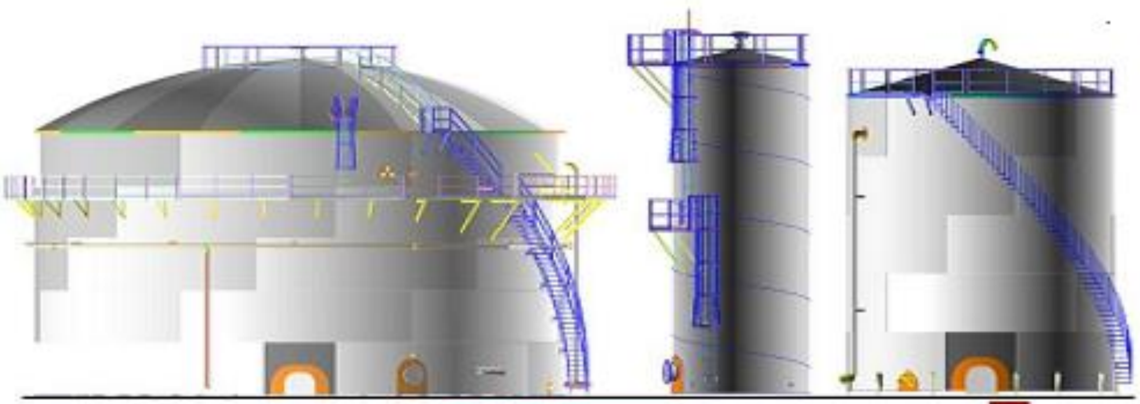
AMETANK REPORT



AMETank

Field Erected and Shop Built Storage Tanks

Engineering Application Software

The following report is subject to the disclaimer statement as stated in the Disclaimer and Special Notes section at the end.

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No Warnings!!

Project Design Data and Summary

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Project Data

Job : 2025-07-22-06-17
Date of Calcs. : 06-Aug-2025
Mfg. or Insp. Date :
Designer : Melior
Project :
Tag ID : Q9294 API
Plant :
Plant Location :
Site :
Design Basis : API-650 13th Edition Errata 1, 2021
Annexes Used : E, J, M, S

Design Parameters and Operating Conditions

Design Parameters

Design Internal Pressure = 0 psi or 0 inh2o
Design External Pressure = -0 psi or -0 inh2o

D of Tank = 13.2217 ft
OD of Tank = 13.2842 ft
ID of Tank = 13.2217 ft
CL of Tank = 13.2529 ft
Shell Height = 60.4167 ft
S.G of Contents = 1
S.G of Hydrotest = 1
Hydrotest Liquid Level = 60.4167 ft
Max Design Liq. Level = 60.4167 ft
Max Operating Liq. Level = 60.4167 ft
Min Liq. Level = 1 ft
Design Temperature = 122 ºF
MDMT (Minimum Design Metal Temperature) = -20 ºF
Tank Joint Efficiency = 0.7
Ground Snow Load = 0 psf
Roof Live Load = 20 psf
Additional Roof Dead Load = 0 psf

Wind Load Basis: ASCE 7-16
3 Second Gust Wind Speed (entered), Vg = 105 mph
Design Wind Speed, V = Vg = 105 mph

Seismic Method: API-650 - ASCE7 Mapped(Ss & S1)
Seismic Use Group = II
Site Class = C

T_L (sec) = 12
Ss (g) = 0.27
S1 (g) = 0.094
Av (g) = 0.1008
Q = 0.6667
Importance Factor = 1.25

Design Remarks

Summary Results

Shell

Shell #	Width (in)	Material	CA (in)	JE	Min Yield Strength (psi)	Tensile Strength (psi)	Reduction Factor	Sd (psi)	St (psi)
1	60	A240-304	0	0.7000	28,900	75,000	1	22,500	27,000
2	60	A240-304	0	0.7000	28,900	75,000	1	22,500	27,000
3	60	A240-304	0	0.7000	28,900	75,000	1	22,500	27,000
4	60	A240-304	0	0.7000	28,900	75,000	1	22,500	27,000
5	60	A240-304	0	0.7000	28,900	75,000	1	22,500	27,000
6	60	A240-304	0	0.7000	28,900	75,000	1	22,500	27,000
7	60	A240-304	0	0.7000	28,900	75,000	1	22,500	27,000
8	60	A240-304	0	0.7000	28,900	75,000	1	22,500	27,000
9	60	A240-304	0	0.7000	28,900	75,000	1	22,500	27,000
10	48	A240-304	0	0.7000	28,900	75,000	1	22,500	27,000
11	48	A240-304	0	0.7000	28,900	75,000	1	22,500	27,000
12	48	A240-304	0	0.7000	28,900	75,000	1	22,500	27,000
13	39.5	A240-304	0	0.7000	28,900	75,000	1	22,500	27,000

(continued)

Shell #	Weight (lbf)	Weight CA (lbf)	t-min Erection (in)	t-Des (in)	t-Test (in)	t-min Seismic (in)	t-min Ext-Pe (in)	t-min (in)	t-Actual (in)
1	3,244	3,244	0.1875	0.1297	0.1081	0.1188	NA	0.1875	0.375
2	1,624	1,624	0.1875	0.1188	0.099	0.1089	NA	0.1875	0.1875

3	1,624	1,624	0.1875	0.1079	0.0899	0.0991	NA	0.1875	0.1875
4	1,624	1,624	0.1875	0.0969	0.0808	0.0893	NA	0.1875	0.1875
5	1,624	1,624	0.1875	0.086	0.0717	0.0795	NA	0.1875	0.1875
6	1,624	1,624	0.1875	0.0751	0.0626	0.0697	NA	0.1875	0.1875
7	1,624	1,624	0.1875	0.0642	0.0535	0.0599	NA	0.1875	0.1875
8	1,624	1,624	0.1875	0.0533	0.0444	0.0501	NA	0.1875	0.1875
9	1,624	1,624	0.1875	0.0424	0.0353	0.0403	NA	0.1875	0.1875
10	1,299	1,299	0.1875	0.0315	0.0262	0.0306	NA	0.1875	0.1875
11	1,299	1,299	0.1875	0.0227	0.0189	0.0228	NA	0.1875	0.1875
12	1,299	1,299	0.1875	0.014	0.0117	0.015	NA	0.1875	0.1875
13	1,069	1,069	0.1875	0.0053	0.0044	0.0071	NA	0.1875	0.1875

(continued)

Shell #	Status
1	OK
2	OK
3	OK
4	OK
5	OK
6	OK
7	OK
8	OK
9	OK
10	OK
11	OK
12	OK
13	OK

Total Weight of Shell = 21,264.1013 lbf

Roof

Type = Self Supported Conical Roof
Plates Material = A240-304
t.required = 0.1875 in
t.actual = 0.1875 in
Roof corrosion allowance = 0 in
Roof Joint Efficiency = 0.7
Plates Overlap Weight = 0 lbf
Plates Weight = 1,111.2243 lbf

Bottom

Type : Flat Bottom Non Annular
Bottom Material = A240-304
t.required = 0.1875 in
t.actual = 0.1875 in

Bottom corrosion allowance = 0 in
Bottom Joint Efficiency = 0.7
Total Weight of Bottom = 1,112.6281 lbf

Top Member

Type = Detail B
Size = L2x2x1/4
Material = A240-304
Weight = 132.6171 lbf

Anchors

Quantity = 8
Size = 1.625 in
Material = A36
Bolt Hole Circle Radius = 6.8191 ft

Nameplate Information

Pressure Combination Factor	0.4
Design Standard	API-650 13th Edition Errata 1, 2021
Appendices Used	E, J, M, S
Roof	A240-304 : 0.1875 in
Shell (1)	A240-304 : 0.375 in
Shell (2)	A240-304 : 0.1875 in
Shell (3)	A240-304 : 0.1875 in
Shell (4)	A240-304 : 0.1875 in
Shell (5)	A240-304 : 0.1875 in
Shell (6)	A240-304 : 0.1875 in
Shell (7)	A240-304 : 0.1875 in
Shell (8)	A240-304 : 0.1875 in
Shell (9)	A240-304 : 0.1875 in
Shell (10)	A240-304 : 0.1875 in
Shell (11)	A240-304 : 0.1875 in
Shell (12)	A240-304 : 0.1875 in
Shell (13)	A240-304 : 0.1875 in
Bottom	A240-304 : 0.1875 in

Roof Design Details [Back]

Roof Type = Cone
Structure Support Type = None (Self Supported)

Material Properties

Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
Density (d) = 0.290 lb/in^3
Modulus of Elasticity at Design Temperature (E) = 27.9680e6 psi

Geometry

Rh = Horizontal Radius (in)
slope = Slope (Rise / Run)

Rh = 80.1035 in
slope = 0.166667

Description	Variable	Equation	Value	Unit
Slope Angle	Theta	ARCTAN(slope)	9.46232	deg
Angle With Vertical Line	Alpha	90 - Theta	80.5377	deg
Height	h	Rh * TAN(Theta)	13.3506	in
Surface Area	A	(pi * (Rh^2)) / COS(Theta)	20.4363e3	in^2
Center of Gravity from Base	CG	h / 3	4.45019	in
Vertical Projected Area	Av	Rh * h	1.06943e3	in^2
Horizontal Projected Area	Ah	pi * (Rh^2)	20.1583e3	in^2
Volume	V	(pi * (Rh^2) * h) / 3	89.7081e3	in^3

Weights

d-ins = Insulation Density (lbf/ft^3)
DL-add = Added dead load (psf)
t = Plates Thickness (in)
t-ins = Insulation Thickness (in)
Wr-pl-add = Additional Weight (lb)

d-ins = 8.0 lbf/ft^3
DL-add = 0.0 psf
t = 0.18750 in
t-ins = 0.0 in
Wr-pl-add = 0.0 lb

Description	Variable	Equation	Value	Unit
Plates Nominal Weight	Wr-pl	(A * d * t) + Wr-pl-add	1.11122e3	lb

Plates Corroded Weight	Wr-pl-corr	(A * d * (t - CA)) + Wr-pl-add	1.11122e3	lb
New Plates Dead Load Pressure	DL-pl	Wr-pl / Ah	7.93801	psf
Corroded Plates Dead Load Pressure	DL-pl-corr	Wr-pl-corr / Ah	7.93801	psf
Insulation Weight	Wr-ins	t-ins * d-ins * A	0.0	lb
Insulation Dead Load Pressure	DL-ins	Wr-ins / Ah	0.0	psf
Dead Load	DL	DL-pl + DL-ins + DL-add	7.93801	psf
Total Nominal Dead Weight	Wr-DL	DL * Ah	1.11122e3	lb
Additional Dead Weight	Wr-DL-add	DL-add * Ah	0.0	lb

Loads

B = Maximum Gravity Load Combination Based on Balanced Snow Load (psf)
e.1b = Gravity Loads Combination 1 Based on Balanced Snow Load per *API 650 Section 5.2.2* (psf)
e.1u = Gravity Loads Combination 1 Based on Unbalanced Snow Load per *API 650 Section 5.2.2* (psf)
e.2b = Gravity Loads Combination 2 Based on Balanced Snow Load per *API 650 Section 5.2.2* (psf)
e.2u = Gravity Loads Combination 2 Based on Unbalanced Snow Load per *API 650 Section 5.2.2* (psf)
Fpe = External Pressure Combination Factor
Lr = Minimum Roof Live Load (psf)
max-gravity-load = Maximum Gravity Load (psf)
Pe = Design External Pressure (psf)
S = Ground Snow Load (psf)
Sb = Balanced Snow load per *API 650 Section 5.2.1 (h)* (psf)
Su = Unbalanced Snow load per *API 650 Section 5.2.1 (h)* (psf)
U = Maximum Gravity Load Combination Based on Unbalanced Snow Load (psf)
W-max-gravity-load = Maximum Gravity Load Weight (lb)

Fpe = 0.40
Lr = 20.0 psf
Pe = 0.0 psf
S = 0.0 psf

Sb = 0.84 * S
Sb = 0.84 * 0.0
Sb = 0.0 psf

Su = Sb
Su = 0.0
Su = 0.0 psf

e.1b = DL + MAX(Lr , Sb) + (Fpe * Pe)
e.1b = 7.93801 + MAX(20.0 , 0.0) + (0.40 * 0.0)
e.1b = 27.9380 psf

e.2b = DL + Pe + (0.4 * MAX(Lr , Sb))
e.2b = 7.93801 + 0.0 + (0.4 * MAX(20.0 , 0.0))
e.2b = 15.9380 psf

B = MAX(e.1b , e.2b)
B = MAX(27.9380 , 15.9380)
B = 27.9380 psf

e.1u = DL + MAX(Lr , Su) + (Fpe * Pe)

e.1u = 7.93801 + MAX(20.0 , 0.0) + (0.40 * 0.0)
e.1u = 27.9380 psf

e.2u = DL + Pe + (0.4 * MAX(Lr , Su))
e.2u = 7.93801 + 0.0 + (0.4 * MAX(20.0 , 0.0))
e.2u = 15.9380 psf

U = MAX(e.1u , e.2u)
U = MAX(27.9380 , 15.9380)
U = 27.9380 psf

max-gravity-load = MAX(B , U)
max-gravity-load = MAX(27.9380 , 27.9380)
max-gravity-load = 27.9380 psf

W-max-gravity-load = max-gravity-load * Ah
W-max-gravity-load = 27.9380 * 139.988
W-max-gravity-load = 3.91098e3 lb

Erection Requirements

t-erec-req = Minimum Erection Thickness Including Corrosion Allowance (in)

As per API-650 5.10.2.2, Minimum Erection Thickness (t-erec) = 0.18750 in

t-erec-req = t-erec + CA
t-erec-req = 0.18750 + 0.0
t-erec-req = 0.18750 in

Gravity Loads Thickness Calculation

B-max = Max Gravity Load Based on Roof Actual Thickness (Balanced Snow Load) (psf)
Pe-max-1 = MAWV Based on Gravity Loads Combination 1 per *API 650 Section 5.2.2* (psf)
t-calc-1 = Calculated Thickness Based on Balanced Snow Load (in)

t-calc-1 = (((2 * 12 * D) / SIN(Theta)) * SQRT((B / (144 * E)))) + CA
t-calc-1 = (((2 * 12 * 13.2217) / SIN(9.46232)) * SQRT((27.9380 / (144 * 27.9680e6)))) + 0.0
t-calc-1 = 0.160762 in

B-max = (((t-actual - CA) * (SIN(Theta) / (2 * 12 * D)))^2) * 144 * E
B-max = (((0.18750 - 0.0) * (SIN(9.46232) / (2 * 12 * 13.2217)))^2) * 144 * 27.9680e6
B-max = 38.0040 psf

Pe-max-1 = MAX(((L_max - DL - MAX(Lr , S)) / Fpe) , 0)
Pe-max-1 = MAX(((38.0040 - 7.93801 - MAX(20.0 , 0.0)) / 0.40) , 0)
Pe-max-1 = 25.1651 psf

Pe-max-2 = MAWV Based on Gravity Loads Combination 1 per *API 650 Section 5.2.2* (psf)
t-calc-2 = Calculated Thickness Based on Unbalanced Snow Load (in)
U-max = Max Gravity Load Based on Roof Actual Thickness (Unbalanced Snow Load) (psf)

t-calc-2 = (((2 * 12 * D) / SIN(Theta)) * SQRT((U / (1.33 * 144 * E)))) + CA
t-calc-2 = (((2 * 12 * 13.2217) / SIN(9.46232)) * SQRT((27.9380 / (1.33 * 144 * 27.9680e6)))) + 0.0
t-calc-2 = 0.139399 in

U-max = (((t-actual - CA) * (SIN(Theta) / (2 * 12 * D)))^2) * 1.33 * 144 * E
U-max = (((0.18750 - 0.0) * (SIN(9.46232) / (2 * 12 * 13.2217)))^2) * 1.33 * 144 * 27.9680e6

U-max = 50.5454 psf

Pe-max-2 = MAX(((L_max - DL - MAX(Lr , S)) / Fpe) , 0)
Pe-max-2 = MAX(((50.5454 - 7.93801 - MAX(20.0 , 0.0)) / 0.40) , 0)
Pe-max-2 = 56.5184 psf

Required Thickness

MAWV-Roof = Maximum Allowable Working Vacuum (psf)
t-act = Installed Thickness (in)
t-req = Required Thickness (in)

t-act = 0.18750 in

t-req = MAX(t-erec-req , t-calc-1 , t-calc-2)
t-req = MAX(0.18750 , 0.160762 , 0.139399)
t-req = 0.18750 in

t >= t-req ==> PASS

MAWV-Roof = MIN(Pe-max-1 , Pe-max-2)
MAWV-Roof = MIN(25.1651 , 56.5184)
MAWV-Roof = 25.1651 psf

Top Member Detail B Design [Back]

F_y_ring = Roof Annular Ring Yield Strength (psi)

F_y_ring = nil

ca_ring_open = Open Roof Annular Ring Corrosion Allowance (in)
DLR = Nominal Weight of Roof Plates and Attached Structural (lbf)
DLS = Nominal Weight of Shell Plates and Framing (lbf)
F_y_ring = Roof Annular Ring Yield Strength (psi)
F_y_ring_open = Open Roof Annular Ring Yield Strength (psi)
R_ring_open = Open Roof Annular Ring Outer Radius (in)
t_ring_open = Open Roof Annular Ring Thickness (in)
W_ring_open = Open Roof Annular Ring Width (in)

ca_ring_open = nil
F_y_ring = nil
F_y_ring_open = nil
R_ring_open = nil
t_ring_open = nil
W_ring_open = 8.0 in

DLS = Ws + W_framing
DLS = 21.2641e3 + 136.572
DLS = 21.4007e3 lbf

DLR = Wr + W_structural
DLR = 1.11122e3 + 45.5909
DLR = 1.15682e3 lbf

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi

Compression Ring Detail b Properties
A_detail = Detail Total Area (in^2)
A_roof = Contributing Roof Area (in^2)
A_shell = Contributing Shell Area (in^2)
A_sum = Total area (in^2)
c_combined = Combined centroid (in)
d_shell = Shell centroid (in)
d_stiff = Stiffener centroid (in)
e1 = Distance from neutral axis to edge 1 (inside) (in)
e2 = Distance from neutral axis to edge 2 (outside) (in)
I_1 = moment of inertia of first body (in^4)
I_2 = moment of inertia of second body (in^4)
I_combined = Combined moment of inertia (in^4)
I_shell = Contributing Shell Moment Of Inertia (in^4)
I_sum = Sum of moments of inertia's (in^4)
R2 = Length of Normal to Head (in)
S = Combined stiffener shell section modulus (in^3)
Wc = Maximum Width of Participating Shell per *API-650 Figure F-2* (in)

Wh = Maximum Width of Participating Head per *API-650 Figure F-2* (in)

R2 = (ID / 2) / SIN(Theta)
R2 = (158.660 / 2) / SIN(9.46232)
R2 = 482.546 in

Wh = 0.3 * SQRT((R2 * (th - CA-head)))
Wh = 0.3 * SQRT((482.546 * (0.18750 - 0.0)))
Wh = 2.85359 in

Wc = 0.6 * SQRT(((ID / 2) * (tc-nominal - CA-shell)))
Wc = 0.6 * SQRT(((158.660 / 2) * (0.18750 - 0.0)))
Wc = 2.31404 in

Angle Size L2X2X1/4 Section Properties

Description	Variable	New	Corroded	Unit
Weight	W	3.190	3.190	lbf/ft
Cross Sectional Area	A	0.9440	0.9440	in^2
Moment Of Inertia About X Axis	Ix	0.3460	0.3460	in^4
Moment Of Inertia About Y Axis	Iy	0.3460	0.3460	in^4
Section Modulus About X Axis	Sx	0.2440	0.2440	in^3
Section Modulus About Y Axis	Sy	0.2440	0.2440	in^3
Centroid X Coords	cx	0.5860	0.5860	in
Centroid Y Coords	cy	0.5860	0.5860	in
Angle Long Leg Length	L1-angle	2.0	2.0	in
Angle Short Leg Length	L2-angle	2.0	2.0	in
Angle Thickness	t-angle	0.250	0.250	in

I_shell = ((Wc - h) * ((tc-nominal - CA-shell)^3)) / 12
I_shell = ((2.31404 - 0.18750) * ((0.18750 - 0.0)^3)) / 12
I_shell = 0.00116814 in^4

A_shell = (Wc - h) * (tc-nominal - CA-shell)
A_shell = (2.31404 - 0.18750) * (0.18750 - 0.0)
A_shell = 0.398726 in^2

A_roof = Wh * (th - CA-head)
A_roof = 2.85359 * (0.18750 - 0.0)
A_roof = 0.535047 in^2

A_detail = A_shell + A_roof + A-corr
A_detail = 0.398726 + 0.535047 + 0.9440
A_detail = 1.87777 in^2

Stiffener and Shell Combined Section Properties

Description	Variable	Equation	Value	Unit
Shell centroid	d_shell	(tc-nominal - CA-shell) / 2	0.093750	in
Stiffener centroid	d_stiff	cy + (tc-nominal - CA-shell)	0.77350	in

moment of inertia of first body	I_1	Ic + (Area * (Distance^2))	0.910797	in^4
moment of inertia of second body	I_2	Ic + (Area * (Distance^2))	0.00467257	in^4
Total area	A_sum	A_1 + A_2	1.34273	in^2
Sum of moments of inertia's	I_sum	I_1 + I_2	0.915470	in^4
Combined centroid	c_combined	((Centroid-1 * Area-1) + (Centroid-2 * Area-2)) / (Area-1 + Area-2)	0.571646	in
Combined moment of inertia	I_combined	Ic - (Area * (Distance^2))	0.476694	in^4
Distance from neutral axis to edge 1 (inside)	e1	c_combined	0.571646	in
Distance from neutral axis to edge 2 (outside)	e2	((tc-nominal - CA-shell) + L1-angle) - e1	1.61585	in
Combined stiffener shell section modulus	S	I / MAX(d-1 , d-2)	0.295011	in^3

d_shell = (tc-nominal - CA-shell) / 2
d_shell = (0.18750 - 0.0) / 2
d_shell = 0.093750 in

d_stiff = cy + (tc-nominal - CA-shell)
d_stiff = 0.5860 + (0.18750 - 0.0)
d_stiff = 0.77350 in

I_1 = Ic + (Area * (Distance^2))
I_1 = 0.3460 + (0.9440 * (0.77350^2))
I_1 = 0.910797 in^4

I_2 = Ic + (Area * (Distance^2))
I_2 = 0.00116814 + (0.398726 * (0.093750^2))
I_2 = 0.00467257 in^4

A_sum = A_1 + A_2
A_sum = 0.9440 + 0.398726
A_sum = 1.34273 in^2

I_sum = I_1 + I_2
I_sum = 0.910797 + 0.00467257
I_sum = 0.915470 in^4

c_combined = ((Centroid-1 * Area-1) + (Centroid-2 * Area-2)) / (Area-1 + Area-2)
c_combined = ((0.77350 * 0.9440) + (0.093750 * 0.398726)) / (0.9440 + 0.398726)
c_combined = 0.571646 in

I_combined = Ic - (Area * (Distance^2))
I_combined = 0.915470 - (1.34273 * (0.571646^2))
I_combined = 0.476694 in^4

e1 = c_combined
e1 = 0.571646
e1 = 0.571646 in

e2 = ((tc-nominal - CA-shell) + L1-angle) - e1
e2 = ((0.18750 - 0.0) + 2.0) - 0.571646
e2 = 1.61585 in

S = I / MAX(d-1 , d-2)
S = 0.476694 / MAX(0.571646 , 1.61585)
S = 0.295011 in^3

Design Requirements per API-650 Section 5
A_roof = Compression Region Required Area for Self Supported Cone Roof per *API-650 5.10.5.2* (in^2)
Fa = Least Allowable Tensile Stress for the Materials in the Roof-To-Shell Joint (psi)
Fy = Minimum Specified Yield Strength (psi)
Max-p = Maximum Allowable Load for the Actual Resisting Area per *API-650 5.10.5.2* (psf)
p = Max Gravity Load per *API-650 5.2.2 e)* (psf)

Fy = 28.90e3 psi
p = 27.9380 psf

Fa = 0.6 * Fy
Fa = 0.6 * 28.90e3
Fa = 17.340e3 psi

A_roof = (p * (D^2)) / (8 * Fa * TAN(theta))
A_roof = (27.9380 * (13.2217^2)) / (8 * 17.340e3 * TAN(9.46232))
A_roof = 0.211242 in^2

A_detail >= A_roof ==> PASS

Max-p = (A_detail / (D^2)) * 8 * Fa * TAN(theta)
Max-p = (1.87777 / (13.2217^2)) * 8 * 17.340e3 * TAN(9.46232)
Max-p = 248.347 psf

Internal Pressure - Appendix F Requirements
A_actual = Area resisting compressive force (in^2)
D = Tank nominal diameter (ft)
DLR = Nominal weight of roof plates and attached structural (lbf)
DLS = Nominal weight of shell plates and framing (lbf)
Fp = Internal Pressure Combination Factor
Fy = Minimum specified yield-strength of the materials in the roof-to-shell junction (psi)
ID = Tank inside diameter (ft)
MDL = Moment About the Shell-to-Bottom Joint from the Nominal Weight of the Shell and Roof Structural Supported by the Shell that is not Attached to the Roof Plate (ft.lbf)
MDLR = Moment About the Shell-to-Bottom Joint from the Nominal Weight of the Roof Plate Plus any Structural Components Attached to the Roof (ft.lbf)
MF = Moment About the Shell-to-Bottom Joint from Liquid Weight (ft.lbf)
Mw = Wind Moment From Horizontal Plus Vertical Wind Pressures (ft.lbf)
Mws = Wind Moment From Horizontal Wind Pressure (ft.lbf)
P = Design pressure (psi)
P_uplift = Uplift due to internal pressure per *API-650 F.1.2* (lbf)
Theta angle = Angle between the roof and a horizontal plane at the roof-to-shell junction (deg)
W_add_DL = Additional dead load weight (lbf)
W_framing = Weight of framing supported by the shell and roof (lbf)
Wr = Roof plates weight (lbf)
Ws = Shell plates weight (lbf)
W_structural = Weight of roof attached structural (lbf)

A_actual = 1.87777 in^2
D = 13.2217 ft
DLR = 1.15682e3 lbf
DLS = 21.4007e3 lbf
Fp = 0.40
Fy = 28.90e3 psi
ID = 13.2217 ft
MDL = 141.476e3 ft.lbf
MDLR = 7.64751e3 ft.lbf
MF = 98.7070e3 ft.lbf
Mw = 223.420e3 ft.lbf
Mws = 210.056e3 ft.lbf
P = 0.0 psi
Theta angle = 9.46232 deg
W_add_DL = 0.0 lbf
W_framing = 136.572 lbf
Wr = 1.11122e3 lbf
Ws = 21.2641e3 lbf
W_structural = 45.5909 lbf

P_uplift = P * pi * ((ID^2) / 4)
P_uplift = 0.0 * pi * ((158.660^2) / 4)
P_uplift = 0.0 lbf

P_uplift <= Wr , Tank design does not need to meet App. F requirements.

