.0448)(14434 + 1446 + 1220 + 277944) = 13218$ lbs
Per E.6.1-3, $V_c = A_cW_c = (0.0448)(19478) = 873$ lbs
Per E.6.1-1, $V = \sqrt{(V_i^2 + V_c^2)} = \sqrt{[(13218)^2 + (873)^2]} = 13247$ lbs

Per E.6.1.2.1

$D/H < 1.333$

Per E.6.1.2.1-2, $X_i = [0.5 - 0.094D/H]H = [0.5 - (0.094)(0.2857)](42.0000)$
$= 19.8720$ ft

Per E.6.1.2.1-3,

$$X_c = \left[1.0 - \frac{\cosh(3.67H/D) - 1}{3.67H/D \sinh(3.67H/D)} \right] H =$$

$$\left[1.0 - \frac{\cosh(3.67/0.2857) - 1}{(3.67/0.2857)\sinh(3.67/0.2857)} \right] (42.0000) = 38.7303 \text{ ft}$$

Per E.6.1.2.2

$D/H < 1.333$

Per E6.1.2.2-2, $X_{is} = [0.500 + 0.060D/H]H = [0.500 + (0.060)(0.2857)](42.0000) = 21.7200$ ft

Per E.6.1.2.2-3,

$$X_{cs} = \left[1.0 - \frac{\cosh(3.67H/D) - 1.937}{3.67H/D \sinh(3.67H/D)} \right] H =$$

$$\left[1.0 - \frac{\cosh(3.67/0.2857) - 1.937}{(3.67/0.2857)\sinh(3.67/0.2857)} \right] (42.0000) = 38.7303 \text{ ft}$$

Per E.6.1.5

Per E.6.1.5-1, $M_{rw} = \sqrt{\{[A_i(W_iX_i + W_sX_s + W_rX_r)]^2 + [A_c(W_cX_c)]^2\}} =$
$\sqrt{\{[0.0448(277944*19.8720 + 14434*19.5600 + 1446*42.3333)]^2 + [0.0448(19478*38.7303)]^2\}} = 264999$ ft-lbs

Per E.6.1.5-2, $M_s = \sqrt{\{[A_i(W_iX_{is} + W_sX_s + W_rX_r)]^2 + [A_c(W_cX_{cs})]^2\}} =$
$\sqrt{\{[0.0448(277944*21.7200 + 14434*19.5600 + 1446*42.3333)]^2 + [0.0448(19478*38.7303)]^2\}} = 287837$ ft-lbs

Mechanically-anchored tank (new condition)

Per E.6.2.1.1.1

$W_s = 14434$ lbs
$w_{rs} = 38.3605$ lbf/ft
$t_s = 0.0870$ in
Per E.6.2.1.1.1-2, $w_t = W_s/(\pi D) + w_{rs} = 14434/(\pi * 12.0000) + 38.3605 = 421.2355$ lbf/ft

Shell compression per E.6.2.2.2-1b

$\sigma_c = [w_t(1 + 0.4A_v) + 1.273M_{rw}/D^2]/(12t_s) =$
$[421.2355(1 + (0.4)(0.0842)) + (1.273)(264999)/(12.0000)^2]/(12 * 0.0870) =$
2660 psi

Mechanically-anchored tank (corroded condition)

Per E.6.2.1.1.1

W_s = 14434 lbs
w_{rs} = 38.3605 lbf/ft
t_s = 0.0870 in
Per E.6.2.1.1.1-2, $w_t = W_s/(\pi D) + w_{rs} = 14434/(\pi * 12.0000) + 38.3605$
$= 421.2355$ lbf/ft

Shell compression per E.6.2.2.2-1b

$\sigma_c = [w_t(1 + 0.4A_v) + 1.273M_{rw}/D^2]/(12t_s) =$
$[421.2355(1 + (0.4)(0.0842)) + (1.273)(264999)/(12.0000)^2]/(12 * 0.0870) =$
2660 psi

Allowable Compression Stresses in Shell per E.6.2.2.3

For new condition:
$GHD^2/t^2 = (1.0000)(42.0000)(12.0000)^2/(0.0870)^2 = 798674$

For $GHD^2/t^2 < 1000000$
F_{ty} = 36000 psi
Per E.6.2.2.3-2b, $F_c = 1000000t_s/(2.5D) + 600.0\sqrt{GH} =$
$(1000000)(0.0870)/(2.5 * 12.0000) + 600.0\sqrt{(1.0000 * 42.0000)} = 6789$ psi
$< 0.5F_{ty} = (0.5)(36000) = 18000.0000$ psi
therefore, $F_c = 6789$ psi

Freeboard requirements per E.7.2

$T_c \leq 4$
Per E.7.2-2, $A_f = KS_{D1}I/T_c = (1.5)(0.1424)(1.0000)/2.0023 = 0.1067$

Wave Height Per E.7.2-1: $\delta_s = 0.42DA_f = (0.42)(12.0000)(0.1067) = 0.5377$ ft
Per Table E-7, minimum freeboard = $0.7\delta_s = (0.7)(0.5377) = 0.3764$ ft

Freeboard equal to 0.7 times the calculated wave height is recommended but not required. The required minimum freeboard = 0.376. The available freeboard = 0.000.

