PT.HANAZONO Engineering Indonesia

COMO ENGINEERS

CPM PT Citra Palu Minerals

OBJECT

Strength Calculation for Clean Water Tank
Poboya 2000tpd Expansion Project
Client Doc Number: HNZ-V-PT0061.08-4800-STR-CAL-005

REFERENCES

B	Issued for Approval	06/05/2026	Wawan	Ardiyanto	Muraasto	
A	Issued for Review	12/03/2026	Wawan	Ardiyanto	Muraasto	
Revision	Description	Date	Prepared By	Reviewed By	Approved	Client App

CLIENT	PT Citra Palu Mineral			TITLE	Strength Calculation for Clean Water Tank		REV B
PROJECT	Poboya 2000tpd Expansion Project			PT. COMO ENGINEERS	PROJECT No.	E2602	
BY Wawan	DATE 06/05/2026	CHECKED Ardiyanto	DATE 06/05/2026		Doc No	E2602-4800-CAL-501	

DESIGN DATA

PROJECT NAME	**POBOYA 2000 TPD EXPANSION PROJECT**	
TAG NO.	**4800-TK-122**	
DESCRIPTION	**CLEAN WATER TANK**	
CODE	**API-650 13TH EDITION**	
FLUID NAME	**CLEAN WATER**	
SPECIFIC GRAVITY	1	gr/cm3
DESIGN PRESSURE	FULL OF CONTENT	kPa
DESIGN TEMPERATURE	32	DEG. C
M.D.M.T	0	DEG. C
OPERATING PRESSURE	ATM	kPa
OPERATING TEMP. (MIN/MAX.)	AMB	DEG. C
CORROSION ALLOWANCE	SHELL : 3	MM
	BOTTOM : 3	MM
	STRUCTURE : 3	MM
RADIOGRAPHY / JOINT EFICIENCY	SPOT / 0.85	
P.W.H.T	NO	
INSULATION THICKNESS	NO	MM
DESIGN WIND VELOCITY	40	m/s
WIND & SEISMIC CODE	API-650 - ASCE7	
MATERIAL	SHELL : ASTM A36	
	ROOF : ASTM A36	
	BOTTOM : ASTM A36	
	NOZZLE (PIPE/PLATE) : ASTM A106 Gr.B / ASTM A36	
	FLANGE : ASTM A36 / ASTM A105	
	NOZZLE PAD : ASTM A36	
	TOP ANGLE : ASTM A36	
M.A.W.P	-	
HYDRO. TEST PRESSURE	FULLOF WATER	kPa
PNEUMATIC TEST PRESSURE	-	kPa

AMETANK REPORT

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

Designer : Wawan
Tag ID : 4800-TK-122
Site : Poboya
Design Basis : API-650 13th Edition Errata 1, 2021

Design Parameters and Operating Conditions

Design Parameters

Design Internal Pressure = 0 KPa or 0 mmh2o
Design External Pressure = -0 KPa or -0 mmh2o

D of Tank = 6.5 m
OD of Tank = 6.52 m
ID of Tank = 6.5 m
CL of Tank = 6.51 m
Shell Height = 7.5 m
S.G of Contents = 1
S.G of Hydrotest = 1.02
Max Design Liq. Level = 6.72 m
Max Operating Liq. Level = 6.72 m
Min Liq. Level = 0 m
Design Temperature = 32 ºC
MDMT (Minimum Design Metal Temperature) = 0 ºC
Tank Joint Efficiency = 0.85
Ground Snow Load = 0 KPa
Roof Live Load = 1.17 KPa
Additional Roof Dead Load = 0 KPa

Wind Load Basis: ASCE7-10
3 Second Gust Wind Speed (entered), Vg = 40 m/s = 144 kph
Wind Importance Factor, Iw = 1.5
Design Wind Speed, V = Vg * 0.78 = 112.32 kph

Seismic Method: API-650 - ASCE7 Mapped(Ss & S1)
Seismic Use Group = III
Site Class = D
T_L (sec) = 4
Ss (g) = 1.2
S1 (g) = 0.5
Av (g) = 0.38
Q = 0.67
Importance Factor = 1.5

Design Remarks

Summary Results

Shell

Shell #	Width (mm)	Material	CA (mm)	JE	Min Yield Strength (MPa)	Tensile Strength (MPa)	Sd (MPa)	St (MPa)	Weight (kg)
1	1828	A36	3	0.70	250	400	145	145	2,338
2	1828	A36	3	0.70	250	400	145	145	1,754
3	1828	A36	3	0.70	250	400	145	145	1,754
4	1000	A36	3	0.70	250	400	145	145	959
5	1016	A36	3	0.70	250	400	145	145	975