P_F51 = Maximum allowable internal pressure for the actual resisting area per *API 650 F.5.1* (inH2O)
P_max_internal = Maximum allowable internal pressure (psi)

P_std = 2.50 psi

P_F51 = ((0.962 * Fy * TAN(Theta angle) * A_actual) / (D^2)) + ((0.245 * DLR) / (D^2))
P_F51 = ((0.962 * 28.90e3 * TAN(9.46232) * 1.87777) / (13.2217^2)) + ((0.245 * 1.15682e3) / (13.2217^2))
P_F51 = 51.3941 inH2O

P_max_internal = MIN(P_std , P_F51)
P_max_internal = MIN(2.50 , 1.85668)
P_max_internal = 1.85668 psi

Shell Design [Back]

Ac = Convective Design Response Spectrum Acceleration Coefficient
Ai = Impulsive Design Response Spectrum Acceleration Coefficient
Av = Vertical ground acceleration coefficient description
CG-shell = Shell center of gravity (ft)
D = Tank Nominal Diameter per *API-650 5.6.1.1 Note 1* (ft)
d-ins = Insulation Density (lbf/ft^3)
G = Product Design Specific Gravity
Gt = Hydrotest Specific Gravity
H = Shell height (ft)
H-Hydrotest-L = Max Hydrotest Liquid Level (ft)
HL = Max Liquid Level (ft)
h-min = Minimum Shell Course Height per *API-650 5.6.1.2* (in)
Pe = Design External Pressure (psf)
Pi = Design Internal Pressure (psi)
Rwi = Impulsive Force Reduction Factor
t-ins = Insulation Thickness (in)
V = Wind velocity (mile/hr)
W-ins = Shell Insulation Weight (lbf)
W-shell = Shell Nominal Weight (lb)
W-shell-add = Shell Additional Weight (lb)
W-shell-corr = Shell Corroded Weight (lb)

Ac = 0.04750
Ai = 0.06750
Av = 0.10080
D = 13.2217 ft
d-ins = 8.0 lbf/ft^3
G = 1.0
Gt = 1.0
H = 60.4167 ft
H-Hydrotest-L = 60.4167 ft
HL = 60.4167 ft
h-min = 30.0 in
Pe = 0.0 psf
Pi = 0.0 psi
Rwi = 4.0
t-ins = 0.0 in
V = 81.90 mile/hr
W-shell-add = 0.0 lb

API-650 Design Method: One Foot (1ft)

Rwi = Impulsive Force Reduction Factor

Rwi = 4.0

Course # 1 (bottom course) Design

CA = Corrosion allowance per *API-650 5.3.2* (in)
D1 = Shell Course Centerline Diameter (in)
H = Design Liquid Level per *API-650 5.6.3.2* (ft)
H' = Effective Design Liquid Level per *API-650 Section F.2* (ft)
h1 = Course Height (ft)

H-Hydrotest = Hydrotest Liquid Level per *API-650 5.6.3.2* (ft)
H-max = Maximum Liquid Level for the Installed Thickness (ft)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (ft)
Ht' = Effective Hydrostatic Test Liquid Level per *API-650 F.2* (ft)
JE = Joint efficiency
loc = Course Location (ft)
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (inH2O)
Rwi = Impulsive Force Reduction Factor
t = Installed Thickness (in)
t_d = Course Design Thickness per *API-650 Section S.3.2.2.3* (in)
t-min = Minimum Required Thickness (in)
t_t = Course Hydrostatic Test Thickness per *S.3.2.2.3* (in)
W-1 = Shell Course Nominal Weight (lb)
W-1-corr = Shell Course Nominal Weight (lb)

CA = 0.0 in
H = 60.4167 ft
h1 = 5.0 ft
H-Hydrotest = 60.4167 ft
JE = 0.70
loc = 0.0 ft
Ma = A240-304
Rwi = 4.0
t = 0.3750 in

Shell Course Center of Gravity (CG-1) = 2.50 ft

D1 = ID + t
D1 = 158.660 + 0.3750
D1 = 159.035 in

W-1 = pi * Dc * t * h1 * d
W-1 = pi * 159.035 * 0.3750 * 60.0 * 0.290
W-1 = 3.26004e3 lb

W-1-corr = pi * Dc * (t - CA) * h1 * d
W-1-corr = pi * 159.035 * (0.3750 - 0.0) * 60.0 * 0.290
W-1-corr = 3.26004e3 lb

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St) = 27.0e3 psi

Thickness Required by Erection
As per API-650 S.3.2.1.1 and 5.6.1.1, Thickness Required by Erection (t_erec) = 0.18750 in

Thickness Required by Design
H' = H
H' = 60.4167
H' = 60.4167 ft

t_d = ((2.6 * D * (H' - 1) * SG) / (JE * Sd)) + CA
t_d = ((2.6 * 13.2217 * (60.4167 - 1) * 1.0) / (0.70 * 22.50e3)) + 0.0
t_d = 0.129684 in

Hydrostatic Test Required Thickness
Ht' = H-Hydrotest
Ht' = 60.4167
Ht' = 60.4167 ft

t_t = (2.6 * D * (Ht' - 1) * SGt) / (JE * St)
t_t = (2.6 * 13.2217 * (60.4167 - 1) * 1.0) / (0.70 * 27.0e3)
t_t = 0.108070 in

Seismic Design Required Thickness
Nc = Convective Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Nh = Product Hydrostatic Membrane Force per *API 650 Section E.6.1.4 and Section 5.6.3.2* (lbf/in)
Ni = Impulsive Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Sd-seismic = Maximum Allowable Hoop Tension Membrane Stress per *API-650 E.6.2.4* (psi)
ts = Seismic Minimum Thickness per *API 650 Section E.6.2.4* (in)

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 60.4167 ft

Ni = 1.39 * Ai * G * (D^2)
Ni = 1.39 * 0.06750 * 1.0 * (13.2217^2)
Ni = 16.4018 lbf/in

Nc = (0.98 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (0.98 * 0.04750 * 1.0 * (13.2217^2) * COSH(((3.68 * (60.4167 - 60.4167)) / 13.2217))) / COSH(((3.68 * 60.4167) / 13.2217))
Nc = 810.026e-9 lbf/in

Nh = 2.6 * (H - H_offset) * D * G
Nh = 2.6 * (60.4167 - 0.0) * 13.2217 * 1.0
Nh = 2.07690e3 lbf/in

sigma_T- = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)
sigma_T+ = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)

sigma_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T+ = (2.07690e3 + SQRT(((16.4018^2) + (810.026e-9^2) + (((0.10080 * 2.07690e3) / 2.5)^2)))) / MAX((0.3750 - 0.0) , 0.0001)
sigma_T+ = 5.76596e3 psi

sigma_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T- = (2.07690e3 - SQRT(((16.4018^2) + (810.026e-9^2) + (((0.10080 * 2.07690e3) / 2.5)^2)))) / MAX((0.3750 - 0.0) , 0.0001)
sigma_T- = 5.31086e3 psi

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 22.50e3) , (0.9 * 28.90e3 * 0.70))
Sd-seismic = 18.2070e3 psi

ts = ((sigma_T+ * (tn - CA)) / S_membrane) + CA
ts = ((5.76596e3 * (0.3750 - 0.0)) / 18.2070e3) + 0.0
ts = 0.118758 in

Minimum Required Thickness
t-min = MAX(t_erec , t_d , t_t , ts)
t-min = MAX(0.18750 , 0.129684 , 0.108070 , 0.118758)
t-min = 0.18750 in

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (2.6 * D * SG)) + 1) + loc
H-max = ((((0.3750 - 0.0) * 22.50e3 * 0.70) / (2.6 * 13.2217 * 1.0)) + 1) + 0.0
H-max = 172.812 ft

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(172.812 , 0)
H-max-@-Pi = 172.812 ft

Pi-max-@-H = MAX((((H-max - (H + loc)) * (12 * SG)) + P) , 0)
Pi-max-@-H = MAX((((172.812 - (60.4167 + 0.0)) * (12 * 1.0)) + 0.0) , 0)
Pi-max-@-H = 1.34874e3 inH2O

Course # 2 Design
CA = Corrosion allowance per *API-650 5.3.2* (in)
D2 = Shell Course Centerline Diameter (in)
H = Design Liquid Level per *API-650 5.6.3.2* (ft)
H' = Effective Design Liquid Level per *API-650 Section F.2* (ft)
h2 = Course Height (ft)
H-Hydrotest = Hydrotest Liquid Level per *API-650 5.6.3.2* (ft)
H-max = Maximum Liquid Level for the Installed Thickness (ft)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (ft)
Ht' = Effective Hydrostatic Test Liquid Level per *API-650 F.2* (ft)
JE = Joint efficiency
loc = Course Location (ft)
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (inH2O)
Rwi = Impulsive Force Reduction Factor
t = Installed Thickness (in)
t_d = Course Design Thickness per *API-650 Section S.3.2.2.3* (in)
t-min = Minimum Required Thickness (in)
t_t = Course Hydrostatic Test Thickness per *S.3.2.2.3* (in)
W-2 = Shell Course Nominal Weight (lb)
W-2-corr = Shell Course Nominal Weight (lb)

CA = 0.0 in
H = 55.4167 ft
h2 = 5.0 ft
H-Hydrotest = 55.4167 ft
JE = 0.70
loc = 5.0 ft
Ma = A240-304
Rwi = 4.0
t = 0.18750 in

Shell Course Center of Gravity (CG-2) = 7.50 ft

D2 = ID + t
D2 = 158.660 + 0.18750
D2 = 158.848 in

W-2 = pi * Dc * t * h2 * d
W-2 = pi * 158.848 * 0.18750 * 60.0 * 0.290
W-2 = 1.62810e3 lb

W-2-corr = pi * Dc * (t - CA) * h2 * d
W-2-corr = pi * 158.848 * (0.18750 - 0.0) * 60.0 * 0.290
W-2-corr = 1.62810e3 lb

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St) = 27.0e3 psi

Thickness Required by Erection
As per API-650 S.3.2.1.1 and 5.6.1.1, Thickness Required by Erection (t_erec) = 0.18750 in

Thickness Required by Design
H' = H
H' = 55.4167
H' = 55.4167 ft

t_d = ((2.6 * D * (H' - 1) * SG) / (JE * Sd)) + CA
t_d = ((2.6 * 13.2217 * (55.4167 - 1) * 1.0) / (0.70 * 22.50e3)) + 0.0
t_d = 0.118771 in

Hydrostatic Test Required Thickness
Ht' = H-Hydrotest
Ht' = 55.4167
Ht' = 55.4167 ft

t_t = (2.6 * D * (Ht' - 1) * SGt) / (JE * St)
t_t = (2.6 * 13.2217 * (55.4167 - 1) * 1.0) / (0.70 * 27.0e3)
t_t = 0.0989760 in

Seismic Design Required Thickness
Nc = Convective Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Nh = Product Hydrostatic Membrane Force per *API 650 Section E.6.1.4 and Section 5.6.3.2* (lbf/in)
Ni = Impulsive Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Sd-seismic = Maximum Allowable Hoop Tension Membrane Stress per *API-650 E.6.2.4* (psi)
ts = Seismic Minimum Thickness per *API 650 Section E.6.2.4* (in)

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 55.4167 ft

Ni = 1.39 * Ai * G * (D^2)
Ni = 1.39 * 0.06750 * 1.0 * (13.2217^2)
Ni = 16.4018 lbf/in

Nc = (0.98 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (0.98 * 0.04750 * 1.0 * (13.2217^2) * COSH(((3.68 * (60.4167 - 55.4167)) / 13.2217))) / COSH(((3.68 * 60.4167) / 13.2217))
Nc = 1.72947e-6 lbf/in

Nh = 2.6 * (H - H_offset) * D * G

Nh = 2.6 * (55.4167 - 0.0) * 13.2217 * 1.0
Nh = 1.90502e3 lbf/in

sigma_T- = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)
sigma_T+ = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)

sigma_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T+ = (1.90502e3 + SQRT(((16.4018^2) + (1.72947e-6^2) + (((0.10080 * 1.90502e3) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T+ = 10.5790e3 psi

sigma_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T- = (1.90502e3 - SQRT(((16.4018^2) + (1.72947e-6^2) + (((0.10080 * 1.90502e3) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T- = 9.74122e3 psi

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 22.50e3) , (0.9 * 28.90e3 * 0.70))
Sd-seismic = 18.2070e3 psi

ts = ((sigma_T+ * (tn - CA)) / S_membrane) + CA
ts = ((10.5790e3 * (0.18750 - 0.0)) / 18.2070e3) + 0.0
ts = 0.108945 in

Minimum Required Thickness
t-min = MAX(t_erec , t_d , t_t , ts)
t-min = MAX(0.18750 , 0.118771 , 0.0989760 , 0.108945)
t-min = 0.18750 in

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (2.6 * D * SG)) + 1) + loc
H-max = ((((0.18750 - 0.0) * 22.50e3 * 0.70) / (2.6 * 13.2217 * 1.0)) + 1) + 5.0
H-max = 91.9058 ft

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(91.9058 , 0)
H-max-@-Pi = 91.9058 ft

Pi-max-@-H = MAX((((H-max - (H + loc)) * (12 * SG)) + P) , 0)
Pi-max-@-H = MAX((((91.9058 - (55.4167 + 5.0)) * (12 * 1.0)) + 0.0) , 0)
Pi-max-@-H = 377.869 inH2O

Course # 3 Design
CA = Corrosion allowance per *API-650 5.3.2* (in)
D3 = Shell Course Centerline Diameter (in)
H = Design Liquid Level per *API-650 5.6.3.2* (ft)
H' = Effective Design Liquid Level per *API-650 Section F.2* (ft)
h3 = Course Height (ft)
H-Hydrotest = Hydrotest Liquid Level per *API-650 5.6.3.2* (ft)
H-max = Maximum Liquid Level for the Installed Thickness (ft)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (ft)
Ht' = Effective Hydrostatic Test Liquid Level per *API-650 F.2* (ft)
JE = Joint efficiency
loc = Course Location (ft)
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level

(inH2O)
Rwi = Impulsive Force Reduction Factor
t = Installed Thickness (in)
t_d = Course Design Thickness per *API-650 Section S.3.2.2.3* (in)
t-min = Minimum Required Thickness (in)
t_t = Course Hydrostatic Test Thickness per *S.3.2.2.3* (in)
W-3 = Shell Course Nominal Weight (lb)
W-3-corr = Shell Course Nominal Weight (lb)

CA = 0.0 in
H = 50.4167 ft
h3 = 5.0 ft
H-Hydrotest = 50.4167 ft
JE = 0.70
loc = 10.0 ft
Ma = A240-304
Rwi = 4.0
t = 0.18750 in

Shell Course Center of Gravity (CG-3) = 12.50 ft

D3 = ID + t
D3 = 158.660 + 0.18750
D3 = 158.848 in

W-3 = pi * Dc * t * h3 * d
W-3 = pi * 158.848 * 0.18750 * 60.0 * 0.290
W-3 = 1.62810e3 lb

W-3-corr = pi * Dc * (t - CA) * h3 * d
W-3-corr = pi * 158.848 * (0.18750 - 0.0) * 60.0 * 0.290
W-3-corr = 1.62810e3 lb

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St) = 27.0e3 psi

Thickness Required by Erection
As per API-650 S.3.2.1.1 and 5.6.1.1, Thickness Required by Erection (t_erec) = 0.18750 in

Thickness Required by Design
H' = H
H' = 50.4167
H' = 50.4167 ft

t_d = ((2.6 * D * (H' - 1) * SG) / (JE * Sd)) + CA
t_d = ((2.6 * 13.2217 * (50.4167 - 1) * 1.0) / (0.70 * 22.50e3)) + 0.0
t_d = 0.107858 in

Hydrostatic Test Required Thickness
Ht' = H-Hydrotest
Ht' = 50.4167
Ht' = 50.4167 ft

t_t = (2.6 * D * (Ht' - 1) * SGt) / (JE * St)
t_t = (2.6 * 13.2217 * (50.4167 - 1) * 1.0) / (0.70 * 27.0e3)
t_t = 0.0898817 in

Seismic Design Required Thickness
Nc = Convective Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Nh = Product Hydrostatic Membrane Force per *API 650 Section E.6.1.4 and Section 5.6.3.2* (lbf/in)
Ni = Impulsive Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Sd-seismic = Maximum Allowable Hoop Tension Membrane Stress per *API-650 E.6.2.4* (psi)
ts = Seismic Minimum Thickness per *API 650 Section E.6.2.4* (in)

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 50.4167 ft

Ni = 1.39 * Ai * G * (D^2)
Ni = 1.39 * 0.06750 * 1.0 * (13.2217^2)
Ni = 16.4018 lbf/in

Nc = (0.98 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (0.98 * 0.04750 * 1.0 * (13.2217^2) * COSH(((3.68 * (60.4167 - 50.4167)) / 13.2217))) / COSH(((3.68 * 60.4167) / 13.2217))
Nc = 6.57510e-6 lbf/in

Nh = 2.6 * (H - H_offset) * D * G
Nh = 2.6 * (50.4167 - 0.0) * 13.2217 * 1.0
Nh = 1.73314e3 lbf/in

sigma_T- = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)
sigma_T+ = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)

sigma_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T+ = (1.73314e3 + SQRT(((16.4018^2) + (6.57510e-6^2) + (((0.10080 * 1.73314e3) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T+ = 9.62624e3 psi

sigma_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T- = (1.73314e3 - SQRT(((16.4018^2) + (6.57510e-6^2) + (((0.10080 * 1.73314e3) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T- = 8.86059e3 psi

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 22.50e3) , (0.9 * 28.90e3 * 0.70))
Sd-seismic = 18.2070e3 psi

ts = ((sigma_T+ * (tn - CA)) / S_membrane) + CA
ts = ((9.62624e3 * (0.18750 - 0.0)) / 18.2070e3) + 0.0
ts = 0.0991333 in

Minimum Required Thickness
t-min = MAX(t_erec , t_d , t_t , ts)
t-min = MAX(0.18750 , 0.107858 , 0.0898817 , 0.0991333)
t-min = 0.18750 in

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (2.6 * D * SG)) + 1) + loc
H-max = ((((0.18750 - 0.0) * 22.50e3 * 0.70) / (2.6 * 13.2217 * 1.0)) + 1) + 10.0

H-max = 96.9058 ft

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(96.9058 , 0)
H-max-@-Pi = 96.9058 ft

Pi-max-@-H = MAX((((H-max - (H + loc)) * (12 * SG)) + P) , 0)
Pi-max-@-H = MAX((((96.9058 - (50.4167 + 10.0)) * (12 * 1.0)) + 0.0) , 0)
Pi-max-@-H = 437.869 inH2O

Course # 4 Design

CA = Corrosion allowance per *API-650 5.3.2* (in)
D4 = Shell Course Centerline Diameter (in)
H = Design Liquid Level per *API-650 5.6.3.2* (ft)
H' = Effective Design Liquid Level per *API-650 Section F.2* (ft)
h4 = Course Height (ft)
H-Hydrotest = Hydrotest Liquid Level per *API-650 5.6.3.2* (ft)
H-max = Maximum Liquid Level for the Installed Thickness (ft)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (ft)
Ht' = Effective Hydrostatic Test Liquid Level per *API-650 F.2* (ft)
JE = Joint efficiency
loc = Course Location (ft)
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (inH2O)
Rwi = Impulsive Force Reduction Factor
t = Installed Thickness (in)
t_d = Course Design Thickness per *API-650 Section S.3.2.2.3* (in)
t-min = Minimum Required Thickness (in)
t_t = Course Hydrostatic Test Thickness per *S.3.2.2.3* (in)
W-4 = Shell Course Nominal Weight (lb)
W-4-corr = Shell Course Nominal Weight (lb)

CA = 0.0 in
H = 45.4167 ft
h4 = 5.0 ft
H-Hydrotest = 45.4167 ft
JE = 0.70
loc = 15.0 ft
Ma = A240-304
Rwi = 4.0
t = 0.18750 in

Shell Course Center of Gravity (CG-4) = 17.50 ft

D4 = ID + t
D4 = 158.660 + 0.18750
D4 = 158.848 in

W-4 = pi * Dc * t * h4 * d
W-4 = pi * 158.848 * 0.18750 * 60.0 * 0.290
W-4 = 1.62810e3 lb

W-4-corr = pi * Dc * (t - CA) * h4 * d
W-4-corr = pi * 158.848 * (0.18750 - 0.0) * 60.0 * 0.290
W-4-corr = 1.62810e3 lb

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St) = 27.0e3 psi

Thickness Required by Erection
As per API-650 S.3.2.1.1 and 5.6.1.1, Thickness Required by Erection (t_erec) = 0.18750 in

Thickness Required by Design
H' = H
H' = 45.4167
H' = 45.4167 ft

t_d = ((2.6 * D * (H' - 1) * SG) / (JE * Sd)) + CA
t_d = ((2.6 * 13.2217 * (45.4167 - 1) * 1.0) / (0.70 * 22.50e3)) + 0.0
t_d = 0.0969449 in

Hydrostatic Test Required Thickness
Ht' = H-Hydrotest
Ht' = 45.4167
Ht' = 45.4167 ft

t_t = (2.6 * D * (Ht' - 1) * SGt) / (JE * St)
t_t = (2.6 * 13.2217 * (45.4167 - 1) * 1.0) / (0.70 * 27.0e3)
t_t = 0.0807874 in

Seismic Design Required Thickness
Nc = Convective Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Nh = Product Hydrostatic Membrane Force per *API 650 Section E.6.1.4 and Section 5.6.3.2* (lbf/in)
Ni = Impulsive Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Sd-seismic = Maximum Allowable Hoop Tension Membrane Stress per *API-650 E.6.2.4* (psi)
ts = Seismic Minimum Thickness per *API 650 Section E.6.2.4* (in)

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 45.4167 ft

Ni = 1.39 * Ai * G * (D^2)
Ni = 1.39 * 0.06750 * 1.0 * (13.2217^2)
Ni = 16.4018 lbf/in

Nc = (0.98 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (0.98 * 0.04750 * 1.0 * (13.2217^2) * COSH(((3.68 * (60.4167 - 45.4167)) / 13.2217))) / COSH(((3.68 * 60.4167) / 13.2217))
Nc = 26.3473e-6 lbf/in

Nh = 2.6 * (H - H_offset) * D * G
Nh = 2.6 * (45.4167 - 0.0) * 13.2217 * 1.0
Nh = 1.56126e3 lbf/in

sigma_T- = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)
sigma_T+ = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)

sigma_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T+ = (1.56126e3 + SQRT(((16.4018^2) + (26.3473e-6^2) + (((0.10080 * 1.56126e3) / 2.5)^2)))) /

MAX((0.18750 - 0.0) , 0.0001)
sigma_T+ = 8.67365e3 psi

sigma_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T- = (1.56126e3 - SQRT(((16.4018^2) + (26.3473e-6^2) + (((0.10080 * 1.56126e3) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T- = 7.97977e3 psi

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 22.50e3) , (0.9 * 28.90e3 * 0.70))
Sd-seismic = 18.2070e3 psi

ts = ((sigma_T+ * (tn - CA)) / S_membrane) + CA
ts = ((8.67365e3 * (0.18750 - 0.0)) / 18.2070e3) + 0.0
ts = 0.0893233 in

Minimum Required Thickness
t-min = MAX(t_erec , t_d , t_t , ts)
t-min = MAX(0.18750 , 0.0969449 , 0.0807874 , 0.0893233)
t-min = 0.18750 in

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (2.6 * D * SG)) + 1) + loc
H-max = ((((0.18750 - 0.0) * 22.50e3 * 0.70) / (2.6 * 13.2217 * 1.0)) + 1) + 15.0
H-max = 101.906 ft

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(101.906 , 0)
H-max-@-Pi = 101.906 ft

Pi-max-@-H = MAX((((H-max - (H + loc)) * (12 * SG)) + P) , 0)
Pi-max-@-H = MAX((((101.906 - (45.4167 + 15.0)) * (12 * 1.0)) + 0.0) , 0)
Pi-max-@-H = 497.869 inH2O