Hoop Stress per E.6.1.4

G = 1.000
D = 12.0000 ft
H = 42.0000 ft
Ai = 0.0448
Ac = 0.0448
Av = 0.0842
D/H = 0.2857

Shell Course 01

Y = 42.0000 ft

D/H < 1.33 and Y ≥ 0.75D

Per E.6.1.4-3b, $N_i = 1.39AiGD^2 = (1.39)(0.0448)(1.000)(12.0000)^2 = 8.9672$ lbf/in

Per E.6.1.4-4b, $N_c = \dfrac{0.98AcGD^2\cosh[3.68(H - Y)/D]}{\cosh[3.68H/D]} =$

$$\frac{(0.98)(0.0448)(1.0000)(12.0000)^2\cosh[3.68(42.0000 - 42.0000)/12.0000]}{\cosh[(3.68)(42.0000/12.0000)]}$$

$= 0.0000$ lbf/in

$N_h = 2.60D(Y-1)G = (2.60)(12.0000)((42.0000)-1)(1.000) = 1279.2000$ lbf/in

Shell thickness (t) = 0.2500 in

Per E.6.1.4-6, $\sigma_T = [N_h + \sqrt{\{N_i^2 + N_c^2 + (A_vN_h/2.5)^2\}}]/t =$
$[1279.2000 + \sqrt{\{(8.9672)^2 + (0.0000)^2 + (0.0842 * 1279.2000/2.5)^2\}}]/0.2500$
$= 5292.8751$ psi

Allowable stress per E.6.2.4
Lesser of:
1.33SE = (1.33)(21000.0000)(0.7000) = 19551.0000 psi
or
0.90FyE = (0.90)(36000.0000)(0.7000) = 22680.0000 psi
Therefore, Allowable stress = 19551.0000 psi

Minimum required thickness = $(\sigma_T * t)/Sa =$
$(5292.8751 * 0.2500)/19551.0000 = 0.0677$ in

Shell Course 02

Y = 36.0000 ft

D/H < 1.33 and Y ≥ 0.75D

Per E.6.1.4-3b, $N_i = 1.39AiGD^2 = (1.39)(0.0448)(1.000)(12.0000)^2 = 8.9672$ lbf/in

Per E.6.1.4-4b, $N_c = \dfrac{0.98AcGD^2\cosh[3.68(H - Y)/D]}{\cosh[3.68H/D]} =$

$$\frac{(0.98)(0.0448)(1.0000)(12.0000)^2\cosh[3.68(42.0000 - 36.0000)/12.0000]}{\cosh[(3.68)(42.0000/12.0000)]}$$

$$= 0.0001 \text{ lbf/in}$$

$N_h = 2.60D(Y-1)G = (2.60)(12.0000)((36.0000)-1)(1.000) = 1092.0000$ lbf/in

Shell thickness (t) = 0.2500 in

Per E.6.1.4-6, $\sigma_T = [N_h + \sqrt{\{N_i^2 + N_c^2 + (A_vN_h/2.5)^2\}}]/t =$

$[1092.0000 + \sqrt{\{(8.9672)^2 + (0.0001)^2 + (0.0842 * 1092.0000/2.5)^2\}}]/0.2500$

$= 4519.4645$ psi

Allowable stress per E.6.2.4

Lesser of:

$1.33SE = (1.33)(21000.0000)(0.7000) = 19551.0000$ psi

or

$0.90F_yE = (0.90)(36000.0000)(0.7000) = 22680.0000$ psi

Therefore, Allowable stress = 19551.0000 psi

Minimum required thickness = $(\sigma_T * t)/Sa =$

$(4519.4645 * 0.2500)/19551.0000 = 0.0578$ in

Shell Course 03

Y = 30.0000 ft

D/H < 1.33 and Y ≥ 0.75D

Per E.6.1.4-3b, $N_i = 1.39AiGD^2 = (1.39)(0.0448)(1.000)(12.0000)^2 = 8.9672$ lbf/in