(continued)

Shell #	Weight CA (kg)	t-min Erection (mm)	t-Des (mm)	t-Test (mm)	t-min Seismic (mm)	t-min Ext-Pe (mm)	t-min (mm)	t-Actual (mm)	Status
1	1,462	6	5.01	2.06	4.66	NA	6	8	OK
2	877	5	4.44	1.48	4.25	NA	5	6	OK
3	877	5	3.87	0.89	3.83	NA	5	6	OK
4	480	5	3.29	0.30	3.36	NA	5	6	OK
5	487	5	2.98	0	3.14	NA	5	6	OK

Total Weight of Shell = 7,797.52 kg

Stiffeners

Stiffener #	Size	Elevation (m)	Z-Req'd (cm3)	Z-Actual (cm3)	Weight (kg)
1	L75X75X6	1.68	1.91	20.62	143.45
2	L75X75X6	3.48	1.91	19.86	143.36
3	L75X75X6	5.28	1.06	19.86	143.36
4	L75X75X6	6.28	1.29	19.86	143.36

Roof

Type = Structurally Supported Conical Roof
Plates Material = A36
Structural Material = A36
t.required = 5 mm
t.actual = 6 mm
Roof corrosion allowance = 3 mm
Roof Joint Efficiency = 0.7
Plates Overlap Weight = 17.09 kg
Plates Weight = 1,623.62 kg

Structure

Rafters

Qty	At Radius (m)	Size	Length (m)	W (N/m)	Ind. Weight (kg)	Total Weight (kg)
16	3.25	PFC-150X75X6.5X10	2.89	241.24	71.27	1,140.36

Rafters Total Weight = 1,140.36 kg

Crown Ring

Rolled Plate Outer Diameter = 402 mm
Rolled Plate Height = 152.06 mm
Rolled Plate Thickness = 14 mm
Upper Flange Inner Diameter = 374 mm
Upper Flange Outer Diameter = 555 mm
Upper Flange Thickness = 14 mm
Lower Flange Inner Diameter = 374 mm
Lower Flange Outer Diameter = 555 mm
Lower Flange Thickness = 14 mm

Bottom

Type : Flat Bottom Non Annular
Bottom Material = A36
t.required = 9 mm
t.actual = 10 mm
Bottom corrosion allowance = 3 mm
Bottom Joint Efficiency = 0.7
Total Weight of Bottom = 2,695.23 kg

Top Member

Type = Detail B
Size = L130x130x12
Material = A36
Weight = 480.76 kg

Anchors

Quantity = 12
Size = M30 mm
Material = A307-B
Bolt Hole Circle Radius = 3.34 m

Nameplate Information

Pressure Combination Factor	0.4
Design Standard	API-650 13th Edition Errata 1, 2021
Appendices Used	A, E
Roof	A36 : 6 mm
Shell (1)	A36 : 8 mm
Shell (2)	A36 : 6 mm
Shell (3)	A36 : 6 mm
Shell (4)	A36 : 6 mm
Shell (5)	A36 : 6 mm
Bottom	A36 : 10 mm

Roof and Structure Design Details Back

Roof Type (Cone) = Cone
Structure Support Type (Rafter Single Size on the Inside no Columns) = Rafter Single Size on the Inside no Columns

Material Properties

Material (A36) = A36
Minimum Tensile Strength (Sut) = 400.0 MPa
Minimum Yield Strength (Sy) = 250.0 MPa
As per API-650 A.4.1, Allowable Design Stress (Sd) = 145 MPa
Density (d) = 7,840 kg/m^3

Geometry

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

Rh = 3.29 m
slope = 0.17

Description	Variable	Equation	Value	Unit
Slope Angle	Theta	ARCTAN(slope)	9.46	deg
Angle With Vertical Line	Alpha	90 - Theta	80.54	deg
Height	h	Rh * TAN(Theta)	0.55	m
Surface Area	A	(pi * (Rh^2)) / COS(Theta)	34.52	m^2
Center of Gravity from Base	CG	h / 3	0.18	m
Vertical Projected Area	Av	Rh * h	1.81	m^2
Horizontal Projected Area	Ah	pi * (Rh^2)	34.05	m^2
Volume	V	(pi * (Rh^2) * h) / 3	6.23	m^3