Course # 5 Design
CA = Corrosion allowance per *API-650 5.3.2* (in)
D5 = Shell Course Centerline Diameter (in)
H = Design Liquid Level per *API-650 5.6.3.2* (ft)
H' = Effective Design Liquid Level per *API-650 Section F.2* (ft)
h5 = Course Height (ft)
H-Hydrotest = Hydrotest Liquid Level per *API-650 5.6.3.2* (ft)
H-max = Maximum Liquid Level for the Installed Thickness (ft)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (ft)
Ht' = Effective Hydrostatic Test Liquid Level per *API-650 F.2* (ft)
JE = Joint efficiency
loc = Course Location (ft)
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (inH2O)
Rwi = Impulsive Force Reduction Factor
t = Installed Thickness (in)
t_d = Course Design Thickness per *API-650 Section S.3.2.2.3* (in)
t-min = Minimum Required Thickness (in)
t_t = Course Hydrostatic Test Thickness per *S.3.2.2.3* (in)
W-5 = Shell Course Nominal Weight (lb)
W-5-corr = Shell Course Nominal Weight (lb)

CA = 0.0 in
H = 40.4167 ft
h5 = 5.0 ft
H-Hydrotest = 40.4167 ft
JE = 0.70
loc = 20.0 ft
Ma = A240-304
Rwi = 4.0
t = 0.18750 in

Shell Course Center of Gravity (CG-5) = 22.50 ft

D5 = ID + t
D5 = 158.660 + 0.18750
D5 = 158.848 in

W-5 = pi * Dc * t * h5 * d
W-5 = pi * 158.848 * 0.18750 * 60.0 * 0.290
W-5 = 1.62810e3 lb

W-5-corr = pi * Dc * (t - CA) * h5 * d
W-5-corr = pi * 158.848 * (0.18750 - 0.0) * 60.0 * 0.290
W-5-corr = 1.62810e3 lb

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St) = 27.0e3 psi

Thickness Required by Erection
As per API-650 S.3.2.1.1 and 5.6.1.1, Thickness Required by Erection (t_erec) = 0.18750 in

Thickness Required by Design
H' = H
H' = 40.4167
H' = 40.4167 ft

t_d = ((2.6 * D * (H' - 1) * SG) / (JE * Sd)) + CA
t_d = ((2.6 * 13.2217 * (40.4167 - 1) * 1.0) / (0.70 * 22.50e3)) + 0.0
t_d = 0.0860318 in

Hydrostatic Test Required Thickness
Ht' = H-Hydrotest
Ht' = 40.4167
Ht' = 40.4167 ft

t_t = (2.6 * D * (Ht' - 1) * SGt) / (JE * St)
t_t = (2.6 * 13.2217 * (40.4167 - 1) * 1.0) / (0.70 * 27.0e3)
t_t = 0.0716931 in

Seismic Design Required Thickness
Nc = Convective Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Nh = Product Hydrostatic Membrane Force per *API 650 Section E.6.1.4 and Section 5.6.3.2* (lbf/in)

Ni = Impulsive Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Sd-seismic = Maximum Allowable Hoop Tension Membrane Stress per *API-650 E.6.2.4* (psi)
ts = Seismic Minimum Thickness per *API 650 Section E.6.2.4* (in)

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 40.4167 ft

Ni = 1.39 * Ai * G * (D^2)
Ni = 1.39 * 0.06750 * 1.0 * (13.2217^2)
Ni = 16.4018 lbf/in

Nc = (0.98 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (0.98 * 0.04750 * 1.0 * (13.2217^2) * COSH(((3.68 * (60.4167 - 40.4167)) / 13.2217))) / COSH(((3.68 * 60.4167) / 13.2217))
Nc = 105.932e-6 lbf/in

Nh = 2.6 * (H - H_offset) * D * G
Nh = 2.6 * (40.4167 - 0.0) * 13.2217 * 1.0
Nh = 1.38938e3 lbf/in

sigma_T- = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)
sigma_T+ = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)

sigma_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T+ = (1.38938e3 + SQRT(((16.4018^2) + (105.932e-6^2) + (((0.10080 * 1.38938e3) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T+ = 7.72132e3 psi

sigma_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T- = (1.38938e3 - SQRT(((16.4018^2) + (105.932e-6^2) + (((0.10080 * 1.38938e3) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T- = 7.09870e3 psi

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 22.50e3) , (0.9 * 28.90e3 * 0.70))
Sd-seismic = 18.2070e3 psi

ts = ((sigma_T+ * (tn - CA)) / S_membrane) + CA
ts = ((7.72132e3 * (0.18750 - 0.0)) / 18.2070e3) + 0.0
ts = 0.0795160 in

Minimum Required Thickness
t-min = MAX(t_erec , t_d , t_t , ts)
t-min = MAX(0.18750 , 0.0860318 , 0.0716931 , 0.0795160)
t-min = 0.18750 in

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (2.6 * D * SG)) + 1) + loc
H-max = ((((0.18750 - 0.0) * 22.50e3 * 0.70) / (2.6 * 13.2217 * 1.0)) + 1) + 20.0
H-max = 106.906 ft

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(106.906 , 0)
H-max-@-Pi = 106.906 ft

Pi-max-@-H = MAX((((H-max - (H + loc)) * (12 * SG)) + P) , 0)
Pi-max-@-H = MAX((((106.906 - (40.4167 + 20.0)) * (12 * 1.0)) + 0.0) , 0)

Pi-max-@-H = 557.869 inH2O

Course # 6 Design

CA = Corrosion allowance per *API-650 5.3.2* (in)
D6 = Shell Course Centerline Diameter (in)
H = Design Liquid Level per *API-650 5.6.3.2* (ft)
H' = Effective Design Liquid Level per *API-650 Section F.2* (ft)
h6 = Course Height (ft)
H-Hydrotest = Hydrotest Liquid Level per *API-650 5.6.3.2* (ft)
H-max = Maximum Liquid Level for the Installed Thickness (ft)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (ft)
Ht' = Effective Hydrostatic Test Liquid Level per *API-650 F.2* (ft)
JE = Joint efficiency
loc = Course Location (ft)
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (inH2O)
Rwi = Impulsive Force Reduction Factor
t = Installed Thickness (in)
t_d = Course Design Thickness per *API-650 Section S.3.2.2.3* (in)
t-min = Minimum Required Thickness (in)
t_t = Course Hydrostatic Test Thickness per *S.3.2.2.3* (in)
W-6 = Shell Course Nominal Weight (lb)
W-6-corr = Shell Course Nominal Weight (lb)

CA = 0.0 in
H = 35.4167 ft
h6 = 5.0 ft
H-Hydrotest = 35.4167 ft
JE = 0.70
loc = 25.0 ft
Ma = A240-304
Rwi = 4.0
t = 0.18750 in

Shell Course Center of Gravity (CG-6) = 27.50 ft

D6 = ID + t
D6 = 158.660 + 0.18750
D6 = 158.848 in

W-6 = pi * Dc * t * h6 * d
W-6 = pi * 158.848 * 0.18750 * 60.0 * 0.290
W-6 = 1.62810e3 lb

W-6-corr = pi * Dc * (t - CA) * h6 * d
W-6-corr = pi * 158.848 * (0.18750 - 0.0) * 60.0 * 0.290
W-6-corr = 1.62810e3 lb

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St) = 27.0e3 psi

Thickness Required by Erection
As per API-650 S.3.2.1.1 and 5.6.1.1, Thickness Required by Erection (t_erec) = 0.18750 in

Thickness Required by Design
H' = H
H' = 35.4167
H' = 35.4167 ft

t_d = ((2.6 * D * (H' - 1) * SG) / (JE * Sd)) + CA
t_d = ((2.6 * 13.2217 * (35.4167 - 1) * 1.0) / (0.70 * 22.50e3)) + 0.0
t_d = 0.0751187 in

Hydrostatic Test Required Thickness
Ht' = H-Hydrotest
Ht' = 35.4167
Ht' = 35.4167 ft

t_t = (2.6 * D * (Ht' - 1) * SGt) / (JE * St)
t_t = (2.6 * 13.2217 * (35.4167 - 1) * 1.0) / (0.70 * 27.0e3)
t_t = 0.0625989 in

Seismic Design Required Thickness
Nc = Convective Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Nh = Product Hydrostatic Membrane Force per *API 650 Section E.6.1.4 and Section 5.6.3.2* (lbf/in)
Ni = Impulsive Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Sd-seismic = Maximum Allowable Hoop Tension Membrane Stress per *API-650 E.6.2.4* (psi)
ts = Seismic Minimum Thickness per *API 650 Section E.6.2.4* (in)

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 35.4167 ft

Ni = 1.39 * Ai * G * (D^2)
Ni = 1.39 * 0.06750 * 1.0 * (13.2217^2)
Ni = 16.4018 lbf/in

Nc = (0.98 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (0.98 * 0.04750 * 1.0 * (13.2217^2) * COSH(((3.68 * (60.4167 - 35.4167)) / 13.2217))) / COSH(((3.68 * 60.4167) / 13.2217))
Nc = 426.0e-6 lbf/in

Nh = 2.6 * (H - H_offset) * D * G
Nh = 2.6 * (35.4167 - 0.0) * 13.2217 * 1.0
Nh = 1.21750e3 lbf/in

sigma_T- = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)
sigma_T+ = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)

sigma_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T+ = (1.21750e3 + SQRT(((16.4018^2) + (426.0e-6^2) + (((0.10080 * 1.21750e3) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T+ = 6.76934e3 psi

sigma_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T- = (1.21750e3 - SQRT(((16.4018^2) + (426.0e-6^2) + (((0.10080 * 1.21750e3) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T- = 6.21727e3 psi

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 22.50e3) , (0.9 * 28.90e3 * 0.70))
Sd-seismic = 18.2070e3 psi

ts = ((sigma_T+ * (tn - CA)) / S_membrane) + CA
ts = ((6.76934e3 * (0.18750 - 0.0)) / 18.2070e3) + 0.0
ts = 0.0697123 in

Minimum Required Thickness
t-min = MAX(t_erec , t_d , t_t , ts)
t-min = MAX(0.18750 , 0.0751187 , 0.0625989 , 0.0697123)
t-min = 0.18750 in

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (2.6 * D * SG)) + 1) + loc
H-max = ((((0.18750 - 0.0) * 22.50e3 * 0.70) / (2.6 * 13.2217 * 1.0)) + 1) + 25.0
H-max = 111.906 ft

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(111.906 , 0)
H-max-@-Pi = 111.906 ft

Pi-max-@-H = MAX((((H-max - (H + loc)) * (12 * SG)) + P) , 0)
Pi-max-@-H = MAX((((111.906 - (35.4167 + 25.0)) * (12 * 1.0)) + 0.0) , 0)
Pi-max-@-H = 617.869 inH2O

Course # 7 Design
CA = Corrosion allowance per *API-650 5.3.2* (in)
D7 = Shell Course Centerline Diameter (in)
H = Design Liquid Level per *API-650 5.6.3.2* (ft)
H' = Effective Design Liquid Level per *API-650 Section F.2* (ft)
h7 = Course Height (ft)
H-Hydrotest = Hydrotest Liquid Level per *API-650 5.6.3.2* (ft)
H-max = Maximum Liquid Level for the Installed Thickness (ft)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (ft)
Ht' = Effective Hydrostatic Test Liquid Level per *API-650 F.2* (ft)
JE = Joint efficiency
loc = Course Location (ft)
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (inH2O)
Rwi = Impulsive Force Reduction Factor
t = Installed Thickness (in)
t_d = Course Design Thickness per *API-650 Section S.3.2.2.3* (in)
t-min = Minimum Required Thickness (in)
t_t = Course Hydrostatic Test Thickness per *S.3.2.2.3* (in)
W-7 = Shell Course Nominal Weight (lb)
W-7-corr = Shell Course Nominal Weight (lb)

CA = 0.0 in
H = 30.4167 ft
h7 = 5.0 ft
H-Hydrotest = 30.4167 ft
JE = 0.70
loc = 30.0 ft
Ma = A240-304

Rwi = 4.0
t = 0.18750 in

Shell Course Center of Gravity (CG-7) = 32.50 ft

D7 = ID + t
D7 = 158.660 + 0.18750
D7 = 158.848 in

W-7 = pi * Dc * t * h7 * d
W-7 = pi * 158.848 * 0.18750 * 60.0 * 0.290
W-7 = 1.62810e3 lb

W-7-corr = pi * Dc * (t - CA) * h7 * d
W-7-corr = pi * 158.848 * (0.18750 - 0.0) * 60.0 * 0.290
W-7-corr = 1.62810e3 lb

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St) = 27.0e3 psi

Thickness Required by Erection
As per API-650 S.3.2.1.1 and 5.6.1.1, Thickness Required by Erection (t_erec) = 0.18750 in

Thickness Required by Design
H' = H
H' = 30.4167
H' = 30.4167 ft

t_d = ((2.6 * D * (H' - 1) * SG) / (JE * Sd)) + CA
t_d = ((2.6 * 13.2217 * (30.4167 - 1) * 1.0) / (0.70 * 22.50e3)) + 0.0
t_d = 0.0642055 in

Hydrostatic Test Required Thickness
Ht' = H-Hydrotest
Ht' = 30.4167
Ht' = 30.4167 ft

t_t = (2.6 * D * (Ht' - 1) * SGt) / (JE * St)
t_t = (2.6 * 13.2217 * (30.4167 - 1) * 1.0) / (0.70 * 27.0e3)
t_t = 0.0535046 in

Seismic Design Required Thickness
Nc = Convective Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Nh = Product Hydrostatic Membrane Force per *API 650 Section E.6.1.4 and Section 5.6.3.2* (lbf/in)
Ni = Impulsive Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Sd-seismic = Maximum Allowable Hoop Tension Membrane Stress per *API-650 E.6.2.4* (psi)
ts = Seismic Minimum Thickness per *API 650 Section E.6.2.4* (in)

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 30.4167 ft

Ni = 1.39 * Ai * G * (D^2)
Ni = 1.39 * 0.06750 * 1.0 * (13.2217^2)

Ni = 16.4018 lbf/in

Nc = (0.98 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (0.98 * 0.04750 * 1.0 * (13.2217^2) * COSH(((3.68 * (60.4167 - 30.4167)) / 13.2217))) / COSH(((3.68 * 60.4167) / 13.2217))
Nc = 0.00171316 lbf/in

Nh = 2.6 * (H - H_offset) * D * G
Nh = 2.6 * (30.4167 - 0.0) * 13.2217 * 1.0
Nh = 1.04561e3 lbf/in

sigma_T- = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)
sigma_T+ = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)

sigma_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T+ = (1.04561e3 + SQRT(((16.4018^2) + (0.00171316^2) + (((0.10080 * 1.04561e3) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T+ = 5.81787e3 psi

sigma_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T- = (1.04561e3 - SQRT(((16.4018^2) + (0.00171316^2) + (((0.10080 * 1.04561e3) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T- = 5.33534e3 psi

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 22.50e3) , (0.9 * 28.90e3 * 0.70))
Sd-seismic = 18.2070e3 psi

ts = ((sigma_T+ * (tn - CA)) / S_membrane) + CA
ts = ((5.81787e3 * (0.18750 - 0.0)) / 18.2070e3) + 0.0
ts = 0.0599138 in

Minimum Required Thickness
t-min = MAX(t_erec , t_d , t_t , ts)
t-min = MAX(0.18750 , 0.0642055 , 0.0535046 , 0.0599138)
t-min = 0.18750 in

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (2.6 * D * SG)) + 1) + loc
H-max = ((((0.18750 - 0.0) * 22.50e3 * 0.70) / (2.6 * 13.2217 * 1.0)) + 1) + 30.0
H-max = 116.906 ft

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(116.906 , 0)
H-max-@-Pi = 116.906 ft

Pi-max-@-H = MAX((((H-max - (H + loc)) * (12 * SG)) + P) , 0)
Pi-max-@-H = MAX((((116.906 - (30.4167 + 30.0)) * (12 * 1.0)) + 0.0) , 0)
Pi-max-@-H = 677.869 inH2O

Course # 8 Design
CA = Corrosion allowance per *API-650 5.3.2* (in)
D8 = Shell Course Centerline Diameter (in)
H = Design Liquid Level per *API-650 5.6.3.2* (ft)
H' = Effective Design Liquid Level per *API-650 Section F.2* (ft)
h8 = Course Height (ft)

H-Hydrotest = Hydrotest Liquid Level per *API-650 5.6.3.2* (ft)
H-max = Maximum Liquid Level for the Installed Thickness (ft)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (ft)
Ht' = Effective Hydrostatic Test Liquid Level per *API-650 F.2* (ft)
JE = Joint efficiency
loc = Course Location (ft)
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (inH2O)
Rwi = Impulsive Force Reduction Factor
t = Installed Thickness (in)
t_d = Course Design Thickness per *API-650 Section S.3.2.2.3* (in)
t-min = Minimum Required Thickness (in)
t_t = Course Hydrostatic Test Thickness per *S.3.2.2.3* (in)
W-8 = Shell Course Nominal Weight (lb)
W-8-corr = Shell Course Nominal Weight (lb)

CA = 0.0 in
H = 25.4167 ft
h8 = 5.0 ft
H-Hydrotest = 25.4167 ft
JE = 0.70
loc = 35.0 ft
Ma = A240-304
Rwi = 4.0
t = 0.18750 in

Shell Course Center of Gravity (CG-8) = 37.50 ft

D8 = ID + t
D8 = 158.660 + 0.18750
D8 = 158.848 in

W-8 = pi * Dc * t * h8 * d
W-8 = pi * 158.848 * 0.18750 * 60.0 * 0.290
W-8 = 1.62810e3 lb

W-8-corr = pi * Dc * (t - CA) * h8 * d
W-8-corr = pi * 158.848 * (0.18750 - 0.0) * 60.0 * 0.290
W-8-corr = 1.62810e3 lb

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St) = 27.0e3 psi

Thickness Required by Erection
As per API-650 S.3.2.1.1 and 5.6.1.1, Thickness Required by Erection (t_erec) = 0.18750 in

Thickness Required by Design
H' = H
H' = 25.4167
H' = 25.4167 ft

t_d = ((2.6 * D * (H' - 1) * SG) / (JE * Sd)) + CA
t_d = ((2.6 * 13.2217 * (25.4167 - 1) * 1.0) / (0.70 * 22.50e3)) + 0.0
t_d = 0.0532924 in

Hydrostatic Test Required Thickness
Ht' = H-Hydrotest
Ht' = 25.4167
Ht' = 25.4167 ft

t_t = (2.6 * D * (Ht' - 1) * SGt) / (JE * St)
t_t = (2.6 * 13.2217 * (25.4167 - 1) * 1.0) / (0.70 * 27.0e3)
t_t = 0.0444103 in

Seismic Design Required Thickness
Nc = Convective Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Nh = Product Hydrostatic Membrane Force per *API 650 Section E.6.1.4 and Section 5.6.3.2* (lbf/in)
Ni = Impulsive Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Sd-seismic = Maximum Allowable Hoop Tension Membrane Stress per *API-650 E.6.2.4* (psi)
ts = Seismic Minimum Thickness per *API 650 Section E.6.2.4* (in)

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 25.4167 ft

Ni = 1.39 * Ai * G * (D^2)
Ni = 1.39 * 0.06750 * 1.0 * (13.2217^2)
Ni = 16.4018 lbf/in

Nc = (0.98 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (0.98 * 0.04750 * 1.0 * (13.2217^2) * COSH(((3.68 * (60.4167 - 25.4167)) / 13.2217))) / COSH(((3.68 * 60.4167) / 13.2217))
Nc = 0.00688947 lbf/in

Nh = 2.6 * (H - H_offset) * D * G
Nh = 2.6 * (25.4167 - 0.0) * 13.2217 * 1.0
Nh = 873.732 lbf/in

sigma_T- = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)
sigma_T+ = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)

sigma_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T+ = (873.732 + SQRT(((16.4018^2) + (0.00688947^2) + (((0.10080 * 873.732) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T+ = 4.86716e3 psi

sigma_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T- = (873.732 - SQRT(((16.4018^2) + (0.00688947^2) + (((0.10080 * 873.732) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T- = 4.45265e3 psi

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 22.50e3) , (0.9 * 28.90e3 * 0.70))
Sd-seismic = 18.2070e3 psi

ts = ((sigma_T+ * (tn - CA)) / S_membrane) + CA
ts = ((4.86716e3 * (0.18750 - 0.0)) / 18.2070e3) + 0.0
ts = 0.0501231 in

Minimum Required Thickness
t-min = MAX(t_erec , t_d , t_t , ts)
t-min = MAX(0.18750 , 0.0532924 , 0.0444103 , 0.0501231)
t-min = 0.18750 in

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (2.6 * D * SG)) + 1) + loc
H-max = ((((0.18750 - 0.0) * 22.50e3 * 0.70) / (2.6 * 13.2217 * 1.0)) + 1) + 35.0
H-max = 121.906 ft

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(121.906 , 0)
H-max-@-Pi = 121.906 ft

Pi-max-@-H = MAX((((H-max - (H + loc)) * (12 * SG)) + P) , 0)
Pi-max-@-H = MAX((((121.906 - (25.4167 + 35.0)) * (12 * 1.0)) + 0.0) , 0)
Pi-max-@-H = 737.869 inH2O

Course # 9 Design

CA = Corrosion allowance per *API-650 5.3.2* (in)
D9 = Shell Course Centerline Diameter (in)
H = Design Liquid Level per *API-650 5.6.3.2* (ft)
H' = Effective Design Liquid Level per *API-650 Section F.2* (ft)
h9 = Course Height (ft)
H-Hydrotest = Hydrotest Liquid Level per *API-650 5.6.3.2* (ft)
H-max = Maximum Liquid Level for the Installed Thickness (ft)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (ft)
Ht' = Effective Hydrostatic Test Liquid Level per *API-650 F.2* (ft)
JE = Joint efficiency
loc = Course Location (ft)
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (inH2O)
Rwi = Impulsive Force Reduction Factor
t = Installed Thickness (in)
t_d = Course Design Thickness per *API-650 Section S.3.2.2.3* (in)
t-min = Minimum Required Thickness (in)
t_t = Course Hydrostatic Test Thickness per *S.3.2.2.3* (in)
W-9 = Shell Course Nominal Weight (lb)
W-9-corr = Shell Course Nominal Weight (lb)

CA = 0.0 in
H = 20.4167 ft
h9 = 5.0 ft
H-Hydrotest = 20.4167 ft
JE = 0.70
loc = 40.0 ft
Ma = A240-304
Rwi = 4.0
t = 0.18750 in

Shell Course Center of Gravity (CG-9) = 42.50 ft

D9 = ID + t
D9 = 158.660 + 0.18750
D9 = 158.848 in

W-9 = pi * Dc * t * h9 * d
W-9 = pi * 158.848 * 0.18750 * 60.0 * 0.290
W-9 = 1.62810e3 lb

W-9-corr = pi * Dc * (t - CA) * h9 * d
W-9-corr = pi * 158.848 * (0.18750 - 0.0) * 60.0 * 0.290
W-9-corr = 1.62810e3 lb

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St) = 27.0e3 psi

Thickness Required by Erection
As per API-650 S.3.2.1.1 and 5.6.1.1, Thickness Required by Erection (t_erec) = 0.18750 in

Thickness Required by Design
H' = H
H' = 20.4167
H' = 20.4167 ft

t_d = ((2.6 * D * (H' - 1) * SG) / (JE * Sd)) + CA
t_d = ((2.6 * 13.2217 * (20.4167 - 1) * 1.0) / (0.70 * 22.50e3)) + 0.0
t_d = 0.0423793 in

Hydrostatic Test Required Thickness
Ht' = H-Hydrotest
Ht' = 20.4167
Ht' = 20.4167 ft

t_t = (2.6 * D * (Ht' - 1) * SGt) / (JE * St)
t_t = (2.6 * 13.2217 * (20.4167 - 1) * 1.0) / (0.70 * 27.0e3)
t_t = 0.0353161 in

Seismic Design Required Thickness
Nc = Convective Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Nh = Product Hydrostatic Membrane Force per *API 650 Section E.6.1.4 and Section 5.6.3.2* (lbf/in)
Ni = Impulsive Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Sd-seismic = Maximum Allowable Hoop Tension Membrane Stress per *API-650 E.6.2.4* (psi)
ts = Seismic Minimum Thickness per *API 650 Section E.6.2.4* (in)

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 20.4167 ft

Ni = 1.39 * Ai * G * (D^2)
Ni = 1.39 * 0.06750 * 1.0 * (13.2217^2)
Ni = 16.4018 lbf/in

Nc = (0.98 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (0.98 * 0.04750 * 1.0 * (13.2217^2) * COSH(((3.68 * (60.4167 - 20.4167)) / 13.2217))) / COSH(((3.68 * 60.4167) / 13.2217))
Nc = 0.0277060 lbf/in

Nh = 2.6 * (H - H_offset) * D * G

Nh = 2.6 * (20.4167 - 0.0) * 13.2217 * 1.0
Nh = 701.850 lbf/in

sigma_T- = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)
sigma_T+ = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)

sigma_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T+ = (701.850 + SQRT(((16.4018^2) + (0.0277060^2) + (((0.10080 * 701.850) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T+ = 3.91764e3 psi

sigma_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T- = (701.850 - SQRT(((16.4018^2) + (0.0277060^2) + (((0.10080 * 701.850) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T- = 3.56876e3 psi

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 22.50e3) , (0.9 * 28.90e3 * 0.70))
Sd-seismic = 18.2070e3 psi

ts = ((sigma_T+ * (tn - CA)) / S_membrane) + CA
ts = ((3.91764e3 * (0.18750 - 0.0)) / 18.2070e3) + 0.0
ts = 0.0403448 in

Minimum Required Thickness
t-min = MAX(t_erec , t_d , t_t , ts)
t-min = MAX(0.18750 , 0.0423793 , 0.0353161 , 0.0403448)
t-min = 0.18750 in

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (2.6 * D * SG)) + 1) + loc
H-max = ((((0.18750 - 0.0) * 22.50e3 * 0.70) / (2.6 * 13.2217 * 1.0)) + 1) + 40.0
H-max = 126.906 ft

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(126.906 , 0)
H-max-@-Pi = 126.906 ft