Per E.6.1.4-4b, $N_c = \dfrac{0.98AcGD^2\cosh[3.68(H - Y)/D]}{\cosh[3.68H/D]} =$

$$\frac{(0.98)(0.0448)(1.0000)(12.0000)^2\cosh[3.68(42.0000 - 30.0000)/12.0000]}{\cosh[(3.68)(42.0000/12.0000)]}$$

$$= 0.0006 \text{ lbf/in}$$

$N_h = 2.60D(Y-1)G = (2.60)(12.0000)((30.0000)-1)(1.000) = 904.8000$ lbf/in

Shell thickness (t) = 0.2500 in

Per E.6.1.4-6, $\sigma_T = [N_h + \sqrt{\{N_i^2 + N_c^2 + (A_vN_h/2.5)^2\}}]/t =$

$[904.8000 + \sqrt{\{(8.9672)^2 + (0.0006)^2 + (0.0842 * 904.8000/2.5)^2\}}]/0.2500$

$= 3746.2958$ psi

Allowable stress per E.6.2.4

Lesser of:

$1.33SE = (1.33)(21000.0000)(0.7000) = 19551.0000$ psi

or

$0.90F_yE = (0.90)(36000.0000)(0.7000) = 22680.0000$ psi

Therefore, Allowable stress = 19551.0000 psi

Minimum required thickness = $(\sigma_T * t)/Sa =$

$(3746.2958 * 0.2500)/19551.0000 = 0.0479$ in

Shell Course 04

Y = 24.0000 ft

D/H < 1.33 and Y ≥ 0.75D

Per E.6.1.4-3b, $N_i = 1.39AiGD^2 = (1.39)(0.0448)(1.000)(12.0000)^2 = 8.9672$ lbf/in

Per E.6.1.4-4b, $N_c = \dfrac{0.98AcGD^2\cosh[3.68(H - Y)/D]}{\cosh[3.68H/D]} =$

$$\frac{(0.98)(0.0448)(1.0000)(12.0000)^2\cosh[3.68(42.0000 - 24.0000)/12.0000]}{\cosh[(3.68)(42.0000/12.0000)]}$$

$= 0.0040$ lbf/in

$N_h = 2.60D(Y-1)G = (2.60)(12.0000)((24.0000)-1)(1.000) = 717.6000$ lbf/in

Shell thickness (t) = 0.2500 in

Per E.6.1.4-6, $\sigma_T = [N_h + \sqrt{\{N_i^2 + N_c^2 + (A_vN_h/2.5)^2\}}]/t =$

$[717.6000 + \sqrt{\{(8.9672)^2 + (0.0040)^2 + (0.0842 * 717.6000/2.5)^2\}}]/0.2500$

$= 2973.5405$ psi

Allowable stress per E.6.2.4

Lesser of:

$1.33SE = (1.33)(21000.0000)(0.7000) = 19551.0000$ psi

or

$0.90F_yE = (0.90)(36000.0000)(0.7000) = 22680.0000$ psi

Therefore, Allowable stress = 19551.0000 psi

Minimum required thickness = $(\sigma_T * t)/Sa =$

$(2973.5405 * 0.2500)/19551.0000 = 0.0380$ in

Shell Course 05

$Y = 18.0000$ ft

$D/H < 1.33$ and $Y \geq 0.75D$

Per E.6.1.4-3b, $N_i = 1.39AiGD^2 = (1.39)(0.0448)(1.000)(12.0000)^2 = 8.9672$ lbf/in

Per E.6.1.4-4b, $N_c = \dfrac{0.98AcGD^2\cosh[3.68(H - Y)/D]}{\cosh[3.68H/D]} =$

$$\frac{(0.98)(0.0448)(1.0000)(12.0000)^2\cosh[3.68(42.0000 - 18.0000)/12.0000]}{\cosh[(3.68)(42.0000/12.0000)]}$$

$= 0.0253$ lbf/in

$N_h = 2.60D(Y-1)G = (2.60)(12.0000)((18.0000)-1)(1.000) = 530.4000$ lbf/in

Shell thickness $(t) = 0.1875$ in

Per E.6.1.4-6, $\sigma_T = [N_h + \sqrt{\{N_i^2 + N_c^2 + (A_vN_h/2.5)^2\}}]/t =$

$[530.4000 + \sqrt{\{(8.9672)^2 + (0.0253)^2 + (0.0842 * 530.4000/2.5)^2\}}]/0.1875$

$= 2935.4281$ psi

Allowable stress per E.6.2.4

Lesser of:

$1.33SE = (1.33)(21000.0000)(0.7000) = 19551.0000$ psi

or

$0.90F_yE = (0.90)(36000.0000)(0.7000) = 22680.0000$ psi

Therefore, Allowable stress = 19551.0000 psi

Minimum required thickness $= (\sigma_T * t)/Sa =$

$(2935.4281 * 0.1875)/19551.0000 = 0.0282$ in

Shell Course 06

Y = 12.0000 ft

D/H < 1.33 and Y ≥ 0.75D

Per E.6.1.4-3b, $N_i = 1.39AiGD^2 = (1.39)(0.0448)(1.000)(12.0000)^2 = 8.9672$ lbf/in

Per E.6.1.4-4b, $N_c = \dfrac{0.98AcGD^2\cosh[3.68(H - Y)/D]}{\cosh[3.68H/D]} =$

$$\frac{(0.98)(0.0448)(1.0000)(12.0000)^2\cosh[3.68(42.0000 - 12.0000)/12.0000]}{\cosh[(3.68)(42.0000/12.0000)]}$$

$= 0.1595$ lbf/in

$N_h = 2.60D(Y-1)G = (2.60)(12.0000)((12.0000)-1)(1.000) = 343.2000$ lbf/in

Shell thickness (t) = 0.1875 in

Per E.6.1.4-6, $\sigma_T = [N_h + \sqrt{\{N_i^2 + N_c^2 + (A_vN_h/2.5)^2\}}]/t =$

$[343.2000 + \sqrt{\{(8.9672)^2 + (0.1595)^2 + (0.0842 * 343.2000/2.5)^2\}}]/0.1875$

$= 1908.4421$ psi

Allowable stress per E.6.2.4

Lesser of:

$1.33SE = (1.33)(21000.0000)(0.7000) = 19551.0000$ psi

or

$0.90F_yE = (0.90)(36000.0000)(0.7000) = 22680.0000$ psi

Therefore, Allowable stress = 19551.0000 psi

Minimum required thickness = $(\sigma_T * t)/Sa =$

$(1908.4421 * 0.1875)/19551.0000 = 0.0183$ in

Shell Course 07

Y = 6.0000 ft

D/H < 1.33 and Y < 0.75D

Per E.6.1.4-2b, $N_i = 2.77 A_i G D^2 \left[\frac{Y}{0.75D} - 0.5 \left(\frac{Y}{0.75D} \right)^2 \right] =$

$$(2.77)(0.0448)(1.000)(12.0000)^2 \left[\frac{6.0000}{(0.75)(12.0000)} - 0.5 \left(\frac{6.0000}{(0.75)(12.0000)} \right)^2 \right]$$

$$= 7.9421 \text{ lbf/in}$$

Per E.6.1.4-4b, $N_c = \frac{0.98 A_c G D^2 \cosh[3.68(H - Y)/D]}{\cosh[3.68H/D]} =$

$$\frac{(0.98)(0.0448)(1.0000)(12.0000)^2 \cosh[3.68(42.0000 - 6.0000)/12.0000]}{\cosh[(3.68)(42.0000/12.0000)]}$$

$$= 1.0041 \text{ lbf/in}$$

$N_h = 2.60D(Y-1)G = (2.60)(12.0000)((6.0000)-1)(1.000) = 156.0000$ lbf/in

Shell thickness (t) = 0.1875 in

Per E.6.1.4-6, $\sigma_T = [N_h + \sqrt{\{N_i^2 + N_c^2 + (A_v N_h/2.5)^2\}}]/t =$

$$[156.0000 + \sqrt{\{(7.9421)^2 + (1.0041)^2 + (0.0842 * 156.0000/2.5)^2\}}]/0.1875$$

$$= 883.0740 \text{ psi}$$

Allowable stress per E.6.2.4

Lesser of:

$1.33SE = (1.33)(21000.0000)(0.7000) = 19551.0000$ psi

or

$0.90F_yE = (0.90)(36000.0000)(0.7000) = 22680.0000$ psi

Therefore, Allowable stress = 19551.0000 psi

Minimum required thickness = $(\sigma_T * t)/Sa =$

$(883.0740 * 0.1875)/19551.0000 = 0.0085$ in

Appendix 5

Foundation and Maximum Anchor Bolt Loading

Anchor Bolt Design

Tank Diameter (D) = 12.0000 ft
Quantity of Equal Spaced Anchor Bolts (N) = 8

Anchor Bolt Diameter (Sd) = 1 inch

Note: Anchor bolt shall be tightened snug fit (hand tight plus a maximum of 1/8 turn with wrench). Measures such as peening the threads, adding lock nut, or tack welding the nut to the top plate shall be taken.