Weights

DL-add = Added dead load (kPa)
d-ins = Insulation Density (kg/m^3)
t = Plates Thickness (mm)
t-ins = Insulation Thickness (mm)

DL-add = 0.0 kPa
d-ins = 130 kg/m^3
t = 6 mm
t-ins = 0 mm

Description	Variable	Equation	Value	Unit
Plates Nominal Weight	Wr-pl	A * d * t	1,623.63	kg
Plates Corroded Weight	Wr-pl-corr	A * d * (t - CA)	811.81	kg
New Plates Dead Load Pressure	DL-pl	((9.80665 * Wr-pl) / Ah) * (1 / 1000)	0.47	kPa
Corroded Plates Dead Load Pressure	DL-pl-corr	((9.80665 * Wr-pl-corr) / Ah) * (1 / 1000)	0.23	kPa
Insulation Weight	Wr-ins	t-ins * d-ins * A	0.0	kg

Insulation Dead Load Pressure	DL-ins	((9.80665 * Wr-ins) / Ah) * (1 / 1000)	0.0	kPa
Dead Load	DL	DL-pl + DL-ins + DL-add	0.47	kPa
Total Nominal Dead Weight	Wr-DL	(DL * Ah) / 9.80665	1,623.63	kg
Additional Dead Weight	Wr-DL-add	(DL-add * Ah) / 9.80665	0.0	kg

Loads

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

Fpe = 0.4
Lr = 1.17 kPa
Pe = 0.0 kPa
S = 0.0 kPa

Sb = 0.84 * S
Sb = 0.84 * 0.0
Sb = 0.0 kPa

Su = Sb
Su = 0.0
Su = 0.0 kPa

e.1b = DL + MAX(Lr , S) + (Fpe * Pe)
e.1b = 0.4677 + MAX(1.17 , 0.0) + (0.4 * 0.0)
e.1b = 1.64 kPa

e.2b = DL + Pe + (0.4 * MAX(Lr , S))
e.2b = 0.4677 + 0.0 + (0.4 * MAX(1.17 , 0.0))
e.2b = 0.94 kPa

B = MAX(e.1b , e.2b)
B = MAX(1.6377 , 0.9357)
B = 1.64 kPa

e.1u = DL + MAX(Lr , S) + (Fpe * Pe)
e.1u = 0.4677 + MAX(1.17 , 0.0) + (0.4 * 0.0)
e.1u = 1.64 kPa

e.2u = DL + Pe + (0.4 * MAX(Lr , S))
e.2u = 0.4677 + 0.0 + (0.4 * MAX(1.17 , 0.0))
e.2u = 0.94 kPa

U = MAX(e.1u , e.2u)
U = MAX(1.6377 , 0.9357)
U = 1.64 kPa

max-gravity-load = MAX(B , U)
max-gravity-load = MAX(1.6377 , 1.6377)
max-gravity-load = 1.64 kPa

W-max-gravity-load = (max-gravity-load * Ah * 1000) / 9.80665
W-max-gravity-load = (1.6377 * 34.0463 * 1000) / 9.80665
W-max-gravity-load = 5,685.58 kg

Erection Requirements
As per API-650 5.10.2.2, Minimum Erection Thickness (t-erec) = 5 mm

Required Thickness
t-req = Required Thickness (mm)

t-req = t-erec
t-req = 5
t-req = 5 mm

t >= t-req ==> PASS

Structure Design Calculations
A-req = Rafter Required Cross Sectional Area (mm^2)
Area = Rafter Load Area (m^2)
F-horizontal = Rafter Horizontal Force (N)
Fa = Rafter Allowable Compressive Stress (MPa)
G = Rafter Uniform Load (N)
H-GB = Rafter Reaction at the Inner Side due to Uniform Load (Rafter Weight) (N)
H-QB = Rafter Reaction at the Inner Side due to Triangular Load (Roof Load) (N)
L-rft = Rafter Length (m)
M-G-Max = Rafter Bending Moment due to Uniform Load (N.m)
M-Q-Max = Rafter Bending Moment due to Triangular Load (N.m)
Ma-rft = Rafter Material
Mmax = Rafter Maximum Bending Moment (N.m)
N = Rafters Quantity
N-G-Max = Rafter Axial Load due to Uniform Load (N)
N-Q-Max = Rafter Axial Load due to Triangular Load (N)
N-braces = Rafter Recommended Number of Braces
Nmax = Rafter Maximum Axial Load (N)
QQ = Rafter Triangular Load (N)
Sd = Rafter Allowable Stress (MPa)
Sx-required = Rafter Section Modulus Required (cm^3)
TL = Roof Total Load (Dead + Live) (kPa)
Theta = Roof Slope Angle (deg)
fa = Rafter Maximum Compressive Stress (MPa)
fbx = Rafter Maximum Bending Stress (MPa)
h = Rafter Rise (m)
l = Rafter Horizontal Length (m)
stress-ratio = Rafter Actual to Allowable Stress Ratio