Pi-max-@-H = MAX((((H-max - (H + loc)) * (12 * SG)) + P) , 0)
Pi-max-@-H = MAX((((126.906 - (20.4167 + 40.0)) * (12 * 1.0)) + 0.0) , 0)
Pi-max-@-H = 797.869 inH2O

Course # 10 Design
CA = Corrosion allowance per *API-650 5.3.2* (in)
D10 = Shell Course Centerline Diameter (in)
H = Design Liquid Level per *API-650 5.6.3.2* (ft)
H' = Effective Design Liquid Level per *API-650 Section F.2* (ft)
h10 = Course Height (ft)
H-Hydrotest = Hydrotest Liquid Level per *API-650 5.6.3.2* (ft)
H-max = Maximum Liquid Level for the Installed Thickness (ft)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (ft)
Ht' = Effective Hydrostatic Test Liquid Level per *API-650 F.2* (ft)
JE = Joint efficiency
loc = Course Location (ft)
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level

(inH2O)
Rwi = Impulsive Force Reduction Factor
t = Installed Thickness (in)
t_d = Course Design Thickness per *API-650 Section S.3.2.2.3* (in)
t-min = Minimum Required Thickness (in)
t_t = Course Hydrostatic Test Thickness per *S.3.2.2.3* (in)
W-10 = Shell Course Nominal Weight (lb)
W-10-corr = Shell Course Nominal Weight (lb)

CA = 0.0 in
H = 15.4167 ft
h10 = 4.0 ft
H-Hydrotest = 15.4167 ft
JE = 0.70
loc = 45.0 ft
Ma = A240-304
Rwi = 4.0
t = 0.18750 in

Shell Course Center of Gravity (CG-10) = 47.0 ft

D10 = ID + t
D10 = 158.660 + 0.18750
D10 = 158.848 in

W-10 = pi * Dc * t * h10 * d
W-10 = pi * 158.848 * 0.18750 * 48.0 * 0.290
W-10 = 1.30248e3 lb

W-10-corr = pi * Dc * (t - CA) * h10 * d
W-10-corr = pi * 158.848 * (0.18750 - 0.0) * 48.0 * 0.290
W-10-corr = 1.30248e3 lb

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St) = 27.0e3 psi

Thickness Required by Erection
As per API-650 S.3.2.1.1 and 5.6.1.1, Thickness Required by Erection (t_erec) = 0.18750 in

Thickness Required by Design
H' = H
H' = 15.4167
H' = 15.4167 ft

t_d = ((2.6 * D * (H' - 1) * SG) / (JE * Sd)) + CA
t_d = ((2.6 * 13.2217 * (15.4167 - 1) * 1.0) / (0.70 * 22.50e3)) + 0.0
t_d = 0.0314662 in

Hydrostatic Test Required Thickness
Ht' = H-Hydrotest
Ht' = 15.4167
Ht' = 15.4167 ft

t_t = (2.6 * D * (Ht' - 1) * SGt) / (JE * St)
t_t = (2.6 * 13.2217 * (15.4167 - 1) * 1.0) / (0.70 * 27.0e3)
t_t = 0.0262218 in

Seismic Design Required Thickness
Nc = Convective Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Nh = Product Hydrostatic Membrane Force per *API 650 Section E.6.1.4 and Section 5.6.3.2* (lbf/in)
Ni = Impulsive Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Sd-seismic = Maximum Allowable Hoop Tension Membrane Stress per *API-650 E.6.2.4* (psi)
ts = Seismic Minimum Thickness per *API 650 Section E.6.2.4* (in)

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 15.4167 ft

Ni = 1.39 * Ai * G * (D^2)
Ni = 1.39 * 0.06750 * 1.0 * (13.2217^2)
Ni = 16.4018 lbf/in

Nc = (0.98 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (0.98 * 0.04750 * 1.0 * (13.2217^2) * COSH(((3.68 * (60.4167 - 15.4167)) / 13.2217))) / COSH(((3.68 * 60.4167) / 13.2217))
Nc = 0.111420 lbf/in

Nh = 2.6 * (H - H_offset) * D * G
Nh = 2.6 * (15.4167 - 0.0) * 13.2217 * 1.0
Nh = 529.968 lbf/in

sigma_T- = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)
sigma_T+ = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)

sigma_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T+ = (529.968 + SQRT(((16.4018^2) + (0.111420^2) + (((0.10080 * 529.968) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T+ = 2.97017e3 psi

sigma_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T- = (529.968 - SQRT(((16.4018^2) + (0.111420^2) + (((0.10080 * 529.968) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T- = 2.68283e3 psi

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 22.50e3) , (0.9 * 28.90e3 * 0.70))
Sd-seismic = 18.2070e3 psi

ts = ((sigma_T+ * (tn - CA)) / S_membrane) + CA
ts = ((2.97017e3 * (0.18750 - 0.0)) / 18.2070e3) + 0.0
ts = 0.0305875 in

Minimum Required Thickness
t-min = MAX(t_erec , t_d , t_t , ts)
t-min = MAX(0.18750 , 0.0314662 , 0.0262218 , 0.0305875)
t-min = 0.18750 in

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (2.6 * D * SG)) + 1) + loc
H-max = ((((0.18750 - 0.0) * 22.50e3 * 0.70) / (2.6 * 13.2217 * 1.0)) + 1) + 45.0

H-max = 131.906 ft

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(131.906 , 0)
H-max-@-Pi = 131.906 ft

Pi-max-@-H = MAX((((H-max - (H + loc)) * (12 * SG)) + P) , 0)
Pi-max-@-H = MAX((((131.906 - (15.4167 + 45.0)) * (12 * 1.0)) + 0.0) , 0)
Pi-max-@-H = 857.869 inH2O

Course # 11 Design

CA = Corrosion allowance per *API-650 5.3.2* (in)
D11 = Shell Course Centerline Diameter (in)
H = Design Liquid Level per *API-650 5.6.3.2* (ft)
H' = Effective Design Liquid Level per *API-650 Section F.2* (ft)
h11 = Course Height (ft)
H-Hydrotest = Hydrotest Liquid Level per *API-650 5.6.3.2* (ft)
H-max = Maximum Liquid Level for the Installed Thickness (ft)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (ft)
Ht' = Effective Hydrostatic Test Liquid Level per *API-650 F.2* (ft)
JE = Joint efficiency
loc = Course Location (ft)
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (inH2O)
Rwi = Impulsive Force Reduction Factor
t = Installed Thickness (in)
t_d = Course Design Thickness per *API-650 Section S.3.2.2.3* (in)
t-min = Minimum Required Thickness (in)
t_t = Course Hydrostatic Test Thickness per *S.3.2.2.3* (in)
W-11 = Shell Course Nominal Weight (lb)
W-11-corr = Shell Course Nominal Weight (lb)

CA = 0.0 in
H = 11.4167 ft
h11 = 4.0 ft
H-Hydrotest = 11.4167 ft
JE = 0.70
loc = 49.0 ft
Ma = A240-304
Rwi = 4.0
t = 0.18750 in

Shell Course Center of Gravity (CG-11) = 51.0 ft

D11 = ID + t
D11 = 158.660 + 0.18750
D11 = 158.848 in

W-11 = pi * Dc * t * h11 * d
W-11 = pi * 158.848 * 0.18750 * 48.0 * 0.290
W-11 = 1.30248e3 lb

W-11-corr = pi * Dc * (t - CA) * h11 * d
W-11-corr = pi * 158.848 * (0.18750 - 0.0) * 48.0 * 0.290
W-11-corr = 1.30248e3 lb

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St) = 27.0e3 psi

Thickness Required by Erection
As per API-650 S.3.2.1.1 and 5.6.1.1, Thickness Required by Erection (t_erec) = 0.18750 in

Thickness Required by Design
H' = H
H' = 11.4167
H' = 11.4167 ft

t_d = ((2.6 * D * (H' - 1) * SG) / (JE * Sd)) + CA
t_d = ((2.6 * 13.2217 * (11.4167 - 1) * 1.0) / (0.70 * 22.50e3)) + 0.0
t_d = 0.0227357 in

Hydrostatic Test Required Thickness
Ht' = H-Hydrotest
Ht' = 11.4167
Ht' = 11.4167 ft

t_t = (2.6 * D * (Ht' - 1) * SGt) / (JE * St)
t_t = (2.6 * 13.2217 * (11.4167 - 1) * 1.0) / (0.70 * 27.0e3)
t_t = 0.0189464 in

Seismic Design Required Thickness
Nc = Convective Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Nh = Product Hydrostatic Membrane Force per *API 650 Section E.6.1.4 and Section 5.6.3.2* (lbf/in)
Ni = Impulsive Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Sd-seismic = Maximum Allowable Hoop Tension Membrane Stress per *API-650 E.6.2.4* (psi)
ts = Seismic Minimum Thickness per *API 650 Section E.6.2.4* (in)

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 11.4167 ft

Ni = 1.39 * Ai * G * (D^2)
Ni = 1.39 * 0.06750 * 1.0 * (13.2217^2)
Ni = 16.4018 lbf/in

Nc = (0.98 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (0.98 * 0.04750 * 1.0 * (13.2217^2) * COSH(((3.68 * (60.4167 - 11.4167)) / 13.2217))) / COSH(((3.68 * 60.4167) / 13.2217))
Nc = 0.339213 lbf/in

Nh = 2.6 * (H - H_offset) * D * G
Nh = 2.6 * (11.4167 - 0.0) * 13.2217 * 1.0
Nh = 392.463 lbf/in

sigma_T- = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)
sigma_T+ = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)

sigma_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T+ = (392.463 + SQRT(((16.4018^2) + (0.339213^2) + (((0.10080 * 392.463) / 2.5)^2)))) /

MAX((0.18750 - 0.0) , 0.0001)
sigma_T+ = 2.21470e3 psi

sigma_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T- = (392.463 - SQRT(((16.4018^2) + (0.339213^2) + (((0.10080 * 392.463) / 2.5)^2)))) /
MAX((0.18750 - 0.0) , 0.0001)
sigma_T- = 1.97157e3 psi

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 22.50e3) , (0.9 * 28.90e3 * 0.70))
Sd-seismic = 18.2070e3 psi

ts = ((sigma_T+ * (tn - CA)) / S_membrane) + CA
ts = ((2.21470e3 * (0.18750 - 0.0)) / 18.2070e3) + 0.0
ts = 0.0228075 in

Minimum Required Thickness
t-min = MAX(t_erec , t_d , t_t , ts)
t-min = MAX(0.18750 , 0.0227357 , 0.0189464 , 0.0228075)
t-min = 0.18750 in

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (2.6 * D * SG)) + 1) + loc
H-max = ((((0.18750 - 0.0) * 22.50e3 * 0.70) / (2.6 * 13.2217 * 1.0)) + 1) + 49.0
H-max = 135.906 ft

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(135.906 , 0)
H-max-@-Pi = 135.906 ft

Pi-max-@-H = MAX((((H-max - (H + loc)) * (12 * SG)) + P) , 0)
Pi-max-@-H = MAX((((135.906 - (11.4167 + 49.0)) * (12 * 1.0)) + 0.0) , 0)
Pi-max-@-H = 905.869 inH2O

Course # 12 Design
CA = Corrosion allowance per *API-650 5.3.2* (in)
D12 = Shell Course Centerline Diameter (in)
H = Design Liquid Level per *API-650 5.6.3.2* (ft)
H' = Effective Design Liquid Level per *API-650 Section F.2* (ft)
h12 = Course Height (ft)
H-Hydrotest = Hydrotest Liquid Level per *API-650 5.6.3.2* (ft)
H-max = Maximum Liquid Level for the Installed Thickness (ft)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (ft)
Ht' = Effective Hydrostatic Test Liquid Level per *API-650 F.2* (ft)
JE = Joint efficiency
loc = Course Location (ft)
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (inH2O)
Rwi = Impulsive Force Reduction Factor
t = Installed Thickness (in)
t_d = Course Design Thickness per *API-650 Section S.3.2.2.3* (in)
t-min = Minimum Required Thickness (in)
t_t = Course Hydrostatic Test Thickness per *S.3.2.2.3* (in)
W-12 = Shell Course Nominal Weight (lb)
W-12-corr = Shell Course Nominal Weight (lb)

CA = 0.0 in
H = 7.41667 ft
h12 = 4.0 ft
H-Hydrotest = 7.41667 ft
JE = 0.70
loc = 53.0 ft
Ma = A240-304
Rwi = 4.0
t = 0.18750 in

Shell Course Center of Gravity (CG-12) = 55.0 ft

D12 = ID + t
D12 = 158.660 + 0.18750
D12 = 158.848 in

W-12 = pi * Dc * t * h12 * d
W-12 = pi * 158.848 * 0.18750 * 48.0 * 0.290
W-12 = 1.30248e3 lb

W-12-corr = pi * Dc * (t - CA) * h12 * d
W-12-corr = pi * 158.848 * (0.18750 - 0.0) * 48.0 * 0.290
W-12-corr = 1.30248e3 lb

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St) = 27.0e3 psi

Thickness Required by Erection
As per API-650 S.3.2.1.1 and 5.6.1.1, Thickness Required by Erection (t_erec) = 0.18750 in

Thickness Required by Design
H' = H
H' = 7.41667
H' = 7.41667 ft

t_d = ((2.6 * D * (H' - 1) * SG) / (JE * Sd)) + CA
t_d = ((2.6 * 13.2217 * (7.41667 - 1) * 1.0) / (0.70 * 22.50e3)) + 0.0
t_d = 0.0140052 in

Hydrostatic Test Required Thickness
Ht' = H-Hydrotest
Ht' = 7.41667
Ht' = 7.41667 ft

t_t = (2.6 * D * (Ht' - 1) * SGt) / (JE * St)
t_t = (2.6 * 13.2217 * (7.41667 - 1) * 1.0) / (0.70 * 27.0e3)
t_t = 0.0116710 in

Seismic Design Required Thickness
Nc = Convective Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Nh = Product Hydrostatic Membrane Force per *API 650 Section E.6.1.4 and Section 5.6.3.2* (lbf/in)

Ni = Impulsive Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Sd-seismic = Maximum Allowable Hoop Tension Membrane Stress per *API-650 E.6.2.4* (psi)
ts = Seismic Minimum Thickness per *API 650 Section E.6.2.4* (in)

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 7.41667 ft

Ni = 2.77 * Ai * G * (D^2) * ((Y / (0.75 * D)) - (0.5 * ((Y / (0.75 * D))^2)))
Ni = 2.77 * 0.06750 * 1.0 * (13.2217^2) * ((7.41667 / (0.75 * 13.2217)) - (0.5 * ((7.41667 / (0.75 * 13.2217))^2)))
Ni = 15.3044 lbf/in

Nc = (0.98 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (0.98 * 0.04750 * 1.0 * (13.2217^2) * COSH(((3.68 * (60.4167 - 7.41667)) / 13.2217))) / COSH(((3.68 * 60.4167) / 13.2217))
Nc = 1.03272 lbf/in

Nh = 2.6 * (H - H_offset) * D * G
Nh = 2.6 * (7.41667 - 0.0) * 13.2217 * 1.0
Nh = 254.958 lbf/in

sigma_T- = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)
sigma_T+ = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)

sigma_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T+ = (254.958 + SQRT(((15.3044^2) + (1.03272^2) + (((0.10080 * 254.958) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T+ = 1.45826e3 psi

sigma_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T- = (254.958 - SQRT(((15.3044^2) + (1.03272^2) + (((0.10080 * 254.958) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T- = 1.26129e3 psi

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 22.50e3) , (0.9 * 28.90e3 * 0.70))
Sd-seismic = 18.2070e3 psi

ts = ((sigma_T+ * (tn - CA)) / S_membrane) + CA
ts = ((1.45826e3 * (0.18750 - 0.0)) / 18.2070e3) + 0.0
ts = 0.0150175 in

Minimum Required Thickness
t-min = MAX(t_erec , t_d , t_t , ts)
t-min = MAX(0.18750 , 0.0140052 , 0.0116710 , 0.0150175)
t-min = 0.18750 in

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (2.6 * D * SG)) + 1) + loc
H-max = ((((0.18750 - 0.0) * 22.50e3 * 0.70) / (2.6 * 13.2217 * 1.0)) + 1) + 53.0
H-max = 139.906 ft

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(139.906 , 0)
H-max-@-Pi = 139.906 ft

Pi-max-@-H = MAX((((H-max - (H + loc)) * (12 * SG)) + P) , 0)

Pi-max-@-H = MAX((((139.906 - (7.41667 + 53.0)) * (12 * 1.0)) + 0.0) , 0)
Pi-max-@-H = 953.869 inH2O

Course # 13 Design

CA = Corrosion allowance per *API-650 5.3.2* (in)
D13 = Shell Course Centerline Diameter (in)
H = Design Liquid Level per *API-650 5.6.3.2* (ft)
H' = Effective Design Liquid Level per *API-650 Section F.2* (ft)
h13 = Course Height (ft)
H-Hydrotest = Hydrotest Liquid Level per *API-650 5.6.3.2* (ft)
H-max = Maximum Liquid Level for the Installed Thickness (ft)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (ft)
Ht' = Effective Hydrostatic Test Liquid Level per *API-650 F.2* (ft)
JE = Joint efficiency
loc = Course Location (ft)
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (inH2O)
Rwi = Impulsive Force Reduction Factor
t = Installed Thickness (in)
t_d = Course Design Thickness per *API-650 Section S.3.2.2.3* (in)
t-min = Minimum Required Thickness (in)
t_t = Course Hydrostatic Test Thickness per *S.3.2.2.3* (in)
W-13 = Shell Course Nominal Weight (lb)
W-13-corr = Shell Course Nominal Weight (lb)

CA = 0.0 in
H = 3.41667 ft
h13 = 3.29167 ft
H-Hydrotest = 3.41667 ft
JE = 0.70
loc = 57.0 ft
Ma = A240-304
Rwi = 4.0
t = 0.18750 in

Shell Course Center of Gravity (CG-13) = 58.6458 ft

D13 = ID + t
D13 = 158.660 + 0.18750
D13 = 158.848 in

W-13 = pi * Dc * t * h13 * d
W-13 = pi * 158.848 * 0.18750 * 39.50 * 0.290
W-13 = 1.07183e3 lb

W-13-corr = pi * Dc * (t - CA) * h13 * d
W-13-corr = pi * 158.848 * (0.18750 - 0.0) * 39.50 * 0.290
W-13-corr = 1.07183e3 lb

Material Properties
Material = A240-304
Minimum Tensile Strength (Sut) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St) = 27.0e3 psi

Thickness Required by Erection
As per API-650 S.3.2.1.1 and 5.6.1.1, Thickness Required by Erection (t_erec) = 0.18750 in

Thickness Required by Design
H' = H
H' = 3.41667
H' = 3.41667 ft

t_d = ((2.6 * D * (H' - 1) * SG) / (JE * Sd)) + CA
t_d = ((2.6 * 13.2217 * (3.41667 - 1) * 1.0) / (0.70 * 22.50e3)) + 0.0
t_d = 0.00527468 in

Hydrostatic Test Required Thickness
Ht' = H-Hydrotest
Ht' = 3.41667
Ht' = 3.41667 ft

t_t = (2.6 * D * (Ht' - 1) * SGt) / (JE * St)
t_t = (2.6 * 13.2217 * (3.41667 - 1) * 1.0) / (0.70 * 27.0e3)
t_t = 0.00439556 in

Seismic Design Required Thickness
Nc = Convective Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Nh = Product Hydrostatic Membrane Force per *API 650 Section E.6.1.4 and Section 5.6.3.2* (lbf/in)
Ni = Impulsive Hoop Membrane Unit Force per *API 650 Section E.6.1.4* (lbf/in)
Sd-seismic = Maximum Allowable Hoop Tension Membrane Stress per *API-650 E.6.2.4* (psi)
ts = Seismic Minimum Thickness per *API 650 Section E.6.2.4* (in)

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 3.41667 ft

Ni = 2.77 * Ai * G * (D^2) * ((Y / (0.75 * D)) - (0.5 * ((Y / (0.75 * D))^2)))
Ni = 2.77 * 0.06750 * 1.0 * (13.2217^2) * ((3.41667 / (0.75 * 13.2217)) - (0.5 * ((3.41667 / (0.75 * 13.2217))^2)))
Ni = 9.32173 lbf/in

Nc = (0.98 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (0.98 * 0.04750 * 1.0 * (13.2217^2) * COSH(((3.68 * (60.4167 - 3.41667)) / 13.2217))) / COSH(((3.68 * 60.4167) / 13.2217))
Nc = 3.14408 lbf/in

Nh = 2.6 * (H - H_offset) * D * G
Nh = 2.6 * (3.41667 - 0.0) * 13.2217 * 1.0
Nh = 117.452 lbf/in

sigma_T- = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)
sigma_T+ = Total Combined Hoop Stress per *API 650 Eq E.6.1.4-6, Sections E.6.1.4, EC.6.1.3* (psi)

sigma_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T+ = (117.452 + SQRT(((9.32173^2) + (3.14408^2) + (((0.10080 * 117.452) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)
sigma_T+ = 684.643 psi

sigma_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
sigma_T- = (117.452 - SQRT(((9.32173^2) + (3.14408^2) + (((0.10080 * 117.452) / 2.5)^2)))) / MAX((0.18750 - 0.0) , 0.0001)

sigma_T- = 568.183 psi

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 22.50e3) , (0.9 * 28.90e3 * 0.70))
Sd-seismic = 18.2070e3 psi

ts = ((sigma_T+ * (tn - CA)) / S_membrane) + CA
ts = ((684.643 * (0.18750 - 0.0)) / 18.2070e3) + 0.0
ts = 0.00705062 in

Minimum Required Thickness
t-min = MAX(t_erec , t_d , t_t , ts)
t-min = MAX(0.18750 , 0.00527468 , 0.00439556 , 0.00705062)
t-min = 0.18750 in

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (2.6 * D * SG)) + 1) + loc
H-max = ((((0.18750 - 0.0) * 22.50e3 * 0.70) / (2.6 * 13.2217 * 1.0)) + 1) + 57.0
H-max = 143.906 ft

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(143.906 , 0)
H-max-@-Pi = 143.906 ft

Pi-max-@-H = MAX((((H-max - (H + loc)) * (12 * SG)) + P) , 0)
Pi-max-@-H = MAX((((143.906 - (3.41667 + 57.0)) * (12 * 1.0)) + 0.0) , 0)
Pi-max-@-H = 1.00187e3 inH2O

Shell Design Summary Results
W-ins = t-ins * d-ins * pi * (OD + t-ins) * H
W-ins = 0.0 * 8.0 * pi * (13.2842 + 0.0) * 60.4167
W-ins = 0.0 lbf

W-shell-corr = (W-1-corr + W-2-corr + W-3-corr + W-4-corr + W-5-corr + W-6-corr + W-7-corr + W-8-corr + W-9-corr + W-10-corr + W-11-corr + W-12-corr + W-13-corr) + W-shell-add
W-shell-corr = (3.26004e3 + 1.62810e3 + 1.62810e3 + 1.62810e3 + 1.62810e3 + 1.62810e3 + 1.62810e3 + 1.62810e3 + 1.62810e3 + 1.30248e3 + 1.30248e3 + 1.30248e3 + 1.07183e3) + 0.0
W-shell-corr = 21.2641e3 lb

W-shell = (W-1 + W-2 + W-3 + W-4 + W-5 + W-6 + W-7 + W-8 + W-9 + W-10 + W-11 + W-12 + W-13) + W-shell-add
W-shell = (3.26004e3 + 1.62810e3 + 1.62810e3 + 1.62810e3 + 1.62810e3 + 1.62810e3 + 1.62810e3 + 1.62810e3 + 1.62810e3 + 1.30248e3 + 1.30248e3 + 1.30248e3 + 1.07183e3) + 0.0
W-shell = 21.2641e3 lb

CG-shell = ((CG-1 * W-1) + (CG-2 * W-2) + (CG-3 * W-3) + (CG-4 * W-4) + (CG-5 * W-5) + (CG-6 * W-6) + (CG-7 * W-7) + (CG-8 * W-8) + (CG-9 * W-9) + (CG-10 * W-10) + (CG-11 * W-11) + (CG-12 * W-12) + (CG-13 * W-13)) / W-shell
CG-shell = ((2.50 * 3.26004e3) + (7.50 * 1.62810e3) + (12.50 * 1.62810e3) + (17.50 * 1.62810e3) + (22.50 * 1.62810e3) + (27.50 * 1.62810e3) + (32.50 * 1.62810e3) + (37.50 * 1.62810e3) + (42.50 * 1.62810e3) + (47.0 * 1.30248e3) + (51.0 * 1.30248e3) + (55.0 * 1.30248e3) + (58.6458 * 1.07183e3)) / 21.2641e3
CG-shell = 28.0241 ft

Shell Design Summary

Course	Height (ft)	Material	CA (in)	JE	Sy (psi)	Sut (psi)	Sd (psi)	St (psi)	t_erec (in)
13	3.29167	A240-304	0.0	0.70	28.90e3	75.0e3	22.50e3	27.0e3	0.18750
12	4.0	A240-304	0.0	0.70	28.90e3	75.0e3	22.50e3	27.0e3	0.18750
11	4.0	A240-304	0.0	0.70	28.90e3	75.0e3	22.50e3	27.0e3	0.18750
10	4.0	A240-304	0.0	0.70	28.90e3	75.0e3	22.50e3	27.0e3	0.18750
9	5.0	A240-304	0.0	0.70	28.90e3	75.0e3	22.50e3	27.0e3	0.18750
8	5.0	A240-304	0.0	0.70	28.90e3	75.0e3	22.50e3	27.0e3	0.18750
7	5.0	A240-304	0.0	0.70	28.90e3	75.0e3	22.50e3	27.0e3	0.18750
6	5.0	A240-304	0.0	0.70	28.90e3	75.0e3	22.50e3	27.0e3	0.18750
5	5.0	A240-304	0.0	0.70	28.90e3	75.0e3	22.50e3	27.0e3	0.18750
4	5.0	A240-304	0.0	0.70	28.90e3	75.0e3	22.50e3	27.0e3	0.18750
3	5.0	A240-304	0.0	0.70	28.90e3	75.0e3	22.50e3	27.0e3	0.18750
2	5.0	A240-304	0.0	0.70	28.90e3	75.0e3	22.50e3	27.0e3	0.18750
1	5.0	A240-304	0.0	0.70	28.90e3	75.0e3	22.50e3	27.0e3	0.18750