Anchor Bolt Material: A36 Galvanized
Anchor Bolt Yield Strength = 36000 psi
but not greater than 55000 psi per Table 5-21
therefore, Anchor Bolt Yield Strength (F_{yb}) = 36000 psi
Anchor Bolt Corrosion Allowance (B_c) = 0.0000 in
Anchor Bolt Root Area (new) (A_n) = 0.5510 in²
Anchor Bolt Area (A) = 0.5510 in²

Distance from outside of shell to Anchor Bolt (D_1) = 3.0000 in

Bottom Shell Thickness (t_s) = 0.2500 in
Anchor Bolt Circle Diameter (d) = $D + 2(D_1 + t_s)/12$ =
12.0000 + 2 * (3.0000 + 0.2500)/12 = 12.5417 ft

Bolt Load due to Wind

W_2 = 15604.6992 lbs
P_{WR} = 3.4988 inches of water
$M_{WS} = DP_{ws}H^2/2$ =(10.0000)(12.0000)(42.0000)²/2 = 105840.0000 ft-lbs

Per Table 5-21, $U = (P_{WR})(D^2)(4.080) + 4M_{WS}/D - W_2$ =
(3.4988)(12.0000)²(4.080) + 4 * 105840.0000/12.0000 - 15604.6992
= 21730.9309 lbs

Bolt load per 5.12.2: Tb = U/N = 21730.9309/8.0000 = 2716.3664 lbs

Bolt Stress = Tb/A = 2716.3664/0.5510 = 4929.8845 psi

Allowable bolt load per Table 5-21 = $0.8F_{yb}$ = 0.8 * 36000.0000 = 28800.0000 psi

Bolt Load due to Seismic

M_{rw} = 264998.7286 ft-lbs
A_v = 0.0842
W_2 = 15604.6992 lbs
Per Table 5-21, $U = 4M_{rw}/D - W_2(1 - 0.4A_v)$ =
4 * 264998.7286/12.0000 - 15604.6992 * (1 - 0.4 * 0.0842) = 73253.9264 lbs

Bolt load per 5.12.2: Tb = U/N = 73253.9264/8.0000 = 9156.7408 lbs

Bolt Stress = Tb/A = 9156.7408/0.5510 = 16618.4044 psi

Allowable stress per Table 5-21 = $0.8F_{yb}$ = 0.8 * 36000.0000 = 28800.0000 psi

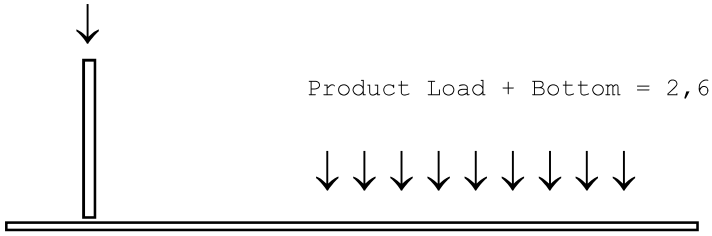
Foundation Loads

Dead Load = 414 lbf/ft
Dead Load + Live Load = 474 lbf/ft
Dead Load + Snow Load = 487 lbf/ft
Wind Load + Dead Load = 1,350 lbf/ft

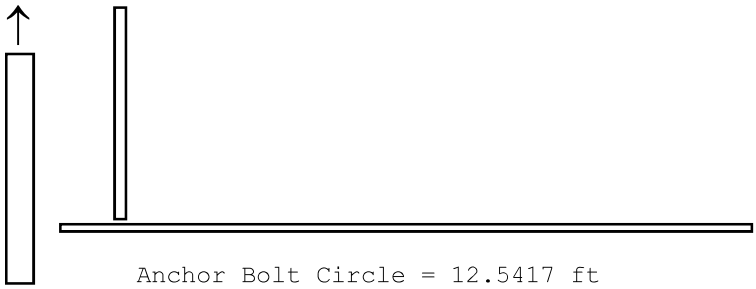
(Wind Foundation Moment = 105,840 ft-lbs)
(Wind Horizontal Force = 5,040 lbs)

Seismic Values needed for E.6.2.3
WP = 296,405 lbs
Wf = 1,220 lbs
WT = 315,985 lbs
Ms = 287,837 ft-lbs

(Seismic Horizontal Force = 13,247 lbs)



Anchor Bolt Load:
Wind = 2,716 lbs
Seismic = 9,157 lbs
Bolt Area x Yield Strength = 19,836 lbs



Total Weight of Tank: 17,039 lbs
Total Operating Weight: 313,444 lbs
Total Testing Weight: 313,444 lbs