L-rft = 3.09 m
Ma-rft = A36
N = 16
TL = 1.64 kPa
Theta = 9.46 deg

Rafter Design

Rafter Material Properties
Material (A36) = A36
Minimum Tensile Strength (Sut) = 400.0 MPa
Minimum Yield Strength (Sy) = 250.0 MPa

Rafter C-Channel Size PFC-150X75X6.5X10 Section Properties

Description	Variable	New	Corroded	Unit
Weight	W	24.6	15.46	kg/m
Cross Sectional Area	A	2,270	1,426.37	mm^2
Radius of Gyration About X Axis	rx	70.0	70.0	mm
Radius of Gyration About Y Axis	ry	36.0	35.3	mm
Moment Of Inertia About X Axis	Ix	8,610,000	5,667,322.34	mm^4
Moment Of Inertia About Y Axis	Iy	1,309,999.0	791,269.56	mm^4
Section Modulus About X Axis	Sx	114,800	77,106.43	mm^3
Section Modulus About Y Axis	Sy	26,600.0	17,103.91	mm^3
Plastic Section Modulus About X Axis	Zx	132,000	85,737.47	mm^3
Plastic Section Modulus About Y Axis	Zy	48,300	30,317.75	mm^3
Warping Constant	cw	340,000	209,273.77	mm^6
Torsional Constant	j	64,999.0	19,360.58	mm^4
Centroid X Coords	cx	48.0	48.0	mm
Centroid to Edge Max x Distance	ex	48.0	48.0	mm
Centroid to Edge Max y Distance	ey	75.0	73.5	mm
C-Channel Flange Width	wf	75.0	72.0	mm
C-Channel Flange Thickness	tf	10.0	7.0	mm
C-Channel Depth	d	150.0	147.0	mm
C-Channel Web Thickness	tw	6.5	3.5	mm
• Corrosion allowance, 1.5 mm, is applied to all sides of the structural member.				

Rafter Allowable Flexural Strength per AISC-360
Lp = Limiting laterally unbraced length for the limit state of yielding per AISC-360 F2-5 (mm)
Lr = Limiting laterally unbraced length for the limit state of inelastic lateral-torsional buckling per AISC-360 F2-6 (mm)
M = Lateral torsional buckling per AISC-360 F2-2 (N.mm)
Ma = Allowable Flexural Strength (N.mm)
Mn = Nominal flexural strength per AISC-360 F2 (N.mm)
Mp = Yielding per AISC-360 F2-1 (N.mm)
Mpa = Allowable Flexural Strength Assuming the Member is Braced (N.mm)
Ypf = Limiting slenderness parameter for compact flange
Ypw = Limiting slenderness parameter for compact web
Yrf = Limiting slenderness parameter for noncompact flange
Yrw = Limiting slenderness parameter for noncompact web
bf = Flange width (mm)
c = Coefficient per AISC-360 F2-8b
h = Web height (mm)
ho = Distance between the flange centroids (mm)
rts = Effective radius of gyration per AISC-360 F2-7 (mm)

bf = wf = 72.0 mm

h = d - (2 * tf) = 133.0 mm

Ypf = 0.38 * SQRT((E / Fy))
Ypf = 0.38 * SQRT((199,000 / 250.0))
Ypf = 10.72

Yrf = 1 * SQRT((E / Fy))
Yrf = 1 * SQRT((199,000 / 250.0))
Yrf = 28.21

Ypw = 3.76 * SQRT((E / Fy))
Ypw = 3.76 * SQRT((199,000 / 250.0))
Ypw = 106.08

Yrw = 5.7 * SQRT((E / Fy))
Yrw = 5.7 * SQRT((199,000 / 250.0))
Yrw = 160.82

As per AISC-360 table B4.1b Flange width to thickness ratio check :
(bf / tf) <= Ypf