Shell Design Summary (continued)

Course	t-design (in)	t-test (in)	t-seismic (in)	t-ext (in)	t-min (in)	t-installed (in)	Status	H-max-@-Pi (ft)	Pi-max-@-H (psi)
13	0.00527468	0.00439556	0.00705062	N/A	0.18750	0.18750	PASS	143.906	36.1938
12	0.0140052	0.0116710	0.0150175	N/A	0.18750	0.18750	PASS	139.906	34.4598
11	0.0227357	0.0189464	0.0228075	N/A	0.18750	0.18750	PASS	135.906	32.7257
10	0.0314662	0.0262218	0.0305875	N/A	0.18750	0.18750	PASS	131.906	30.9916
9	0.0423793	0.0353161	0.0403448	N/A	0.18750	0.18750	PASS	126.906	28.8241
8	0.0532924	0.0444103	0.0501231	N/A	0.18750	0.18750	PASS	121.906	26.6565
7	0.0642055	0.0535046	0.0599138	N/A	0.18750	0.18750	PASS	116.906	24.4889
6	0.0751187	0.0625989	0.0697123	N/A	0.18750	0.18750	PASS	111.906	22.3213
5	0.0860318	0.0716931	0.0795160	N/A	0.18750	0.18750	PASS	106.906	20.1537
4	0.0969449	0.0807874	0.0893233	N/A	0.18750	0.18750	PASS	101.906	17.9862
3	0.107858	0.0898817	0.0991333	N/A	0.18750	0.18750	PASS	96.9058	15.8186
2	0.118771	0.0989760	0.108945	N/A	0.18750	0.18750	PASS	91.9058	13.6510
1	0.129684	0.108070	0.118758	N/A	0.18750	0.3750	PASS	172.812	48.7249

Intermediate Stiffeners Design

Stiffeners Design For Wind Loading

D = Nominal Tank Diameter (ft)
E = Modulus Of Elasticity (psi)
E_ambient = Modulus Of Elasticity at Ambient Temperature (psi)
H1 = Maximum Unstiffened Transformed Shell Height per *API-650 5.9.6.1* (ft)
ME = Reduction Factor per *API-650 S.3.6.5*
N = Actual Wind Girders Quantity
Ns = Required Number of Girders per *API 650 5.9.6.3 and 5.9.6.4*
Pwd = Design Wind Pressure Including Inward Drag per *API-650 5.9.6.1* (psf)

Pwv = Wind Pressure where Design Wind Speed V is Used per *API-650 5.9.6.1* (psf)
ts_min = Thickness of the Thinnest Shell Course (in)
V = Wind velocity (mile/hr)

D = 13.2217 ft
E = 27.9680e6 psi
E_ambient = 28.10e6 psi
N = 0.0
V = 81.90 mile/hr

Shell Courses Heights (W) = [5.0 5.0 5.0 5.0 5.0 5.0 5.0 5.0 5.0 4.0 4.0 4.0 3.29167] ft

ts_min = MIN(ts_1 , ts_2 , ts_3 , ts_4 , ts_5 , ts_6 , ts_7 , ts_8 , ts_9 , ts_10 , ts_11 , ts_12 , ts_13)
ts_min = MIN(0.3750 , 0.18750 , 0.18750 , 0.18750 , 0.18750 , 0.18750 , 0.18750 , 0.18750 , 0.18750 , 0.18750 , 0.18750 , 0.18750 , 0.18750)
ts_min = 0.18750 in

ME = E / E_ambient
ME = 27.9680e6 / 28.10e6
ME = 0.995302

Stiffeners Required Quantity

HTS = Height of Transformed Shell per *API 650 5.9.6.2* (ft)

Transformed shell courses heights

Variable	Equation	Value	Unit		
Wtr_1	W_1 * SQRT(((t_min / ts_1)^5))	0.8839	ft	N/A	N/A
Wtr_2	W_2 * SQRT(((t_min / ts_2)^5))	5.0000	ft	N/A	N/A
Wtr_3	W_3 * SQRT(((t_min / ts_3)^5))	5.0000	ft	N/A	N/A
Wtr_4	W_4 * SQRT(((t_min / ts_4)^5))	5.0000	ft	N/A	N/A
Wtr_5	W_5 * SQRT(((t_min / ts_5)^5))	5.0000	ft	N/A	N/A
Wtr_6	W_6 * SQRT(((t_min / ts_6)^5))	5.0000	ft	N/A	N/A
Wtr_7	W_7 * SQRT(((t_min / ts_7)^5))	5.0000	ft	N/A	N/A
Wtr_8	W_8 * SQRT(((t_min / ts_8)^5))	5.0000	ft	N/A	N/A
Wtr_9	W_9 * SQRT(((t_min / ts_9)^5))	5.0000	ft	N/A	N/A
Wtr_10	W_10 * SQRT(((t_min / ts_10)^5))	4.0000	ft	N/A	N/A
Wtr_11	W_11 * SQRT(((t_min / ts_11)^5))	4.0000	ft	N/A	N/A
Wtr_12	W_12 * SQRT(((t_min / ts_12)^5))	4.0000	ft	N/A	N/A
Wtr_13	W_13 * SQRT(((t_min / ts_13)^5))	3.2917	ft	N/A	N/A

HTS = Wtr_1 + Wtr_2 + Wtr_3 + Wtr_4 + Wtr_5 + Wtr_6 + Wtr_7 + Wtr_8 + Wtr_9 + Wtr_10 + Wtr_11 + Wtr_12 + Wtr_13
HTS = 0.883883 + 5.0 + 5.0 + 5.0 + 5.0 + 5.0 + 5.0 + 5.0 + 5.0 + 4.0 + 4.0 + 4.0 + 3.29167
HTS = 56.1756 ft

Pwv = 31 * ((V / 120)^2)
Pwv = 31 * ((81.90 / 120)^2)
Pwv = 14.440 psf

Pwd = Pwv + 5
Pwd = 14.440 + 5
Pwd = 19.440 psf

H1 = (600000 * ts_min * SQRT(((ts_min / D)^3)) * (36 / Pwd)) * ME
H1 = (600000 * 0.18750 * SQRT(((0.18750 / 13.2217)^3)) * (36 / 19.440)) * 0.995302
H1 = 350.176 ft

Ns = CEILING(((HTS / Hsafe) - 1))
Ns = CEILING(((56.1756 / 350.176) - 1))
Ns = 0.0

N >= Ns ==> PASS

Flat Bottom: non Annular Plate Design Back

Bottom Type = Flat
Bottom Support Type = Continuously Supported on Foundation

CA = Corrosion allowance (in)
CA_1 = Bottom Shell Course Corrosion Allowance (in)
chime = Outside Projection (Chime Distance) (in)
E = Joint efficiency
Ma_1 = Bottom Shell Course Material
Ma-bottom = Material
S = Bottom Shell Course Maximum Stress (psi)
S1 = Bottom Shell Course Product Stress per *API-650 Table 5.1b Note b* (psi)
S2 = Bottom Shell Course Hydrostatic Stress per *API-650 Table 5.1b Note b* (psi)
Sd_1 = Bottom Shell Course Allowable Design Stress (psi)
St_1 = Bottom Shell Course Allowable Hydrostatic Test Stress (psi)
tb = Installed Thickness (in)
tb-req = Bottom Required Thickness (in)
td_1 = Bottom Shell Course Design Thickness (in)
ts_1 = Bottom Shell Course Nominal Thickness (in)
tt_1 = Bottom Shell Course Hydrotest Thickness (in)

CA = 0.0 in
CA_1 = 0.0 in
chime = 1.0 in
E = 0.70
Ma_1 = A240-304
Ma-bottom = A240-304
Sd_1 = 22.50e3 psi
St_1 = 27.0e3 psi
tb = 0.18750 in
td_1 = 0.129684 in
ts_1 = 0.3750 in
tt_1 = 0.108070 in

Bottom Plates Material Properties
Material = A240-304
Minimum Tensile Strength (Sut-btm) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy-btm) = 28.90e3 psi
Density (d-btm) = 0.290 lb/in^3

Calculation of Hydrostatic Test Stress & Product Stress per API-650 Section 5.5.1
S1 = ((td_1 - CA_1) / (ts_1 - CA_1)) * Sd_1
S1 = ((0.129684 - 0.0) / (0.3750 - 0.0)) * 22.50e3
S1 = 7.78106e3 psi

As per API-650 5.5.1 and S.3.1.3, first shell course material, A240-304, is stainless steel and the stress is less than or equal to 23200; therefore, butt welded annular plates are not required

S2 = (tt_1 / ts_1) * St_1
S2 = (0.108070 / 0.3750) * 27.0e3
S2 = 7.78106e3 psi

As per API-650 5.5.1 and S.3.1.3, first shell course material, A240-304, is stainless steel and the stress is less than or equal to 24900; therefore, butt welded annular plates are not required

S = MAX(S1 , S2)
S = MAX(7.78106e3 , 7.78106e3)
S = 7.78106e3 psi

As per API-650 M.4.1
D <= 100 ==> Butt welded annular ring is not required

Bottom Weight
A-btm = Bottom Surface Area (ft^2)
CA = Corrosion allowance (in)
chime = Outside Projection (Chime Distance) (in)
OD-btm = Bottom Outer Diameter (ft)
tb = Installed Thickness (in)
Wb-pl = Bottom Plates Weight (lb)
Wb-pl-add = Bottom Additional Weight (lb)
Wb-pl-corr = Bottom Corroded Plates Weight (lb)
Wb-pl-corroded-overlap = Bottom Weight Corroded Overlap (lb)
Wb-pl-overlap = Bottom Overlap Weight (lb)

CA = 0.0 in
chime = 1.0 in
tb = 0.18750 in
Wb-pl-add = 0.0 lb
Wb-pl-corroded-overlap = 0.0 lb
Wb-pl-overlap = 0.0 lb

OD-btm = OD + (chime * 2)
OD-btm = 13.2842 + (0.0833333 * 2)
OD-btm = 13.4508 ft

A-btm = pi * ((OD-btm / 2)^2)
A-btm = pi * ((13.4508 / 2)^2)
A-btm = 142.098 ft^2

Wb-pl = (A-btm * tb * d-btm) + Wb-pl-overlap + Wb-pl-add
Wb-pl = (20.4621e3 * 0.18750 * 0.290) + 0.0 + 0.0
Wb-pl = 1.11263e3 lb

Wb-pl-corr = (A-btm * (tb - CA) * d-btm) + Wb-pl-corroded-overlap + Wb-pl-add
Wb-pl-corr = (20.4621e3 * (0.18750 - 0.0) * 0.290) + 0.0 + 0.0
Wb-pl-corr = 1.11263e3 lb

Bottom Design due to External Pressure
P-btm = Downward Pressure (psi)

Liquid Height to Pressure Conversion Factor (f) = 0.433515

P-btm = (d-btm * (tb - CA-btm)) + (Lmin * f * SG)
P-btm = (0.290 * (0.18750 - 0.0)) + (1.0 * 0.433515 * 1.0)
P-btm = 0.487890 psi

P-btm >= Pv ==> There is no uplift due to external pressure

Bottom Required Thickness

As per API-650 S.3.1.2, Required Thickness by Erection (tb-erec) = 0.18750 in

tb-req = tb-erec
tb-req = 0.18750
tb-req = 0.18750 in

tb >= tb-req ==> PASS

Bottom Outside Projection
As per API-650 J.3.2.3, Minimum Required Outside Projection (chime) = 1.0 in

chime >= chime ==> PASS

Wind Moment (Per API-650 Section 5.11)

Back

Wind Pressures per API-650 & ASCE7-16

P_WR = Roof Design Wind Pressure per *API-650 5.2.1.k* (psf)
P_WS = Shell Design Wind Pressure per *API-650 5.2.1.k* (psf)
V = Design Wind Velocity (3-sec gust) per *ASCE 7-16* (mph)
V_s = Adjusted Design Wind Velocity per *API 650 Section 5.2.1.k* (mph)

V = 105.0 mph

Wind Velocity per API-650 and ASCE7-16

V_s = 0.78 * V
V_s = 0.78 * 105.0
V_s = 81.90 mph

Roof Wind Pressure
P_WR = 31 * ((V_s / 120)^2)
P_WR = 31 * ((81.90 / 120)^2)
P_WR = 14.440 psf

Shell Wind Pressure
P_WS = 18.6 * ((V_s / 120)^2)
P_WS = 18.6 * ((81.90 / 120)^2)
P_WS = 8.6640 psf

Wind Overturning and Sliding Stability

Ah = Roof Horizontal Projected Area (ft^2)
Ah-total = Roof Horizontal Projected Area Including Insulation (ft^2)
As = Shell Total Vertical Projected Area (ft^2)
Av-roof = Roof Vertical Projected Area (ft^2)
CA_1 = Bottom Shell Course Corrosion Allowance (in)
CA-btm = Corrosion Allowance of Bottom Plates Under the Shell (in)
CG-roof = Roof Center of Gravity (ft)
COF = Maximum Allowable Sliding Friction Coefficient per *API 650, Section 5.11.4*
DLR = Nominal Weight of Roof Plates and Attached Structural (lbf)
DLS = Nominal Weight of Shell Plates and Framing (lbf)
D-outer = Tank Max Outer Diameter (ft)
Fby = Yield Strength of Bottom Plates Under the Shell (psi)
F-friction = Friction Force per *API 650, Section 5.11.4* (lbf)
F-wind = Sliding Force (lbf)
M_DL = Moment About the Shell-To-Bottom Joint from the Nominal Weight of the Shell (ft.lbf)
M_DLR = Moment About the Shell-To-Bottom Joint from the Nominal Weight of the Roof Plate Plus any Attached Structural (ft.lbf)
M_F = Moment About the Shell-To-Bottom Joint From Liquid Weight (ft.lbf)
M_Pi = Moment About the Shell-To-Bottom Joint From Design Internal Pressure per *API-650 5.11.2.2* (ft.lbf)
M_w = Overturning Moment About the Shell-To-Bottom Joint from Wind Pressures per *API-650 5.11.2.2* (ft.lbf)
M_WR = Roof Wind Overturning Moment per *API-650 5.11.2.2* (ft.lbf)

M_WS = Shell Wind Overturning Moment per *API-650 5.11.2.2* (ft.lbf)
Rh = Roof Horizontal Radius (ft)
tb = Thickness of Bottom Plates Under the Shell (in)
tr-ins = Roof Insulation Thickness (in)
ts_1 = Bottom Shell Course Nominal Thickness (in)
ts-ins = Shell Insulation Thickness (in)
W-access-corr = Access Corroded Weight (lbf)
W-app-corr = Appurtenances Corroded Weight (lbf)
Wb-pl-corr = Bottom Corroded Plates Weight (lbf)
wind-uplift = Wind Uplift per *API-650 5.2.1.k* (psf)
wL = Tank Content Resisting Weight per *API-650 5.11.2.3* (lbf/ft)
Wr-pl = Roof New Plates Weight (lbf)
Wr-pl-corr = Roof Corroded Plates Weight (lbf)
Ws-framing = Shell New Framing Weight (lbf)
Ws-framing-corr = Shell Corroded Framing Weight (lbf)
Ws-pl = Shell New Plates Weight (lbf)
Ws-pl-corr = Shell Corroded Plates Weight (lbf)
Ws-struct-corr = Roof Corroded Structure Weight Supported by Shell (lbf)
W-stairs-corr = Stairways Corroded Weight (lbf)
W-struct = Roof New Structure Weight (lbf)
W-struct-corr = Roof Corroded Structure Weight (lbf)
W-windgirder-corr = Wind Girder Corroded Weight (lbf)
Xs = Moment Arm of Wind Force on Shell (ft)
Xw = Moment Arm of Wind Force on Roof (ft)

Ah = 139.988 ft^2
Av-roof = 7.42659 ft^2
CA_1 = 0.0 in
CA-btm = 0.0 in
CG-roof = 0.370850 ft
COF = 0.40
DLR = 1.15682e3 lbf
DLS = 21.4007e3 lbf
Fby = 28.90e3 psi
Rh = 6.67529 ft
tb = 0.18750 in
tr-ins = 0.0 in
ts_1 = 0.3750 in
ts-ins = 0.0 in
W-access-corr = 0.0 lbf
W-app-corr = 408.465 lbf
Wb-pl-corr = 1.11263e3 lbf
Wr-pl = 1.11122e3 lbf
Wr-pl-corr = 1.11122e3 lbf
Ws-framing = 136.572 lbf
Ws-framing-corr = 132.617 lbf
Ws-pl = 21.2641e3 lbf
Ws-pl-corr = 21.2641e3 lbf
Ws-struct-corr = 0.0 lbf
W-stairs-corr = 0.0 lbf
W-struct = 0.0 lbf
W-struct-corr = 0.0 lbf
W-windgirder-corr = 0.0 lbf

Design Uplift Pressure per API-650 5.2.1.k
The internal pressure uplift force does not exceed the weight of roof plates, Annex F Section F.4.1 is not

applicable. Therefore the wind uplift is not limited per API-650 Section 5.2.1.k.2.

wind-uplift = P_WR
wind-uplift = 14.440
wind-uplift = 14.440 psf

Overturning Moments

Xw = D / 2
Xw = 13.2217 / 2
Xw = 6.61083 ft

Ah-total = pi * ((Rh + tr-ins)^2)
Ah-total = pi * ((6.67529 + 0.0)^2)
Ah-total = 139.988 ft^2

M_Pi = Pg * Ah * Xw
M_Pi = 0.0 * 139.988 * 6.61083
M_Pi = 0.0 ft.lbf

M_WR = wind-uplift * Ah-total * Xw
M_WR = 14.440 * 139.988 * 6.61083
M_WR = 13.3633e3 ft.lbf

D-outer = OD + (2 * (ts-ins / 12))
D-outer = 13.2842 + (2 * (0.0 / 12))
D-outer = 13.2842 ft

As = D-outer * H
As = 13.2842 * 60.4167
As = 802.585 ft^2

Xs = H / 2
Xs = 60.4167 / 2
Xs = 30.2083 ft

M_WS = P_WS * As * Xs
M_WS = 8.6640 * 802.585 * 30.2083
M_WS = 210.056e3 ft.lbf

M_w = M_WR + M_WS
M_w = 13.3633e3 + 210.056e3
M_w = 223.420e3 ft.lbf

Resistance to Overturning per API-650 5.11.2

M_DL = (D / 2) * DLS
M_DL = (13.2217 / 2) * 21.4007e3
M_DL = 141.476e3 ft.lbf

M_DLR = (D / 2) * DLR
M_DLR = (13.2217 / 2) * 1.15682e3
M_DLR = 7.64751e3 ft.lbf

wL = MIN((0.45 * Lmax * D) , (4.67 * (tb-req - CA-btm) * SQRT((Fby * Lmax))))
wL = MIN((0.45 * 60.4167 * 13.2217) , (4.67 * (0.18750 - 0.0) * SQRT((28.90e3 * 60.4167))))
wL = 359.464 lbf/ft

M_F = (D / 2) * wL * pi * D
M_F = (13.2217 / 2) * 359.464 * pi * 13.2217
M_F = 98.7070e3 ft.lbf

An unanchored tank must meet the criteria from API-650 5.11.2.1
Criterion 1
((0.6 * M_w) + M_Pi) < ((M_DL / 1.5) + M_DLR)
((0.6 * 223.420e3) + 0.0) < ((141.476e3 / 1.5) + 7.64751e3)
Since 134.052e3 >= 101.965e3 ==> Tank must be anchored

Criterion 2
(M_w + (Fp * M_Pi)) < (((M_DL + M_F) / 2) + M_DLR)
(223.420e3 + (0.40 * 0.0)) < (((141.476e3 + 98.7070e3) / 2) + 7.64751e3)
Since 223.420e3 >= 127.739e3 ==> Tank must be anchored

Criterion 3
(M_WS + (Fp * M_Pi)) < ((M_DL / 1.5) + M_DLR)
(210.056e3 + (0.40 * 0.0)) < ((141.476e3 / 1.5) + 7.64751e3)
Since 210.056e3 >= 101.965e3 ==> Tank must be anchored

Resistance to Sliding per API-650 5.11.4
F-wind = P_WS * As
F-wind = 8.6640 * 802.585
F-wind = 6.95359e3 lbf

F-friction = COF * (Wr-pl-corr + W-struct-corr + Ws-pl-corr + Ws-framing-corr + Wb-pl-corr + W-stairs-corr + W-access-corr + W-app-corr + W-windgirder-corr)
F-friction = 0.40 * (1.11122e3 + 0.0 + 21.2641e3 + 132.617 + 1.11263e3 + 0.0 + 0.0 + 408.465 + 0.0)
F-friction = 9.61161e3 lbf

F-friction >= F-wind ==> Tank is stable

Anchorage Requirement
Tank must be anchored per API-650 5.11 by Criterion 1, Criterion 2, and Criterion 3

Seismic Design [Back]

Site Ground Motion Design
Seismic Method = ASCE7-MAPPED-SS-AND-S1

Ac = Convective Design Response Spectrum Acceleration Coefficient per *API 650 Sections E.4.6.1*
Ac-min = Adjusted Convective Design Response Spectrum Acceleration Coefficient
Af = Acceleration Coefficient for Sloshing Wave Height per *API 650 Sections E.7.2*
Ai = per *API 650 Sections E.4.6.1*
Ai = Impulsive Design Response Spectrum Acceleration Coefficient per *API 650 Sections E.4.6.1*
Anchorage_System = Anchorage System
Av = Vertical Ground Acceleration Coefficient per *API 650 Sections E.6.1.3 and E.2.2*
D = Nominal Tank Diameter (ft)
Fa = Site Acceleration Coefficient
Fv = Site Velocity Coefficient
H = Maximum Design Product Level (ft)
I = Importance Factor
K = Spectral Acceleration Adjustment Coefficient
Ks = Sloshing Coefficient per *API 650 Section E.4.5.2*
Q = MCE to Design Level Scale Factor
rho_product = Product Mass Density (lbf/ft^3)
Rwc = Convective Force Reduction Factor
Rwi = Impulsive Force Reduction Factor
S1 = Spectral Response Acceleration at a Period of One Second
SD1 = Design Spectral Response Acceleration at a Period of One Second per *API 650 Sections E.4.6.1 and E.2.2*
SDS = Design Spectral Response Acceleration at Short Period per *API 650 Sections E.4.6.1 and E.2.2*
Seismic_Site_Class = Seismic Site Class
Seismic_Use_Group = Seismic Use Group
shell-course-modulus-of-elasticity-information-list = Shell Course Modulus of Elasticity Information List (psi)
shell-course-thickness-information-list = Shell Course Thickness Information List (in)
Ss = Spectral Response Acceleration Short Period
Tc = Convective Natural Period per *API 650 Section E.4.5.2* (sec)
TL = Regional Dependent Transistion Period for Longer Period Ground Motion (sec)

Anchorage_System = MECHANICALLY-ANCHORED
D = 13.2217 ft
Fa = 1.20
Fv = 1.70
H = 60.4167 ft
I = 1.250
K = 1.50
Q = 0.666667
rho_product = 62.4279 lbf/ft^3
Rwc = 2.0
Rwi = 4.0
S1 = 0.0940
Seismic_Site_Class = SEISMIC-SITE-CLASS-C
Seismic_Use_Group = SEISMIC-USE-GROUP-II
shell-course-modulus-of-elasticity-information-list = [27.9680e6 27.9680e6 27.9680e6] psi
shell-course-thickness-information-list = [0.18750 0.3750 0.203049] in
Ss = 0.270
TL = 12.0 sec

SDS = Q * Fa * Ss
SDS = 0.666667 * 1.20 * 0.270
SDS = 0.2160

SD1 = Q * Fv * S1
SD1 = 0.666667 * 1.70 * 0.0940
SD1 = 0.106533

Ks = 0.578 / SQRT(TANH(((3.68 * H) / D)))
Ks = 0.578 / SQRT(TANH(((3.68 * 60.4167) / 13.2217)))
Ks = 0.5780

Tc = Ks * SQRT(D)
Tc = 0.5780 * SQRT(13.2217)
Tc = 2.10170 sec

Ai = SDS * (I / Rwi)
Ai = 0.2160 * (1.250 / 4.0)
Ai = 0.06750

Ai = MAX(Ai , 0.007)
Ai = MAX(0.06750 , 0.007)
Ai = 0.06750

Tc <= TL

Ac = K * SD1 * (1 / Tc) * (I / Rwc)
Ac = 1.50 * 0.10650 * (1 / 2.10170) * (1.250 / 2.0)
Ac = 0.0475062

Ac-min = MIN(Ac , Ai)
Ac-min = MIN(0.0475062 , 0.06750)
Ac-min = 0.0475062

Av = (2 / 3) * 0.7 * SDS
Av = (2 / 3) * 0.7 * 0.2160
Av = 0.10080

Af = K * SD1 * I * (1 / Tc)
Af = 1.50 * 0.10650 * 1.250 * (1 / 2.10170)
Af = 0.0950123

Seismic Design
h_bottom = Bottom Elevation (ft)
h_bottom-ground = Bottom Elevation from Ground (ft)

h_bottom = 0.0 ft
h_bottom-ground = 0.0 ft

A = Roof Surface Area (ft^2)
Ac = Convective Design Response Spectrum Acceleration Coefficient
Af = Acceleration Coefficient for Sloshing Wave Height
Ah-shell = Roof Horizontal Projected Area Supported by The Shell (ft^2)
Ai = Impulsive Design Response Spectrum Acceleration Coefficient

Anchorage_System = Anchorage System
A-rs = Roof Area Supported by The Shell (ft^2)
Av = Vertical Ground Acceleration Coefficient
ca1 = Bottom Shell Course Corrosion Allowance (in)
ca_bottom = Bottom Corrosion Allowance (in)
D = Nominal Tank Diameter (ft)
DELTAs = Sloshing Wave Height Above Product Design Height per *API 650 Section E.7.2* (ft)
Event_Type = Event Type
Fa = Site Acceleration Coefficient
F_c = Allowable Longitudinal Shell Compression Stress per *API 650 Section E.6.2.2.3, Eq E.6.2.2.3-2b* (lbf/in^2)
Freeboard = Actual Freeboard (ft)
Freeboard_recommended = Minimum Recommended Freeboard per *API-650 Table E.7* (ft)
Fv = Site Velocity Coefficient
Fy = Yield Strength (lb/in^2)
G = Specific Gravity
Ge = Effective Specific Gravity per *API 650 Section E.2.2*
H = Maximum Design Product Level (ft)
Hrcg = Top of Shell to Roof and roof appurtenances Center of Gravity (ft)
hs = Additional Shell Height Required Above Sloshing Height (ft)
H_shell = Shell height (ft)
I = Importance Factor
J = Anchorage Ratio per *API 650 Section E.6.2.1.1.1*
K = Spectral Acceleration Adjustment Coefficient
Ks = Sloshing Coefficient
Min_Anchor_Quantity = Minimum Anchor Quantity per *API-650 5.12.2*
Min_Anchor_Spacing = Minimum Anchor Spacing per *API-650 5.12.3* (ft)
Mrw = Ringwall Overturning Moment per *API 650 Section E.6.1.5* (ft.lb)
Ms = Slab Overturning Moment per *API 650 Section E.6.1.5* (ft.lb)
mu = Friction Coefficient per *API 650, Section E.7.6*
Overturn_Stability_Ratio = Overturning Stability Ratio per *API 650 Section E.6.2.3*
P = Design Pressure (lbf/in^2)
Q = MCE to Design Level Scale Factor
S1 = Spectral Response Acceleration at a Period of One Second
Sb = Roof Balanced Snow Load (psf)
SD1 = Design Spectral Response Acceleration at a Period of 1 Second
SDS = Design Spectral Response Acceleration at Short Period
Seismic_Site_Class = Seismic Site Class
Seismic_Use_Group = Seismic Use Group
sigma_c = Mechanically Anchored Maximum Longitudinal Shell Compression Stress per *API 650 Section E.6.2.2.2, Eq E.6.2.2.2-1b* (lbf/in^2)
Ss = Spectral Response Acceleration Short Period
ta = Thickness, excluding corrosion allowance, of the bottom annulus under the shell required to provide the resisting force for self anchorage per *API-650 E.2.2* (in)
tb-corr = Bottom Plates Corroded Thickness (in)
t_bottom = Bottom Plate Thickness (in)
Tc = Convective Natural Period (sec)
TL = Regional Dependent Transistion Period for Longer Period Ground Motion (sec)
ts1 = Bottom Shell Course Thickness (in)
ts1_c = Shell Course 1 Corroded Thickness (in)
V = Total Design Base Shear per *API 650 Section E.6.1* (lbf)
Vc = Design Base Shear for Convective Component per *API 650 Section E.6.1* (lbf)
Vi = Design Base Shear for Impulsive Component per *API 650 Section E.6.1* (lbf)
Vmax = Local Shear Transfer per *API 650 Section E.7.7* (lbf/ft)
Vs = Self Anchored Sliding Resistance Maximum Allowable Base Shear per *API 650 Section E.7.6* (lbf)
w_a = Force Resisting Uplift - Self Anchored per *API 650 Section E.6.2.1.1* (lbf/ft)

w_a = (lbf/ft)
wa_limit = Self Anchored Force Resisting Uplift Max Limit per *API 650 Section E.6.2.1.1, Eq E.6.2.1.1-1b* (lbf/ft)
w_a_self-anchored = Self Anchored Force Resisting Uplift per *API 650 Section E.6.2.1.1, Eq E.6.2.1.1-1b* (lbf/ft)
Wb-attachments = Bottom Attachments Weight (lb)
Wb-pl = Bottom Plates Weight (lb)
Wc = Convective Effective Weight per *API 650 Section E.6.1.1* (lbf)
Weff = Total Effective Weight per *API 650 Section E.6.1.1* (lbf)
Wf = Tank Bottom Total Weight (lbf)
Wfd = Tank Foundation Weight (lbf)
Wg = Soil Weight (lbf)
Wi = Impulsive Effective Weight per *API 650 Section E.6.1.1* (lbf)
wint = Calculated Design Uplift Due to Product Pressure (lbf/ft)
Wp = Tank Contents Total Weight (lbf)
Wr = Total Weight of Fixed Tank Roof including Framing, Knuckles, any Permanent Attachments and 10 % of the Roof Balanced Design Snow Load (lbf)
Wr-attachments = Roof Attachments Weight (lb)
Wr-DL-add = Roof Additional Dead Weight (lb)
Wr-pl = Roof Plates Nominal Weight (lb)
wrs = Specified Tank Roof Load Acting on Tank Shell (lbf/ft)
Wrs = Roof Load Acting on The Tank Shell Including 10 % of the Roof Balanced Design Snow Load (lbf)
Ws = Total Weight of Tank Shell and Appurtenances (lbf)
Ws-attachments = Shell Attachments Weight (lb)
Ws-framing = Shell Framing Weight (lb)
Ws-pl = Shell Plates Nominal Weight (lb)
Wss = Roof Structure Weight Supported by The Tank Shell (lb)
W-struct = Roof Structure Weight (lb)
W_T = Total Weight of Tank Shell, Roof, Framing, Knuckles, Product, Bottom, Attachments, Appurtenances, Participating Balanced Snow Load per *API-650 Eq E.6.2.3-1* (lbf)
wt = Tank and Roof Weight Acting at base of Shell per *API 650 Section E.6.2.1.1.1* (lbf/ft)
Xc = Height from tank shell bottom to the center of action of convective lateral force for computing ringwall overturning moment per *API 650 Section E.6.1.2.1* (ft)
Xcs = Height from tank shell bottom to the center of action of convective lateral force for computing slab overturning moment per *API 650 Section E.6.1.2.2* (ft)
Xi = Height from tank shell bottom to the center of action of impulsive lateral force for computing ringwall overturning moment per *API 650 Section E.6.1.2.1* (ft)
Xis = Height from tank shell bottom to the center of action of impulsive lateral force for computing slab overturning moment per *API 650 Section E.6.1.2.2* (ft)
Xr = Height from tank shell bottom to the center of gravity of roof and roof appurtenances per *API 650 Section E.6.1.2* (ft)
Xs = Height from tank shell bottom to shell's center of gravity (ft)

A = 141.919 ft^2
Ac = 0.04750
Af = 0.0950
Ah-shell = 139.988 ft^2
Ai = 0.06750
Anchorage_System = MECHANICALLY-ANCHORED
A-rs = 141.919 ft^2
Av = 0.10080
ca1 = 0.0 in
ca_bottom = 0.0 in
D = 13.2217 ft
Event_Type = MAXIMUM-CONSIDERED-EARTHQUAKE-MCE
Fa = 1.20

Fv = 1.70
Fy = 28.90e3 lb/in^2
G = 1.0
H = 60.4167 ft
Hrcg = 0.370850 ft
hs = 0.0 ft
H_shell = 60.4167 ft
I = 1.250
K = 1.50
Ks = 0.5780
Min_Anchor_Quantity = 4.0
Min_Anchor_Spacing = 10.0 ft
mu = 0.40
P = 0.0 lbf/in^2
Q = 0.666667
S1 = 0.0940
Sb = 0.0 psf
SD1 = 0.10650
SDS = 0.2160
Seismic_Site_Class = SEISMIC-SITE-CLASS-C
Seismic_Use_Group = SEISMIC-USE-GROUP-II
Ss = 0.270
t_bottom = 0.18750 in
Tc = 2.10170 sec
TL = 12.0 sec
ts1 = 0.3750 in
Wb-attachments = 0.0 lb
Wb-pl = 1.11263e3 lb
Wfd = 0.0 lbf
Wg = 0.0 lbf
Wp = 517.843e3 lbf
Wr-attachments = 45.5909 lb
Wr-DL-add = 0.0 lb
Wr-pl = 1.11122e3 lb
Ws-attachments = 615.875 lb
Ws-framing = 136.572 lb
Ws-pl = 21.2641e3 lb
Wss = 0.0 lb
W-struct = 0.0 lb
Xs = 28.0241 ft

Seismic Method (seismic-method) = ASCE7-MAPPED-SS-AND-S1

Weights
Wf = Wb-pl
Wf = 1.11263e3
Wf = 1.11263e3 lbf

Wr = (Wr-pl + Wr-attachments + W-struct + Wr-DL-add) + (0.1 * Sb * Ah)
Wr = (1.11122e3 + 45.5909 + 0.0 + 0.0) + (0.1 * 0.0 * 139.988)
Wr = 1.15682e3 lbf

Wrs = ((Wr-pl + Wr-attachments + Wr-DL-add) * (A-rs / A)) + Wss + (0.1 * Sb * Ah-shell)
Wrs = ((1.11122e3 + 45.5909 + 0.0) * (141.919 / 141.919)) + 0.0 + (0.1 * 0.0 * 139.988)
Wrs = 1.15682e3 lbf

Ws = Ws-pl + Ws-framing + Ws-attachments
Ws = 21.2641e3 + 136.572 + 615.875
Ws = 22.0165e3 lbf

W_T = Ws + Wr + Wp + Wf
W_T = 22.0165e3 + 1.15682e3 + 517.843e3 + 1.11263e3
W_T = 542.129e3 lbf

Effective Weight of Product
Wi = (1.0 - (0.218 * (D / H))) * Wp
Wi = (1.0 - (0.218 * (13.2217 / 60.4167))) * 517.843e3
Wi = 493.138e3 lbf

Wc = 0.23 * (D / H) * TANH(((3.67 * H) / D)) * Wp
Wc = 0.23 * (13.2217 / 60.4167) * TANH(((3.67 * 60.4167) / 13.2217)) * 517.843e3
Wc = 26.0648e3 lbf

Weff = Wi + Wc
Weff = 493.138e3 + 26.0648e3
Weff = 519.203e3 lbf

Design Loads
Vi = Ai * (Ws + Wr + Wf + Wi)
Vi = 0.06750 * (22.0165e3 + 1.15682e3 + 1.11263e3 + 493.138e3)
Vi = 34.9261e3 lbf

Vc = Ac * Wc
Vc = 0.04750 * 26.0648e3
Vc = 1.23808e3 lbf

V = SQRT(((Vi^2) + (Vc^2)))
V = SQRT(((34.9261e3^2) + (1.23808e3^2)))
V = 34.9480e3 lbf

Center of Action for Effective Lateral Forces
Xr = H_shell + Hrcg
Xr = 60.4167 + 0.370850
Xr = 60.7875 ft

Xi = (0.5 - (0.094 * (D / H))) * H
Xi = (0.5 - (0.094 * (13.2217 / 60.4167))) * 60.4167
Xi = 28.9655 ft

Xc = (1.0 - ((COSH(((3.67 * H) / D)) - 1) / (((3.67 * H) / D) * SINH(((3.67 * H) / D))))) * H
Xc = (1.0 - ((COSH(((3.67 * 60.4167) / 13.2217)) - 1) / (((3.67 * 60.4167) / 13.2217) * SINH(((3.67 * 60.4167) / 13.2217))))) * 60.4167
Xc = 56.8140 ft

Xis = (0.5 + (0.06 * (D / H))) * H
Xis = (0.5 + (0.06 * (13.2217 / 60.4167))) * 60.4167
Xis = 31.0016 ft

Xcs = (1.0 - ((COSH(((3.67 * H) / D)) - 1.937) / (((3.67 * H) / D) * SINH(((3.67 * H) / D))))) * H
Xcs = (1.0 - ((COSH(((3.67 * 60.4167) / 13.2217)) - 1.937) / (((3.67 * 60.4167) / 13.2217) * SINH(((3.67 * 60.4167) / 13.2217))))) * 60.4167
Xcs = 56.8140 ft

Overturning Moment
Mrw = SQRT((((Ai * ((Wi * Xi) + (Ws * Xs) + (Wr * Xr)))^2) + ((Ac * (Wc * Xc))^2)))
Mrw = SQRT((((0.06750 * ((493.138e3 * 28.9655) + (22.0165e3 * 28.0241) + (1.15682e3 * 60.7875)))^2) + ((0.04750 * (26.0648e3 * 56.8140))^2)))
Mrw = 1.01301e6 ft.lb

Ms = SQRT((((Ai * ((Wi * Xis) + (Ws * Xs) + (Wr * Xr)))^2) + ((Ac * (Wc * Xcs))^2)))
Ms = SQRT((((0.06750 * ((493.138e3 * 31.0016) + (22.0165e3 * 28.0241) + (1.15682e3 * 60.7875)))^2) + ((0.04750 * (26.0648e3 * 56.8140))^2)))
Ms = 1.08063e6 ft.lb

Resistance to Design Loads
Ge = G * (1 - (0.4 * Av))
Ge = 1.0 * (1 - (0.4 * 0.10080))
Ge = 0.959680

wrs = Wrs / (pi * D)
wrs = 1.15682e3 / (pi * 13.2217)
wrs = 27.8502 lbf/ft

wt = (Ws / (pi * D)) + wrs
wt = (22.0165e3 / (pi * 13.2217)) + 27.8502
wt = 557.896 lbf/ft

wint = P * 144 * ((pi * ((D^2) / 4)) / (pi * D))
wint = 0.0 * 144 * ((pi * ((13.2217^2) / 4)) / (pi * 13.2217))
wint = 0.0 lbf/ft

Bottom Annular Plates Requirements
tb-corr = t_bottom - ca_bottom
tb-corr = 0.18750 - 0.0
tb-corr = 0.18750 in

ts1_c = ts1 - ca1
ts1_c = 0.3750 - 0.0
ts1_c = 0.3750 in

ta = MIN(tb-corr , ts1_c)
ta = MIN(0.18750 , 0.3750)
ta = 0.18750 in

wa_limit = 1.28 * H * D * Ge
wa_limit = 1.28 * 60.4167 * 13.2217 * 0.959680
wa_limit = 981.249 lbf/ft

w_a_self-anchored = 7.9 * ta * SQRT((Fy * H * Ge))
w_a_self-anchored = 7.9 * 0.18750 * SQRT((28.90e3 * 60.4167 * 0.959680))
w_a_self-anchored = 1.91743e3 lbf/ft

w_a = MIN(w_a_self-anchored , wa_limit)
w_a = MIN(1.91743e3 , 981.249)
w_a = 981.249 lbf/ft

w_a = w_a
w_a = 981.249

w_a = 981.249 lbf/ft

Tank Stability
J = Mrw / ((D^2) * (((wt * (1 - (0.4 * Av))) + wa) - (Fp * wint)))
J = 1.01301e6 / ((13.2217^2) * (((557.896 * (1 - (0.4 * 0.10080))) + 981.249) - (0.40 * 0.0)))
J = 3.82080

As per API 650, Section E.6.2.1.1.1, Table E.6
J > 1.54 ==> Tank is not stable, anchoring is required

Seismic Method (seismic-method) = ASCE7-MAPPED-SS-AND-S1

sigma_c = ((wt * (1 + (0.4 * Av))) + ((1.273 * Mrw) / (D^2))) * (1 / (12 * ts))
sigma_c = ((557.896 * (1 + (0.4 * 0.10080))) + ((1.273 * 1.01301e6) / (13.2217^2))) * (1 / (12 * 0.3750))
sigma_c = 1.76827e3 lbf/in^2

F_c = (1.0E6 * (ts / (2.5 * D))) + (600 * SQRT((G * H)))
F_c = (1.0E6 * (0.3750 / (2.5 * 13.2217))) + (600 * SQRT((1.0 * 60.4167)))
F_c = 16.0087e3 lbf/in^2

sigma_c < F_c

Overturn_Stability_Ratio = (0.5 * D * (W_T + Wfd + Wg)) / Ms
Overturn_Stability_Ratio = (0.5 * 13.2217 * (542.129e3 + 0.0 + 0.0)) / 1.08063e6
Overturn_Stability_Ratio = 3.31651

Overturn_Stability_Ratio >= 2.0 ==> PASS

Freeboard
DELTAs = 0.42 * D * Af
DELTAs = 0.42 * 13.2217 * 0.0950
DELTAs = 0.527544 ft

Freeboard = H_shell - Lmax-operating
Freeboard = 60.4167 - 60.4167
Freeboard = 7.10543e-15 ft [85.2651e-15 in]

Freeboard_recommended = 0.7 * DELTAs
Freeboard_recommended = 0.7 * 0.527544
Freeboard_recommended = 0.369281 ft [4.43137 in]

As per API-650 E.7.2 and Table E.7, freeboard is recommended but not required

Sliding Resistance
Vs = MU * (Ws + Wr + Wf + Wp) * (1.0 - (0.4 * Av))
Vs = 0.40 * (22.0165e3 + 1.15682e3 + 1.11263e3 + 517.843e3) * (1.0 - (0.4 * 0.10080))
Vs = 208.108e3 lbf

V <= Vs

Local Shear Transfer
Vmax = (2 * V) / (pi * D)
Vmax = (2 * 34.9480e3) / (pi * 13.2217)
Vmax = 1.68274e3 lbf/ft

Anchor Bolt Design Back

A-s = Installed Bolt Nominal Root Area (in^2)
A-s-r = Anchor Required Root Area (in^2)
Av = Seismic Vertical Earthquake Acceleration Coefficient (g)
Ca-anchor = Anchor Corrosion Allowance (in)
d = Anchor Bolt Diameter (in)
D = Tank nominal diameter (ft)
Dac = Bolt Circle Diameter (ft)
d-req = Bolt Required Diameter per *ANSI B1.1* (in)
Fp = Design Pressure Operating Ratio
Fty = Minimum Yield Strength of the Bottom Shell Course (psi)
Fy = Anchor Yield Strength per *API-650 Table 5.21b* (psi)
Fy-ambient = Anchor Yield Strength at Ambient Temperature per *API-650 Table 5.21b* (psi)
H = Tank Height (ft)
Ma-anchor = Anchor Material
Mrw = Seismic Overturning Moment (ft.lbf)
MWS = Shell Wind Overturning Moment (ft.lbf)
N = Anchors Quantity
n = Number of threads per unit length (in)
N-min = Minimum Required Number of Anchors per *API-650 5.12.3*
OD = Tank Outer diameter (ft)
P = Internal Pressure (inH2O)
p = Bolt Thread Pitch
P_attachment = Anchor Attachment Design Load per *API-650 Section 5.12.13 and Steel Plate Engineering Data-Volume 2 Part V* (lbf)
position_angles = Anchors Position Angles (deg)
Pt = Test Pressure (inH2O)
PWR = Roof Wind Pressure (inH2O)
S_d = Allowable Anchor Stress per *API-650 Table 5.20b* (psi)
S_d_shell = Allowable Shell Stress at Anchor Attachment per *API-650 Table 5.20b* (psi)
T_b = Load per Anchor per *API-650 5.12.2* (lbf)
U = Net Uplift Load per *API-650 Section 5.12.2 and Table 5.20b* (lbf)
W1 = Corroded Weight of the Roof Plates Plus the Corroded Weight of the Shell and any Other Corroded Permanent Attachments Acting on the Shell (lbf)
W2 = Corroded Weight of the Shell and any Corroded Permanent Attachments Acting on the Shell Including the Portion of the Roof Plates and Framing Acting on The Shell (lbf)
W3 = Nominal Weight of the Roof Plates Plus the Nominal Weight of the Shell and any Other Permanent Attachments Acting on the Shell (lbf)
Wr-pl = Roof Plates Nominal Weight (lb)
Wr-pl-corr = Roof Corroded Plates Weight (lb)
Wrs-pl-corr = Roof Plates Corroded Weight Acting on The Shell (lb)
Ws-framing = Shell New Framing Weight (stiffeners) (lbf)
Ws-framing-corr = Shell Corroded Framing Weight (stiffeners) (lbf)
Ws-pl = Shell Plates Nominal Weight (lb)
Ws-pl-corr = Shell Corroded Plates Weight (lb)
Wss = Roof Structure Nominal Weight Acting on The Shell (lb)
Wss-corr = Roof Structure Corroded Weight Acting on The Shell (lb)
Y-bolt = Anchor Yield Load (lbf)

Av = 0.10080 g
Ca-anchor = 0.0 in
D = 13.2217 ft
d = 1.6250 in

Dac = 13.6383 ft
Fp = 0.40
Fty = 28.90e3 psi
H = 60.4167 ft
Ma-anchor = A36
Mrw = 1.01301e6 ft.lbf
MWS = 210.056e3 ft.lbf
n = 8.0 in
N = 8.0
OD = 13.2842 ft
p = 0.130
P = 0.0 inH2O
position_angles = [15.0 60.0 105.0 150.0 195.0 240.0 285.0 330.0] deg
Pt = 0.0 inH2O
PWR = 2.77576 inH2O
Wr-pl = 1.11122e3 lb
Wr-pl-corr = 1.11122e3 lb
Wrs-pl-corr = 1.11122e3 lb
Ws-framing = 136.572 lbf
Ws-framing-corr = 132.617 lbf
Ws-pl = 21.2641e3 lb
Ws-pl-corr = 21.2641e3 lb
Wss = 0.0 lb
Wss-corr = 0.0 lb

Anchors Spacing Requirements

Max Allowable Spacing Between Anchors at Shell Outer Diameter per API-650 5.12.3
Max Allowable Spacing (max_allowable_spacing) = 10.0 ft
Actual Spacing (actual_spacing) = 5.21668 ft

actual_spacing <= max_allowable_spacing ==> PASS

N-min = CEILING(((pi * OD) / 10))
N-min = CEILING(((pi * 13.2842) / 10))
N-min = 5.0

N >= N-min ==> PASS

Anchors meet spacing requirements.

Anchors Average Spacing (half the span on each side of the anchor) at Bolt Circle
Anchors are equally spaced.
Average Spacing (average_spacing) = 5.360 ft
Bolt loads will be based on equally spaced anchors.

Anchor Material Properties

Material = A36
Minimum Tensile Strength (Sut-anchor) = 58.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength at Ambient Temperature (Sy-ambient-anchor) = 36.0e3 psi
As per API-650 Table M.1.b, Minimum Yield Strength (Sy-anchor) = 33.6218e3 psi

Fy = MIN(Sy-anchor , 55000)
Fy = MIN(33.6218e3 , 55000)
Fy = 33.6218e3 psi

Fy-ambient = MIN(Sy-ambient-anchor , 55000)
Fy-ambient = MIN(36.0e3 , 55000)
Fy-ambient = 36.0e3 psi

Uplift Load Cases per API-650 Table 5.20b

W1 = Ws-pl-corr + Ws-framing-corr + Wr-pl-corr
W1 = 21.2641e3 + 132.617 + 1.11122e3
W1 = 22.5079e3 lbf

W2 = Ws-pl-corr + Ws-framing-corr + Wrs-pl-corr + Wss-corr
W2 = 21.2641e3 + 132.617 + 1.11122e3 + 0.0
W2 = 22.5079e3 lbf

W3 = Ws-pl + Ws-framing + Wr-pl + Wss
W3 = 21.2641e3 + 136.572 + 1.11122e3 + 0.0
W3 = 22.5119e3 lbf

As per API-650 Section 5.12.13, Seismic Attachment Load Multiplier (f_seismic) = 3.0
Seismic anchoring is required and API-650 Section 5.12.13 requires a multiplier of 3.