==> Flange is compact

As per AISC-360 table B4.1b Web height to thickness ratio check :
(h / tw) <= Ypw

==> Web is compact

Mp = Fy * Zx
Mp = 250.0 * 85,737.4691
Mp = 21,434,367.27 N.mm

Unbraced length (Lb) = 3,094.61 mm

Lp = 1.76 * ry * SQRT((E / Fy))
Lp = 1.76 * 35.296 * SQRT((199,000 / 250.0))
Lp = 1,752.65 mm

ho = d - tf
ho = 147.0 - 7.0
ho = 140.0 mm

c = (ho / 2) * SQRT((Iy / Cw))
c = (140.0 / 2) * SQRT((791,269.556 / 209,273.7666))
c = 136.11

rts = SQRT((SQRT((Iy * Cw)) / Sx))
rts = SQRT((SQRT((791,269.556 * 209,273.7666)) / 77,106.4264))
rts = 2.3 mm

Lr = 1.95 * rts * (E / (0.7 * Fy)) * SQRT((((J * c) / (Sx * ho)) + SQRT(((((J * c) / (Sx * ho))^2) + (6.76 * (((0.7 * Fy) / E)^2))))))
Lr = 1.95 * 2.2973 * (199,000 / (0.7 * 250.0)) * SQRT((((19,360.5848 * 136.114) / (77,106.4264 * 140.0)) + SQRT(((((19,360.5848 * 136.114) / (77,106.4264 * 140.0))^2) + (6.76 * (((0.7 * 250.0) / 199,000)^2))))))
Lr = 3,559.47 mm

(Lp < Lb) AND (Lb <= Lr)

M = Cb * (Mp - ((Mp - (0.7 * Fy * Sx)) * ((Lb - Lp) / (Lr - Lp))))
M = 1 * (21,434,367.2738 - ((21,434,367.2738 - (0.7 * 250.0 * 77,106.4264)) * ((3,094.6054 - 1,752.6477) / (3,559.4696 - 1,752.6477))))
M = 15,536,641.04 N.mm

Mpa = Mp / 1.67
Mpa = 21,434,367.2738 / 1.67
Mpa = 12,834,950.46 N.mm

Mn = MIN(Mp , M) = 15,536,641.04 N.mm

Ma = Mn / 1.67
Ma = 15,536,641.043 / 1.67
Ma = 9,303,377.87 N.mm

Rafter Allowable Compressive Strength per AISC-360
Fe = Elastic Buckling Stress per AISC-360 E3-4 (MPa)
K = Effective Length Factor
Lx = Unbraced X Length (mm)
Ly = Unbraced Y Length (mm)
Pa = Allowable Compressive Strength (N)
Pn = Nominal compressive strength per AISC-360 E3-1 (N)
Yrf = Limiting slenderness parameter for flanges
Yrw = Limiting slenderness parameter for web
bf = Flange width (mm)
h = Web height (mm)

K = 1
Lx = 3,094.61 mm
Ly = 3,094.61 mm

Radius of gyration :
((K * Ly) / ry) > ((K * Lx) / rx) ==> Radius of gyration about y axis governs

Fe = ((pi^2) * E) / (((K * Ly) / ry)^2)
Fe = ((pi^2) * 199,000) / (((1 * 3,094.6054) / 35.296)^2)
Fe = 255.5 MPa

bf = wf
bf = 72.0
bf = 72.0 mm

h = d - (2 * tf)
h = 147.0 - (2 * 7.0)
h = 133.0 mm

Yrf = 0.56 * SQRT((E / Fy))
Yrf = 0.56 * SQRT((199,000 / 250.0))
Yrf = 15.8

Yrw = 1.49 * SQRT((E / Fy))
Yrw = 1.49 * SQRT((199,000 / 250.0))
Yrw = 42.04

As per AISC-360 table B4.1a Flange width to thickness ratio check :
(bf / tf) <= Yrf ==> Flange is not slender

As per AISC-360 table B4.1a Web height to thickness ratio check :
(h / tw) <= Yrw ==> Web is not slender

Fcr = Critical stress per AISC-360 E3-2 (MPa)

(Fy / Fe) <= 2.25

Fcr = (0.658^(Fy / Fe)) * Fy
Fcr = (0.658^(250.0 / 255.5013)) * 250.0
Fcr = 165.99 MPa