Uplift Case 1: Design Pressure Only
U = (P * (D^2) * 4.08) - W1
U = (0.0 * (13.2217^2) * 4.08) - 22.5079e3
U = -22.5079e3 (Set to 0.0 lbf since it cannot be less than 0.0)

T_b = U / N
T_b = 0.0 / 8.0
T_b = 0.0 lbf

S_d = (5 / 12) * Fy
S_d = (5 / 12) * 33.6218e3
S_d = 14.0091e3 psi

A-s-r = T_b / S_d
A-s-r = 0.0 / 14.0091e3
A-s-r = 0.0 in^2

P_attachment = 1.5 * T_b
P_attachment = 1.5 * 0.0
P_attachment = 0.0 lbf

S_d_shell = (2 / 3) * Fty
S_d_shell = (2 / 3) * 28.90e3
S_d_shell = 19.2667e3 psi

Uplift Case 2: Test Pressure Only
U = (Pt * (D^2) * 4.08) - W3
U = (0.0 * (13.2217^2) * 4.08) - 22.5119e3
U = -22.5119e3 (Set to 0.0 lbf since it cannot be less than 0.0)

T_b = U / N
T_b = 0.0 / 8.0
T_b = 0.0 lbf

S_d = (5 / 9) * Fy-ambient
S_d = (5 / 9) * 36.0e3

S_d = 20.0e3 psi

A-s-r = T_b / S_d
A-s-r = 0.0 / 20.0e3
A-s-r = 0.0 in^2

P_attachment = 1.5 * T_b
P_attachment = 1.5 * 0.0
P_attachment = 0.0 lbf

S_d_shell = (5 / 6) * Fty
S_d_shell = (5 / 6) * 28.90e3
S_d_shell = 24.0833e3 psi

Uplift Case 3: Wind Load Only
U = ((PWR * (D^2) * 4.08) + ((4 * MWS) / D)) - W2
U = ((2.77576 * (13.2217^2) * 4.08) + ((4 * 210.056e3) / 13.2217)) - 22.5079e3
U = 43.0210e3 lbf

T_b = U / N
T_b = 43.0210e3 / 8.0
T_b = 5.37762e3 lbf

S_d = 0.8 * Fy
S_d = 0.8 * 33.6218e3
S_d = 26.8975e3 psi

A-s-r = T_b / S_d
A-s-r = 5.37762e3 / 26.8975e3
A-s-r = 0.199931 in^2

P_attachment = 1.5 * T_b
P_attachment = 1.5 * 5.37762e3
P_attachment = 8.06644e3 lbf

S_d_shell = (5 / 6) * Fty
S_d_shell = (5 / 6) * 28.90e3
S_d_shell = 24.0833e3 psi

Uplift Case 4: Seismic Load Only
U = ((4 * Mrw) / D) - (W2 * (1 - (0.4 * Av)))
U = ((4 * 1.01301e6) / 13.2217) - (22.5079e3 * (1 - (0.4 * 0.10080)))
U = 284.868e3 lbf

T_b = U / N
T_b = 284.868e3 / 8.0
T_b = 35.6086e3 lbf

S_d = 0.8 * Fy
S_d = 0.8 * 33.6218e3
S_d = 26.8975e3 psi

A-s-r = T_b / S_d
A-s-r = 35.6086e3 / 26.8975e3
A-s-r = 1.32386 in^2

P_attachment = f_seismic * T_b
P_attachment = 3.0 * 35.6086e3
P_attachment = 106.826e3 lbf

S_d_shell = (5 / 6) * Fty
S_d_shell = (5 / 6) * 28.90e3
S_d_shell = 24.0833e3 psi

Uplift Case 5: Design Pressure + Wind Load
U = ((((Fp * P) + PWR) * (D^2) * 4.08) + ((4 * MWS) / D)) - W1
U = ((((0.40 * 0.0) + 2.77576) * (13.2217^2) * 4.08) + ((4 * 210.056e3) / 13.2217)) - 22.5079e3
U = 43.0210e3 lbf

T_b = U / N
T_b = 43.0210e3 / 8.0
T_b = 5.37762e3 lbf

S_d = (5 / 9) * Fy
S_d = (5 / 9) * 33.6218e3
S_d = 18.6788e3 psi

A-s-r = T_b / S_d
A-s-r = 5.37762e3 / 18.6788e3
A-s-r = 0.28790 in^2

P_attachment = 1.5 * T_b
P_attachment = 1.5 * 5.37762e3
P_attachment = 8.06644e3 lbf

S_d_shell = (5 / 6) * Fty
S_d_shell = (5 / 6) * 28.90e3
S_d_shell = 24.0833e3 psi

Uplift Case 6: Design Pressure + Seismic Load
U = ((Fp * P * (D^2) * 4.08) + ((4 * Mrw) / D)) - (W1 * (1 - (0.4 * Av)))
U = ((0.40 * 0.0 * (13.2217^2) * 4.08) + ((4 * 1.01301e6) / 13.2217)) - (22.5079e3 * (1 - (0.4 * 0.10080)))
U = 284.868e3 lbf

T_b = U / N
T_b = 284.868e3 / 8.0
T_b = 35.6086e3 lbf

S_d = 0.8 * Fy
S_d = 0.8 * 33.6218e3
S_d = 26.8975e3 psi

A-s-r = T_b / S_d
A-s-r = 35.6086e3 / 26.8975e3
A-s-r = 1.32386 in^2

P_attachment = f_seismic * T_b
P_attachment = 3.0 * 35.6086e3
P_attachment = 106.826e3 lbf

S_d_shell = (5 / 6) * Fty
S_d_shell = (5 / 6) * 28.90e3

S_d_shell = 24.0833e3 psi

Uplift Case 7: Frangibility Pressure
Not applicable. It is applied if the roof to shell joint is frangible.

Summary of Uplift Cases

Uplift Cases	Total Uplift Load (lbf)	Load per Anchor (lbf)	Anchor Allowable Stress (psi)	Anchor Required Area (in^2)	Anchor Bolt Required Diameter (in)	Attachment Design Load (lbf)	Allowable Shell Stress at Anchor Attachment (psi)
Design Pressure	0.0	0.0	14.0091e3	0.0	0.16250	0.0	19.2667e3
Test Pressure	0.0	0.0	20.0e3	0.0	0.16250	0.0	24.0833e3
Wind Load	43.0210e3	5.37762e3	26.8975e3	0.199931	0.667039	8.06644e3	24.0833e3
Seismic Load	284.868e3	35.6086e3	26.8975e3	1.32386	1.46080	106.826e3	24.0833e3
Design Pressure + Wind	43.0210e3	5.37762e3	18.6788e3	0.28790	0.767947	8.06644e3	24.0833e3
Design Pressure + Seismic	284.868e3	35.6086e3	26.8975e3	1.32386	1.46080	106.826e3	24.0833e3

- Anchor Bolt Required Diameter = SQRT((A-s-r * (4 / pi))) + (1.3 / n) + (Ca-anchor * 2)
- Governing Uplift Case = Seismic Load
- Anchor Bolt Minimum Required Area = 1.32386 in^2

Bolt Required Diameter per ANSI B1.1
d-req = SQRT((A * (4 / pi))) + (1.3 / n) + (Ca * 2)
d-req = SQRT((1.32386 * (4 / pi))) + (1.3 / 8.0) + (0.0 * 2)
d-req = 1.46080 in

d >= d-req ==> PASS

A-s = (pi / 4) * ((d - (1.3 / n))^2)
A-s = (pi / 4) * ((1.6250 - (1.3 / 8.0))^2)
A-s = 1.67989 in^2

Y-bolt = A-s * Sy-ambient-anchor
Y-bolt = 1.67989 * 36.0e3
Y-bolt = 60.4761e3 lbf

Anchorage Summary
Required Number of Anchors = 5.0
Actual Number of Anchors = 8.0
Bolt Hole Circle Radius = 6.81917 ft

Required Bolt Diameter = 1.46080 in
Actual Bolt Diameter = 1.6250 in
Bolt Thread Pitch = 0.130
Bolt Embedded Depth = 10.0 in
Bolt Length = 25.9375 in

Anchor Chair Design Back

Anchor Chair Design per AISI T-192 Part V

a = Top Plate Width Along Shell (in)
b = Top Plate Length (in)
bmin = Top Plate Minimum Length (in)
c = Top Plate Thickness (in)
CA = Chair Corrosion Allowance (in)
c_corr = Top Plate Corroded Thickness (in)
D = Tank Nominal Diameter (ft)
d = Anchor Bolt Diameter (in)
e = Anchor Bolt Eccentricity (in)
Earthquakes-Considered = Earthquakes Considered
emin = Minimum Calculated Eccentricity (in)
emin-btm = Minimum Eccentricity Based on Bolt Clearance From Bottom Plates per *API-650 5.12.4* (in)
emin-req = Minimum Required Eccentricity (in)
Et = Bottom Plates Thermal Expansion Coefficient per *API-650 Table P.1b* (in/in.fdeg)
f = Top Plate Outside To Hole Edge Distance (in)
f_min = Distance from Outside of Top Plate to Edge of Hole per *AISI T-192 Part V, Notation* (in)
g = Vertical Plates Distance (in)
g_min = Minimum Distance Between Vertical Plates per *AISI T-192, PartV, Notation* (in)
h = Chair Height (in)
h-eff = Effective Chair Height (in)
hmax = Chair Maximum Height (in)
j = Vertical Plate Thickness (in)
j_corr = Vertical Plate Corroded Thickness (in)
j_min = Vertical Plate Minimum Thickness per *AISI T-192 Part V, Vertical Side Plates* (in)
k = Vertical Plates Average Width (in)
m = Base or Bottom Plate Thickness (in)
Ma-chair = Chair Material
outside-projection = Bottom Outside Projection (in)
R = Nominal Shell Radius (in)
Ssw-chair = Chair Allowable Stress for Seismic or Wind Design per *API-650 5.12.9* (psi)
T = Difference between ambient and design temperature per *API 650 5.12.4* (°F)
t = Shell Thickness (in)
T_ambient = Ambient Temperature (°F)
T_design = Design Temperature (°F)
V = Wind Velocity (mph)
Y-bolt = Anchor Bolt Yield Load (lbf)

a = 8.0 in
b = 8.0 in
c = 0.750 in

CA = 0.0 in
d = 1.6250 in
D = 13.2217 ft
e = 2.1250 in
Earthquakes-Considered = ASCE7-MAPPED-SS-AND-S1
Et = 6.670e-6 in/in.fdeg
f = 4.81250 in
g = 4.250 in
h = 12.0 in
j = 0.6250 in
k = 4.55022 in
m = 0.18750 in
Ma-chair = A240-304
outside-projection = 1.0 in
R = 79.330 in
t = 0.3750 in
T_ambient = 70.0 °F
T_design = 122.0 °F
V = 81.90 mph
Y-bolt = 60.4761e3 lbf

Anchor Chair Material Properties
Material = A240-304
Minimum Tensile Strength (Sut-chair) = 75.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy-chair) = 28.90e3 psi
As per API-650 S.2b, Allowable Design Stress (Sd-chair) = 22.50e3 psi
As per API-650 S.2b, Allowable Hydrostatic Test Stress (St-chair) = 27.0e3 psi

Ssw-chair = 1.33 * Sd-chair
Ssw-chair = 1.33 * 22.50e3
Ssw-chair = 29.9250e3 psi

Size Requirements
c_corr = c - (2 * CA)
c_corr = 0.750 - (2 * 0.0)
c_corr = 0.750 in

j_corr = j - (2 * CA)
j_corr = 0.6250 - (2 * 0.0)
j_corr = 0.6250 in

Chair Minimum Height (hmin) = 12.0 in

h >= hmin ==> PASS

hmax = 3 * a
hmax = 3 * 8.0
hmax = 24.0 in

h-eff = MIN(hmax , h)
h-eff = MIN(24.0 , 12.0)
h-eff = 12.0 in

emin = (0.886 * d) + 0.572
emin = (0.886 * 1.6250) + 0.572
emin = 2.01175 in

T = T_design - T_ambient
T = 122.0 - 70.0
T = 52.0 °F

emin-btm = (d / 2) + outside-projection + 0.125 + (6 * Et * D * T)
emin-btm = (1.6250 / 2) + 1.0 + 0.125 + (6 * 6.670e-6 * 13.2217 * 52.0)
emin-btm = 1.96501 in

emin-req = MAX(emin , emin-btm)
emin-req = MAX(2.01175 , 1.96501)
emin-req = 2.01175 in

e >= emin-req ==> PASS

g_min = d + 1
g_min = 1.6250 + 1
g_min = 2.6250 in

g >= g_min ==> PASS

f_min = (d / 2) + 0.125
f_min = (1.6250 / 2) + 0.125
f_min = 0.93750 in

f >= f_min ==> PASS

j_min = MAX(0.5 , (0.04 * (h-eff - c_corr)) , ((P-design / (25000 * k)) + (2 * CA)))
j_min = MAX(0.5 , (0.04 * (12.0 - 0.750)) , ((60.4761e3 / (25000 * 4.55022)) + (2 * 0.0)))
j_min = 0.531633 in

j >= j_min ==> PASS

bmin = emin + d + 0.25
bmin = 2.01175 + 1.6250 + 0.25
bmin = 3.88675 in

b >= bmin ==> PASS

Top Plate Minimum Required Thickness

Uplift Cases	P-chair (lbf)	P-design (lbf)	Sd-chair (psi)	c_min (in)	Status

Design Pressure	0.0	0.0	22.50e3	0.0	PASS
Test Pressure	0.0	0.0	27.0e3	0.0	PASS
Wind Load	8.06644e3	8.06644e3	29.9250e3	0.263143	PASS
Seismic Load	106.826e3	60.4761e3	29.9250e3	0.720515	PASS
Design Pressure + Wind	8.06644e3	8.06644e3	29.9250e3	0.263143	PASS
Design Pressure + Seismic	106.826e3	60.4761e3	29.9250e3	0.720515	PASS

- P-chair = Anchor Chair Uplift Load
- P-design = Anchor Chair Design Load = min(P-chair, Y-bolt)
- Sd-chair = Anchor Chair Allowable Stress
- c_min = Top Plate Minimum Required Thickness
- c_min = SQRT(((P-design / (Sd-chair * f)) * ((0.375 * g) - (0.22 * d)))) + (2 * CA)
- Governing Uplift Case = Seismic Load
- Governing Thickness (c_min) = 0.720515 in

Top Plate Stress

Uplift Cases	P-chair (lbf)	P-design (lbf)	S_top-plate (psi)	Sd-chair (psi)	Stress Ratio	Status
Design Pressure	0.0	0.0	0.0	22.50e3	0.0%	PASS
Test Pressure	0.0	0.0	0.0	27.0e3	0.0%	PASS
Wind Load	8.06644e3	8.06644e3	3.68379e3	29.9250e3	12.3101%	PASS
Seismic Load	106.826e3	60.4761e3	27.6183e3	29.9250e3	92.2918%	PASS
Design Pressure + Wind	8.06644e3	8.06644e3	3.68379e3	29.9250e3	12.3101%	PASS
Design Pressure + Seismic	106.826e3	60.4761e3	27.6183e3	29.9250e3	92.2918%	PASS

- P-chair = Anchor Chair Uplift Load
- P-design = Anchor Chair Design Load = min(P-chair, Y-bolt)
- S_top-plate = Top Plate Stress
- S_top-plate = (P-design / (f * (c_corr^2))) * ((0.375 * g) - (0.22 * d))
- Sd-chair = Anchor Chair Allowable Stress
- Governing Uplift Case = Seismic Load
- Governing Stress (S_top-plate) = 27.6183e3 psi

Z = Chair Reduction Factor per *AISI T-192 Part V, Eq 5-4*

Shell Stress at Anchor Attachment
Z = 1 / ((((0.177 * a * m) / SQRT((R * t))) * ((m / t)^2)) + 1)
Z = 1 / ((((0.177 * 8.0 * 0.18750) / SQRT((79.330 * 0.3750))) * ((0.18750 / 0.3750)^2)) + 1)
Z = 0.987977

Uplift Cases	P-chair (lbf)	P-design (lbf)	S_Shell (psi)	Sd-shell (psi)	Stress Ratio	Status
Design Pressure	0.0	0.0	0.0	19.2667e3	0.0%	PASS
Test Pressure	0.0	0.0	0.0	24.0833e3	0.0%	PASS

Wind Load	8.06644e3	8.06644e3	2.90156e3	24.0833e3	12.0480%	PASS
Seismic Load	106.826e3	60.4761e3	21.7537e3	24.0833e3	90.3269%	PASS
Design Pressure + Wind	8.06644e3	8.06644e3	2.90156e3	24.0833e3	12.0480%	PASS
Design Pressure + Seismic	106.826e3	60.4761e3	21.7537e3	24.0833e3	90.3269%	PASS

- P-chair = Anchor Chair Uplift Load
- P-design = Anchor Chair Design Load = min(P-chair, Y-bolt)
- S_Shell = Stress at Attachment
- S_Shell = ((P-design * e) / (t^2)) * (((1.32 * Z) / (((1.43 * a * (h^2)) / (R * t)) + ((4 * a * (h^2))^0.333))) + (0.031 / SQRT((R * t))))
- Sd-shell = Allowable Stress at Anchor Attachment
- Governing Uplift Case = Seismic Load
- Governing Stress (S_Shell) = 21.7537e3 psi
- Governing Allowable Stress (Sd-Shell) = 24.0833e3 psi

Appurtenances Design Back

Plan View

LABEL	MARK	CUST. MARK	DESCRIPTION	OUTSIDE PROJ (in)	INSIDE PROJ (in)	ORIENT	RADIUS (in)	REMARKS	REF DWG
N1	RN02A		4" ROOF NOZZLE	6"	1"	0 '	5'-6"		
N2	RN01A		6" ROOF NOZZLE	6"	0"	0 '	0"		
N7	BD01		2" FLUSH DRAIN	3 1/2"	8"	270 '	0"	RADIAL	

Elevation View

LABEL	MARK	CUST. MARK	DESCRIPTION	OUTSIDE PROJ (in)	INSIDE PROJ (in)	ORIENT	ELEVATION (in)	REMARKS	REF DWG
Anchor-Chair-Bolts	AC01A		ANCHOR CHAIRS	--	--	SEE TABLE	--		
N3	SN02A		3" SHELL NOZZLE	7"	1"	0 '	49'-8"		
N4	SN01A		3" SHELL NOZZLE	7"	1"	0 '	9 1/2"		
N5	SM01A		20" SHELL MANWAY	10"	1"	90 '	2'-6"	W/ DAVIT	
N6	SN03A		4" SHELL NOZZLE	7"	0"	180 '	10 1/4"		
Name-Plate	NP01A		STD API	--	--	0 '	3'-4"		

Shell Nozzle: N4

Repad Design

NOZZLE Description : 3 in SCH 40S TYPE RFSO

Material: A312-TP304

t_rpr = (Repad Required Thickness)
t_n = (Thickness of Neck)
Sd_n = (Stress of Neck Material)
Sd_s = (Stress of Shell Course Material)
CA = (Corrosion Allowance of Neck)

MOUNTED ON SHELL 1 : Elevation = 0.7917 ft

COURSE PARAMETERS:
t-calc = 0.1297 in
t_cr = 0.1297 in (Course t-calc less C.A)
t_c = 0.375 in (Course t less C.A.)
t_Basis = 0.1297 in

(SHELL NOZZLE REF. API-650 S.3.3.1, AND FOOTNOTE A OF TABLE 5-7)

Required Area = t_Basis * D
Required Area = 0.1297 * 3.5
Required Area = 0.4539 in2

Available Shell Area = (t_c - t_Basis) * D
Available Shell Area = (0.375 - 0.1297) * 3.5
Available Shell Area = 0.8586 in2

Available Nozzle Neck Area = 2 * [(4 * (t_n - CA)) + t_c] * (t_n - CA) * MIN((Sd_n/Sd_s) 1)
Available Nozzle Neck Area = 2 * [(4 * (0.216 - 0)) + 0.375] * (0.216 - 0) * MIN((22,500/22,500) 1)
Available Nozzle Neck Area = 0.5352 in2

A-rpr = (Required Area - Available Shell Area - Available Nozzle Neck Area)
A-rpr = 0.4539 - 0.8586 - 0.5352
A-rpr = 0 in2

Since A-rpr <= 0, t_rpr = 0

No Reinforcement Pad required.

t_shell_PWHT = Thickness of the shell plate, insert plate, or thickened insert plate for PWHT (in)

Nozzle Neck Material Properties
Material = A312-TP304
As per API-650 S.2b, Allowable Design Stress (Sd-neck) = 22.50e3 psi

t_shell_PWHT = t-plate
t_shell_PWHT = 0.3750
t_shell_PWHT = 0.3750 in

Thermal Stress Relief (PWHT) Requirements
D = Nozzle Nominal Diameter (NPS) (in)
Group = Shell Material Group
t_shell = Shell Plate Thickness (in)

D = 3.0 in

Group = None
t_shell = 0.3750 in

Shell material group (None) is not a group specified by API 650, 13th Ed, Section 5.7.4. Requirement for Thermal Stress Relief (PWHT) is unknown.

Shell Nozzle: N3

Repad Design

NOZZLE Description : 3 in SCH 40S TYPE RFSO
Material: A312-TP304

t_rpr = (Repad Required Thickness)
t_n = (Thickness of Neck)
Sd_n = (Stress of Neck Material)
Sd_s = (Stress of Shell Course Material)
CA = (Corrosion Allowance of Neck)

MOUNTED ON SHELL 11 : Elevation = 49.6667 ft

COURSE PARAMETERS:
t-calc = 0.0228 in
t_cr = 0.0228 in (Course t-calc less C.A)
t_c = 0.1875 in (Course t less C.A.)
t_Basis = 0.0228 in

(SHELL NOZZLE REF. API-650 S.3.3.1, AND FOOTNOTE A OF TABLE 5-7)

Required Area = t_Basis * D
Required Area = 0.0228 * 3.5
Required Area = 0.0798 in2

Available Shell Area = (t_c - t_Basis) * D
Available Shell Area = (0.1875 - 0.0228) * 3.5
Available Shell Area = 0.5764 in2

Available Nozzle Neck Area = 2 * [(4 * (t_n - CA)) + t_c] * (t_n - CA) * MIN((Sd_n/Sd_s) 1)
Available Nozzle Neck Area = 2 * [(4 * (0.216 - 0)) + 0.1875] * (0.216 - 0) * MIN((22,500/22,500) 1)
Available Nozzle Neck Area = 0.4542 in2

A-rpr = (Required Area - Available Shell Area - Available Nozzle Neck Area)
A-rpr = 0.0798 - 0.5764 - 0.4542
A-rpr = 0 in2

Since A-rpr <= 0, t_rpr = 0

No Reinforcement Pad required.

t_shell_PWHT = Thickness of the shell plate, insert plate, or thickened insert plate for PWHT (in)

Nozzle Neck Material Properties
Material = A312-TP304
As per API-650 S.2b, Allowable Design Stress (Sd-neck) = 22.50e3 psi

t_shell_PWHT = t-plate
t_shell_PWHT = 0.18750
t_shell_PWHT = 0.18750 in

Thermal Stress Relief (PWHT) Requirements
D = Nozzle Nominal Diameter (NPS) (in)
Group = Shell Material Group
t_shell = Shell Plate Thickness (in)

D = 3.0 in
Group = None
t_shell = 0.18750 in

Shell material group (None) is not a group specified by API 650, 13th Ed, Section 5.7.4. Requirement for Thermal Stress Relief (PWHT) is unknown.

Shell Nozzle: N6

Repad Design

NOZZLE Description : 4 in SCH 40S TYPE RFSO
Material: A312-TP304

t_rpr = (Repad Required Thickness)
t_n = (Thickness of Neck)
Sd_n = (Stress of Neck Material)
Sd_s = (Stress of Shell Course Material)
CA = (Corrosion Allowance of Neck)

MOUNTED ON SHELL 1 : Elevation = 0.8542 ft

COURSE PARAMETERS:
t-calc = 0.1297 in
t_cr = 0.1297 in (Course t-calc less C.A)
t_c = 0.375 in (Course t less C.A.)
t_Basis = 0.1297 in

(SHELL NOZZLE REF. API-650 S.3.3.1, AND FOOTNOTE A OF TABLE 5-7)

Required Area = t_Basis * D
Required Area = 0.1297 * 4.5
Required Area = 0.5836 in2

Available Shell Area = (t_c - t_Basis) * D
Available Shell Area = (0.375 - 0.1297) * 4.5
Available Shell Area = 1.1039 in2

Available Nozzle Neck Area = 2 * [(4 * (t_n - CA)) + t_c] * (t_n - CA) * MIN((Sd_n/Sd_s) 1)
Available Nozzle Neck Area = 2 * [(4 * (0.237 - 0)) + 0.375] * (0.237 - 0) * MIN((22,500/22,500) 1)
Available Nozzle Neck Area = 0.6271 in2

A-rpr = (Required Area - Available Shell Area - Available Nozzle Neck Area)
A-rpr = 0.5836 - 1.1039 - 0.6271
A-rpr = 0 in2

Since A-rpr <= 0, t_rpr = 0

No Reinforcement Pad required.

t_shell_PWHT = Thickness of the shell plate, insert plate, or thickened insert plate for PWHT (in)

Nozzle Neck Material Properties
Material = A312-TP304
As per API-650 S.2b, Allowable Design Stress (Sd-neck) = 22.50e3 psi

t_shell_PWHT = t-plate
t_shell_PWHT = 0.3750
t_shell_PWHT = 0.3750 in

Thermal Stress Relief (PWHT) Requirements
D = Nozzle Nominal Diameter (NPS) (in)
Group = Shell Material Group
t_shell = Shell Plate Thickness (in)

D = 4.0 in
Group = None
t_shell = 0.3750 in

Shell material group (None) is not a group specified by API 650, 13th Ed, Section 5.7.4. Requirement for Thermal Stress Relief (PWHT) is unknown.

Shell Manway: N5

Repad Design

MANWAY Description : 20 in Neck Thickness 0.25
Material: A240-304

t_rpr = (Repad Required Thickness)
t_n = (Thickness of Neck)
Sd_n = (Stress of Neck Material)
Sd_s = (Stress of Shell Course Material)
CA = (Corrosion Allowance of Neck)

MOUNTED ON SHELL 1 : Elevation = 2.5 ft

COURSE PARAMETERS:
t-calc = 0.1297 in
t_cr = 0.1297 in (Course t-calc less C.A)
t_c = 0.375 in (Course t less C.A.)
t_Basis = 0.1297 in
Repad Type: Circular
Repad Size (Do): = 25 in

(SHELL MANWAY REF. API-650 TABLE 5-6, AND FOOTNOTE A OF TABLE 5-7)

Required Area = t_Basis * D
Required Area = 0.1297 * 20
Required Area = 2.5937 in2

Available Shell Area = (t_c - t_Basis) * D
Available Shell Area = (0.375 - 0.1297) * 20
Available Shell Area = 4.9063 in2

Available Manway Neck Area = 2 * [(4 * (t_n - CA)) + t_c] * (t_n - CA) * MIN((Sd_n/Sd_s) 1)
Available Manway Neck Area = 2 * [(4 * (0.25 - 0)) + 0.375] * (0.25 - 0) * MIN((22,500/22,500) 1)
Available Manway Neck Area = 0.6875 in2

A-rpr = (Required Area - Available Shell Area - Available Manway Neck Area)
A-rpr = 2.5937 - 4.9063 - 0.6875
A-rpr = 0 in2

Since A_rpr <= 0, t_rpr = 0

No Reinforcement Pad required.

t_shell_PWHT = Thickness of the shell plate, insert plate, or thickened insert plate for PWHT (in)

Manway Neck Material Properties
Material = A240-304
As per API-650 S.2b, Allowable Design Stress (Sd-neck) = 22.50e3 psi

Manway Repad Material Properties
Material = A240-304

t_shell_PWHT = MAX(t-repad , t-plate)
t_shell_PWHT = MAX(0.3750 , 0.3750)
t_shell_PWHT = 0.3750 in

Thermal Stress Relief (PWHT) Requirements
D = Nozzle Nominal Diameter (NPS) (in)
Group = Shell Material Group
t_shell = Shell Plate Thickness (in)

D = 20.0 in
Group = None
t_shell = 0.3750 in

Shell material group (None) is not a group specified by API 650, 13th Ed, Section 5.7.4. Requirement for Thermal Stress Relief (PWHT) is unknown.

Cover Plate and Bolting Flange Design

CA-cover = Cover Plate and Bolting Flange Corrosion Allowance (in)
Db = Bolt Circle Diameter (in)
H = Design Liquid Level (ft)
M = Cover Plate Thickness Multiplication Factor per *API-650 S.3.3.3*
M = Bolting Flange Thickness Multiplication Factor per *API-650 S.3.3.3*
Ma-cover = Cover Plate Material
Ma-flange = Bolting Flange Material
Sd = Allowable Stress per *API-650 5.7.5.6* (psi)
SG = Product Specific Gravity
tc = Cover Plate Thickness (in)
tc-design = Cover Plate Required Thickness per *API-650 5.7.5.6* (in)
tc-req = Cover Plate Minimum Required Thickness (in)
tf = Bolting Flange Thickness (in)
tf-design = Cover Plate Required Thickness per *API-650 5.7.5.6* (in)
tf-req = Bolting Flange Minimum Required Thickness (in)
t-neck = Neck Thickness (in)

CA-cover = 0.0 in
Db = 26.250 in
H = 60.4167 ft
Ma-cover = A240-304
Ma-flange = A240-304
SG = 1.0
tc = 0.6250 in
tf = 0.6250 in
t-neck = 0.250 in

Water Density (Y) = 0.4330 psi/ft
As per API-650 5.7.5.6, Coefficient For Circular Plate (C) = 0.30

Cover Plate Material Properties and Required Thickness
Material = A240-304
As per API-650 S.5.b, Minimum Yield Strength at Ambient Temperature (Sy-ambient-cover) = 30.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy-cover) = 28.90e3 psi
Thickness for MDMT-permissible-cover (per API-650 Figure 4.3) = 0.156250 in

Sd = MIN(Sy-ambient-cover , 30000) / 2 = 15.0e3 psi

M = MAX(SQRT((Sy-ambient-cover / Sy-cover)) , SQRT((30000 / Sy-cover)) , 1) = 1.01885

As per API-650 5.7.5.6, Cover Plate Erection Thickness (tc-erec) = 0.31250 in

tc-design = ((Db * SQRT(((C * Y * H * MAX(SG , 1)) / Sd))) + CA-cover) * M
tc-design = ((26.250 * SQRT(((0.30 * 0.4330 * 60.4167 * MAX(1.0 , 1)) / 15.0e3))) + 0.0) * 1.01885
tc-design = 0.611756 in

tc-req = MAX(tc-erec , tc-design)
tc-req = MAX(0.31250 , 0.611756)
tc-req = 0.611756 in

t-cover >= tc-req ==> PASS

Bolting Flange Material Properties and Required Thickness
Material = A240-304

As per API-650 S.5.b, Minimum Yield Strength at Ambient Temperature (Sy-ambient-flange) = 30.0e3 psi
As per API-650 S.5.b, Minimum Yield Strength (Sy-flange) = 28.90e3 psi
Thickness for MDMT-permissible-flange (per API-650 Figure 4.3) = 0.250 in

M = MAX(SQRT((Sy-ambient-flange / Sy-flange)) , SQRT((30000 / Sy-flange)) , 1) = 1.01885

As per API-650 5.7.5.6, Bolting Flange Erection Thickness (tf-erec) = 0.250 in

tf-design = tc-design - 0.125
tf-design = 0.611756 - 0.125
tf-design = 0.486756 in

tf-req = MAX(tf-erec , tf-design)
tf-req = MAX(0.250 , 0.486756)
tf-req = 0.486756 in

t-flange >= tf-req ==> PASS

Roof Nozzle: N2

Repad Design

(Per API-650 and other references below)

NOZZLE Description : 6 in SCH 40S TYPE RFSO
Material: A312-TP304

t_rpr = (Repad Required Thickness)
t_n = (Thickness of Neck)
Sd_n = (Stress of Neck Material)
Sd_s = (Stress of Roof Material)
CA = (Corrosion Allowance of Neck)

MOUNTED ON ROOF: Elevation = 61.5605 ft

ROOF PARAMETERS:
t-calc = 0.1875 in
t_cr = 0.1875 in (Roof t-act less C.A)
t_c = 0.1875 in
t_Basis = 0.1875 in

(FOR ROOF NOZZLES, REF. API-650 FIG 5-19, TABLE 5-14 AND FOOTNOTE A OF TABLE 5-14, or API-650 FIG 5-20, TABLE 5-15 AND FOOTNOTE A OF TABLE 5-15)

Required Area = t_Basis * D
Required Area = 0.1875 * 6.625
Required Area = 1.2422 in2

Available Roof Area = (t_c - t_Basis) * D
Available Roof Area = (0.1875 - 0.1875) * 6.625
Available Roof Area = 0 in2

Available Nozzle Neck Area = 2 * [(4 * (t_n - CA)) + t_c] * (t_n - ca) * MIN((Sd_n/Sd_s) 1)
Available Nozzle Neck Area = 2 * [(4 * (0.28 - 0)) + 0.1875] * (0.28 - 0) * MIN((22,500/22,500) 1)
Available Nozzle Neck Area = 0.7322 in2

A_rpr = (Required Area - Available Roof Area - Available Nozzle Neck Area)
A_rpr = 1.2422 - 0 - 0.7322
A_rpr = 0.51 in2

As per API-650 J.3.6.3, reinforcement pad is not required since roof loads do not exceed 25 psf.

No Reinforcement Pad required.

Roof Nozzle: N1

Repad Design

(Per API-650 and other references below)

NOZZLE Description : 4 in SCH 40S TYPE RFSO
Material: A312-TP304

t_rpr = (Repad Required Thickness)
t_n = (Thickness of Neck)
Sd_n = (Stress of Neck Material)
Sd_s = (Stress of Roof Material)
CA = (Corrosion Allowance of Neck)

MOUNTED ON ROOF: Elevation = 60.644 ft

ROOF PARAMETERS:
t-calc = 0.1875 in
t_cr = 0.1875 in (Roof t-act less C.A)
t_c = 0.1875 in
t_Basis = 0.1875 in

(FOR ROOF NOZZLES, REF. API-650 FIG 5-19, TABLE 5-14 AND FOOTNOTE A OF TABLE 5-14, or API-650 FIG 5-20, TABLE 5-15 AND FOOTNOTE A OF TABLE 5-15)

Required Area = t_Basis * D
Required Area = 0.1875 * 4.5
Required Area = 0.8438 in2

Available Roof Area = (t_c - t_Basis) * D
Available Roof Area = (0.1875 - 0.1875) * 4.5

Available Roof Area = 0 in2

Available Nozzle Neck Area = 2 * [(4 * (t_n - CA)) + t_c] * (t_n - ca) * MIN((Sd_n/Sd_s) 1)
Available Nozzle Neck Area = 2 * [(4 * (0.237 - 0)) + 0.1875] * (0.237 - 0) * MIN((22,500/22,500) 1)
Available Nozzle Neck Area = 0.5382 in2

A_rpr = (Required Area - Available Roof Area - Available Nozzle Neck Area)
A_rpr = 0.8438 - 0 - 0.5382
A_rpr = 0.3055 in2

As per API-650 J.3.6.3, reinforcement pad is not required since roof loads do not exceed 25 psf.

No Reinforcement Pad required.

Bottom Drain: N7

Repad Design

NOZZLE Description : 2 in SCH 80S TYPE RFWN
Material: A312-TP304

t_rpr = (Repad Required Thickness)
t_n = (Thickness of Neck)
Sd_n = (Stress of Neck Material)
Sd_s = (Stress of Shell Course Material)
CA = (Corrosion Allowance of Neck)

MOUNTED ON SHELL 1 : Elevation = 0 ft

COURSE PARAMETERS:
t-calc = 0.1297 in
t_cr = 0.1297 in (Course t-calc less C.A)
t_c = 0.375 in (Course t less C.A.)
t_Basis = 0.1297 in

(SHELL NOZZLE REF. API-650 S.3.3.1, AND FOOTNOTE A OF TABLE 5-7)

Required Area = t_Basis * D
Required Area = 0.1297 * 2.375
Required Area = 0.308 in2

Available Shell Area = (t_c - t_Basis) * D

Available Shell Area = (0.375 - 0.1297) * 2.375
Available Shell Area = 0.5826 in2

Available Nozzle Neck Area = 2 * [(4 * (t_n - CA)) + t_c] * (t_n - CA) * MIN((Sd_n/Sd_s) 1)
Available Nozzle Neck Area = 2 * [(4 * (0.218 - 0)) + 0.375] * (0.218 - 0) * MIN((22,500/22,500) 1)
Available Nozzle Neck Area = 0.5437 in2

A-rpr = (Required Area - Available Shell Area - Available Nozzle Neck Area)
A-rpr = 0.308 - 0.5826 - 0.5437
A-rpr = 0 in2

Since Nozzle size <= NPS 2 (per API-650 Table 5.6 Note f), t_rpr = 0

No Reinforcement Pad required.

Notes:
- As per API-650 J.3.6.6, the provisions for stress relief specified in API-650 5.7.4 and 5.7.8.3 are not required

t_shell_PWHT = Thickness of the shell plate, insert plate, or thickened insert plate for PWHT (in)

Nozzle Neck Material Properties
Material = A312-TP304
As per API-650 S.2b, Allowable Design Stress (Sd-neck) = 22.50e3 psi

t_shell_PWHT = t-plate
t_shell_PWHT = 0.3750
t_shell_PWHT = 0.3750 in

Thermal Stress Relief (PWHT) Requirements
D = Nozzle Nominal Diameter (NPS) (in)
Group = Shell Material Group
t_shell = Shell Plate Thickness (in)

D = 2.0 in
Group = None
t_shell = 0.3750 in

Shell material group (None) is not a group specified by API 650, 13th Ed, Section 5.7.4. Requirement for Thermal Stress Relief (PWHT) is unknown.

Normal and Emergency Venting (API-2000 7th Edition) Back

Normal Venting

insulation_type = Insulation type
latitude = Latitude zone
R_i = Reduction factor for insulation per *API-2000 Sections 3.3.2.3.2 and 3.3.2.3.3*
T = Product storage temperature (°F)
vapor-pressure-type = Vapor pressure type
Vi = Total required in-breathing volumetric flow rate (ft^3/hr)
V_ip = Required in-breathing flow rate due to liquid movement per *API-2000 Section 3.3.2.2, Eq 6* (ft^3/hr)
V_IT = Required in-breathing flow rate due to thermal effects per *API-2000 Section 3.3.2.3.3, Eq 10* (ft^3/hr)
Vo = Total required out-breathing volumetric flow rate (ft^3/hr)
V_op = Required out-breathing flow rate due to liquid movement per *API-2000 Section 3.3.2.2.1-a, Eq 2* (ft^3/hr)
V_OT = Required out-breathing flow rate due to thermal effects per *API-2000 Section 3.3.2.3.2, Eq 8* (ft^3/hr)
V_pe = Maximum emptying rate (gpm)
V_pf = Maximum filling rate (gpm)
V_tk = Tank capacity (gal)

insulation_type = NO-INSULATION
latitude = BETWEEN-42-AND-58
T = 100.0 °F
vapor-pressure-type = HEXANE-OR-SIMILAR
V_pe = 100.0 gpm
V_pf = 100.0 gpm
V_tk = 62.4396e3 gal

R_i = 1
R_i = 1
R_i = 1.0

In-breathing
V_ip = 8.02 * V_pe
V_ip = 8.02 * 100.0
V_ip = 802.0 ft^3/hr

V_ip = 802 ft^3/hr of air

As per API-2000 Section 3.3.2.3.3, Table 2, Vapor Pressure Factor (C) = 5.0

V_IT = 3.08 * C * (V_tk^0.7) * R_i
V_IT = 3.08 * 5.0 * (8.34697e3^0.7) * 1.0
V_IT = 8.56231e3 ft^3/hr

V_IT = 8,562.3059 ft^3/hr of air

Vi = V_ip + V_IT
Vi = 802.0 + 8.56231e3
Vi = 9.36431e3 ft^3/hr

Vi = 9,364.3059 ft^3/hr of air

Out-breathing
V_op = 8.02 * V_pf
V_op = 8.02 * 100.0
V_op = 802.0 ft^3/hr

V_op = 802 ft^3/hr of air

As per API-2000 Section 3.3.2.3.2, Table 1, Latitude Factor (Y) = 0.250

V_OT = 1.51 * Y * (V_tk^0.9) * R_i
V_OT = 1.51 * 0.250 * (8.34697e3^0.9) * 1.0
V_OT = 1.27730e3 ft^3/hr

V_OT = 1,277.2993 ft^3/hr of air

Vo = V_op + V_OT
Vo = 802.0 + 1.27730e3
Vo = 2.07930e3 ft^3/hr

Vo = 2,079.2993 ft^3/hr of air

Emergency Venting
ATWS = Wetted surface area (ft^2)
D = Tank diameter (ft)
F = Environmental factor per *API-2000 Section 3.3.3.3.4*
H = Tank height (ft)
insulation_type = Insulation type
P_g = Design pressure (psi)
q = Required emergency venting capacity per *API-2000 Section 3.3.3.3.4, Table 6* (ft^3/hr)
vapor-pressure-type = Vapor pressure type

D = 13.2217 ft
H = 60.4167 ft
insulation_type = NO-INSULATION
P_g = 0.0 psi
vapor-pressure-type = HEXANE-OR-SIMILAR

As per API-2000 Table 9, Environmental factor for insulation (F_ins) = 1.0
As per API-2000 Table 9, Environmental factor for drainage (F_drain) = 1.0

F = MIN(F_ins , F_drain)
F = MIN(1.0 , 1.0)
F = 1.0

ATWS = pi * D * MIN(H , 30)
ATWS = pi * 13.2217 * MIN(60.4167 , 30)
ATWS = 1.24611e3 ft^2

q = 563916.9089 * F
q = 563916.9089 * 1.0
q = 563.917e3 ft^3/hr

Capacities and Weights Back

Capacity to Top of Shell (to Tank Height) : 62,051 gal
Capacity to Design Liquid Level : 62,051 gal
Capacity to Maximum Liquid Level : 62,051 gal
Working Capacity (to Normal Working Level) : 0 gal
Net working Capacity (Working Capacity - Min Capacity) : 0 gal
Minimum Capacity (to Min Liq Level) : 1,027 gal

Component	New Condition (lbf)	Corroded (lbf)
SHELL	21,265	21,265
ROOF	1,102	1,102
RAFTERS	0	0
GIRDERS	0	0
FRAMING	0	0
COLUMNS	0	0
TRUSS	0	0
STRUCTURE COMPONENTS	0	0
BOTTOM	1,088	1,088
STAIRWAYS	0	0
ACCESS	0	0
STIFFENERS	133	133
WIND GIRDERS	0	0
ANCHOR CHAIRS	253	253
SHELL APPURTENANCES	362	362
ROOF APPURTENANCES	45	45
BOTTOM APPURTENANCES	0	0
INSULATION	0	0
FLOATING ROOF	0	0
TOTAL	24,249.4654	24,249.4654

Weight of Tank, Empty : 24,249.4654 lbf
Weight of Tank, Full of Product (Design SG = 1) : 542,092.4654 lbf
Weight of Tank, Full of Water : 542,092.0668 lbf
Net Working Weight, Full of Product (Design SG = 1) : 533,520.8789 lbf
Net Working Weight Full of Water : 533,520.8789 lbf

Foundation Area Req'd : 142.098 ft2
Foundation Loading, Empty : 170.6529 lbf/ft2
Foundation Loading, Full of Product Design : 3,814.9171 lbf/ft2
Foundation Loading, Full of Water : 3,814.9143 lbf/ft2

SURFACE AREAS
Roof : 141.9188 ft2
Shell : 2,509.5325 ft2
Bottom : 142.098 ft2

Internal Pressure Moment : 0 lbf-ft
Wind Moment : 223,419.782 lbf-ft
Seismic Moment (Ringwall) : 1,013,007.2514 lbf-ft
Seismic Moment (Slab) : 1,080,630.368 lbf-ft

Total weight of the tank contents based on the design specific gravity of the product
C-max = Capacity to Design Liquid Level (ft^3)
Wp = Product Weight at Maximum Design Liquid Level (lbf)

Tank Inner Diameter (ID) = 13.2217 ft
Shell Height (H) = 60.4167 ft
Max Design Liquid Level (Lmax) = 60.4167 ft
Roof Liquid Volume (VrL) = 0.0 ft^3
Bottom Volume (V-bottom) = 0.0 ft^3
Bottom Elevation (h-bottom) = 0.0 ft

C-max = (pi * ((ID^2) / 4) * (MIN(Lmax , H) - h-bottom)) + VrL + V-bottom
C-max = (pi * ((13.2217^2) / 4) * (MIN(60.4167 , 60.4167) - 0.0)) + 0.0 + 0.0
C-max = 8.29505e3 ft^3 [1.47741e3 bbls 62.0513e3 gal]

Wp = C-max * d-water * SG
Wp = 8.29505e3 * 62.4279 * 1.0
Wp = 517.843e3 lbf

MISCELLANEOUS ATTACHED ROOF ITEMS
MISCELLANEOUS ATTACHED SHELL ITEMS

Reactions on Foundation Back

A_rss = Area of Tank Roof Supported by the Tank Shell (ft^2)
A_v = Vertical Earthquake Acceleration Coefficient (g)
D = Tank Nominal Diameter (ft)
F-wind = Wind Horizontal Force (lbf)
gamma_b = Bottom Plate Density (lbf/in^3)
gamma_w = Water Density (lb/ft^3)
Hs = Tank Height (Shell Only) (ft)
L_dead_bottom = Dead Load on Bottom per *API 650, Section 5.13, Table 5.21* (psf)
L_dead_shell = Dead Load on Shell per *API 650, Section 5.13, Table 5.21* (lbf/ft)
L_hydrostatic_bottom = Hydrostatic Load on Bottom per *API 650, Section 5.13, Table 5.21* (psf)
L_internal-pressure_bottom = Internal Pressure Load on Bottom per *API 650, Section 5.13, Table 5.21* (psf)
Lmax = Maximum Liquid Level (ft)
L_minimum-roof-live-load_shell = Minimum Roof Live Load on Shell per *API 650, Section 5.13, Table 5.21* (lbf/ft)
L_pressure-test_bottom = Pressure Test Load on Bottom per *API 650, Section 5.13, Table 5.21* (psf)
Lr = Minimum Roof Live Load (psf)
L_seismic_bottom = Seismic Load on Bottom per *API 650, Section 5.13, Table 5.21* (psf)
L_seismic_shell = Seismic Load on Shell per *API 650, Section 5.13, Table 5.21* (lbf/ft)
L_snow_shell = Snow Load on Shell per *API 650, Section 5.13, Table 5.21* (lbf/ft)
L_stored-liquid_bottom = Stored Liquid Load on Shell per *API 650, Section 5.13, Table 5.21* (psf)
L_vacuum_shell = Vacuum Load on Shell per *API 650, Section 5.13, Table 5.21* (lbf/ft)
L_wind_shell = Wind Load on Shell per *API 650, Section 5.13, Table 5.21* (lbf/ft)
M_rw = Ringwall Foundation Seismic Overturning Moment (ft.lbf)
M_s = Slab Foundation Seismic Overturning Moment (ft.lbf)
P = Design Internal Pressure (psi)
Pt = Test pressure (psi)
Pv = Design External Pressure (psi)
P_WS = Shell Wind Pressure (psi)
S = Design Snow Load (psf)
SG = Product Specific Gravity
tb = Bottom Plate Thickness (in)
Wr-attachments = Roof Attachments Weight (lb)
Wr-ins = Roof Insulation Weight (lb)
Wr-pl = Roof Plates Nominal Weight (lb)
Ws-attachments = Shell Attachments Weight (lb)
Ws-framing = Shell Framing Weight (lb)
Ws-ins = Shell Insulation Weight (lb)
Ws-pl = Shell Plates Nominal Weight (lb)
W-wind = Wind Overturning Moment (ft.lbf)

A_rss = 141.919 ft^2
A_v = 0.10080 g
D = 13.2217 ft
F-wind = 6.95359e3 lbf
gamma_b = 0.290 lbf/in^3 [501.120 lbf/ft^3]
gamma_w = 62.4279 lb/ft^3
Hs = 60.4167 ft
Lmax = 60.4167 ft
Lr = 20.0 psf
M_rw = 1.01301e6 ft.lbf
M_s = 1.08063e6 ft.lbf

P = 0.0 psi
Pt = 0.0 psi
Pv = 0.0 psi
P_WS = 0.0601666 psi
S = 0.0 psf
SG = 1.0
tb = 0.18750 in [0.0156250 ft]
Wr-attachments = 45.5909 lb
Wr-ins = 0.0 lb
Wr-pl = 1.11122e3 lb
Ws-attachments = 615.875 lb
Ws-framing = 136.572 lb
Ws-ins = 0.0 lb
Ws-pl = 21.2641e3 lb
W-wind = 223.420e3 ft.lbf

W_rss = Wr-pl + Wr-ins + Wr-attachments
W_rss = 1.11122e3 + 0.0 + 45.5909
W_rss = 1.15682e3 lbf

Ws = Ws-pl + Ws-ins + Ws-attachments + Ws-framing
Ws = 21.2641e3 + 0.0 + 615.875 + 136.572
Ws = 22.0165e3 lbf

Unfactored (Working Stress) Downward Reactions on Foundations

Load Case	Location	Equation	Value	Unit
Dead Load	Shell	(Ws + W_rss) / (pi * D)	557.896	lbf/ft
Dead Load	Bottom	tb * gamma_b	7.830	psf
Internal Pressure	Bottom	P	0.0	psf
Vacuum	Shell	(Pv * A_rss) / (pi * D)	0.0	lbf/ft
Hydrostatic Test	bottom	Lmax * gamma_w	3.77169e3	psf
Minimum Roof Live Load	Shell	(Lr * A_rss) / (pi * D)	68.3335	lbf/ft
Seismic	Shell	((4 * (M_rw / D)) + (0.4 * (Ws + W_rss) * A_v)) / (pi * D)	7.40069e3	lbf/ft
Seismic	Bottom	(32 * M_s) / (pi * (D^3))	4.76232e3	psf
Snow	Shell	(S * A_rss) / (pi * D)	0.0	lbf/ft
Stored Liquid	Bottom	SG * Lmax * gamma_w	3.77169e3	psf
Pressure Test	Bottom	Pt	0.0	psf
Wind	Shell	(2 * (Hs^2) * P_WS) / (pi * D)	1.52274e3	lbf/ft

- Seismic bottom reaction varies linearly from 32*Ms/(PI*D^3) at the tank shell to zero at the center of the tank
- API 650, Section 5.13, Table 5.21

L_dead_shell = (Ws + W_rss) / (pi * D)
L_dead_shell = (22.0165e3 + 1.15682e3) / (pi * 13.2217)
L_dead_shell = 557.896 lbf/ft

L_dead_bottom = tb * gamma_b
L_dead_bottom = 0.0156250 * 501.120
L_dead_bottom = 7.830 psf

L_internal-pressure_bottom = P
L_internal-pressure_bottom = 0.0
L_internal-pressure_bottom = 0.0 psf

L_vacuum_shell = (Pv * A_rss) / (pi * D)
L_vacuum_shell = (0.0 * 141.919) / (pi * 13.2217)
L_vacuum_shell = 0.0 lbf/ft

L_hydrostatic_bottom = Lmax * gamma_w
L_hydrostatic_bottom = 60.4167 * 62.4279
L_hydrostatic_bottom = 3.77169e3 psf

L_minimum-roof-live-load_shell = (Lr * A_rss) / (pi * D)
L_minimum-roof-live-load_shell = (20.0 * 141.919) / (pi * 13.2217)
L_minimum-roof-live-load_shell = 68.3335 lbf/ft

L_seismic_shell = ((4 * (M_rw / D)) + (0.4 * (Ws + W_rss) * A_v)) / (pi * D)
L_seismic_shell = ((4 * (1.01301e6 / 13.2217)) + (0.4 * (22.0165e3 + 1.15682e3) * 0.10080)) / (pi * 13.2217)
L_seismic_shell = 7.40069e3 lbf/ft

L_seismic_bottom = (32 * M_s) / (pi * (D^3))
L_seismic_bottom = (32 * 1.08063e6) / (pi * (13.2217^3))
L_seismic_bottom = 4.76232e3 psf

L_snow_shell = (S * A_rss) / (pi * D)
L_snow_shell = (0.0 * 141.919) / (pi * 13.2217)
L_snow_shell = 0.0 lbf/ft

L_stored-liquid_bottom = SG * Lmax * gamma_w
L_stored-liquid_bottom = 1.0 * 60.4167 * 62.4279
L_stored-liquid_bottom = 3.77169e3 psf

L_pressure-test_bottom = Pt
L_pressure-test_bottom = 0.0
L_pressure-test_bottom = 0.0 psf

L_wind_shell = (2 * (Hs^2) * P_WS) / (pi * D)
L_wind_shell = (2 * (60.4167^2) * 8.6640) / (pi * 13.2217)
L_wind_shell = 1.52274e3 lbf/ft

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