Pn = Fcr * Ag
Pn = 165.9892 * 1,426.3731
Pn = 236,762.49 N

Pa = Pn / 1.67
Pa = 236,762.4943 / 1.67
Pa = 141,773.95 N

Rafter Recommended Braces Quantity
N-braces = CEILING((L-rft / Lr)) - 1
N-braces = CEILING((3,094.6054 / 3,559.4696)) - 1
N-braces = 0

Rafters Required Spacing and Quantity
CA = Roof Corrosion Allowance (mm)
Fy = Roof Yield Strength (MPa)
N-actual-1 = Actual Number of Rafters
N-min-1 = Rafters Quantity Required
R-1 = Rafters Outer Radius (mm)
l = Maximum Rafter Spacing (mm)
l-actual-1 = Rafters Actual Spacing (mm)
l_calc = Calculated Maximum Rafter Spacing per API-650 5.10.4.4 (mm)
t-actual = Roof Actual Thickness (mm)
t-calc-1 = Roof Required Thickness Based on Rafters Actual Spacing (mm)

CA = 3 mm
Fy = 250.0 MPa
N-actual-1 = 16
R-1 = 3,250 mm
t-actual = 6 mm

l_calc = (t-actual - CA) * SQRT(((1.5 * Fy) / TL))
l_calc = (6 - 3) * SQRT(((1.5 * 250.0) / 0.0016))
l_calc = 1,435.57 mm

l = l-max-by-user
l = 2,100
l = 2,100 mm

N-min-1 = CEILING(((2 * pi * R-1) / l))
N-min-1 = CEILING(((2 * pi * 3,250) / 2,100))
N-min-1 = 10

N-recommended-1 must be a multiple of 1, therefore N-recommended-1 = 10.

N-actual-1 >= N-min-1 ==> PASS

l-actual-1 = (2 * pi * R-1) / N-actual-1
l-actual-1 = (2 * pi * 3,250) / 16
l-actual-1 = 1,276.27 mm

t-calc-1 = (l-actual-1 / SQRT(((1.5 * Fy) / TL))) + CA
t-calc-1 = (1,276.272 / SQRT(((1.5 * 250.0) / 0.0016))) + 3
t-calc-1 = 5.67 mm

Rafter Weight Loads (Uniform Load)
Area = ((pi * (OD^2)) / 4) / N
Area = ((pi * (6.516^2)) / 4) / 16
Area = 2.08 m^2

l = L-rft * COS(Theta)
l = 3.0946 * COS(9.4623)
l = 3.05 m

h = l * TAN(Theta)
h = 3.0525 * TAN(9.4623)
h = 0.51 m

Sum of braces lengths (L-braces) = 0 m
Rafter brace weight (W-brace) = 13.4 kg/m

G = (W * L-rft) + (W-brace * L-braces)
G = (241.2436 * 3.0946) + (131.4091 * 0)
G = 746.55 N

H-GB = (G / 2) * (l / h)
H-GB = (746.5537 / 2) * (3.0525 / 0.5087)
H-GB = 2,239.66 N

M-G-Max = (G * l) / 8
M-G-Max = (746.5537 * 3.0525) / 8
M-G-Max = 284.86 N.m

N-G-Max = (G * SIN(Theta)) + (H-GB * COS(Theta))
N-G-Max = (746.5537 * SIN(9.4623)) + (2,239.6612 * COS(9.4623))
N-G-Max = 2,331.92 N

Rafter Design Loads (Dead Load + Live Load + Snow Load + Roof Plates)
QQ = (((pi * (ID^2)) / 4) / N) * TL
QQ = (((pi * (6.5^2)) / 4) / 16) * 1,637.6679
QQ = 3,396.43 N

H-QB = (QQ / 3) * (l / (l * TAN(Theta)))
H-QB = (3,396.4284 / 3) * (3.0525 / (3.0525 * TAN(9.4623)))
H-QB = 6,792.86 N

M-Q-Max = 0.128 * QQ * l
M-Q-Max = 0.128 * 3,396.4284 * 3.0525
M-Q-Max = 1,327.05 N.m

N-Q-Max = (QQ * SIN(Theta)) + (H-QB * COS(Theta))
N-Q-Max = (3,396.4284 * SIN(9.4623)) + (6,792.8567 * COS(9.4623))
N-Q-Max = 7,258.8 N

Rafter Required Section Modulus
Mmax = M-G-Max + M-Q-Max
Mmax = 284.8569 + 1,327.0525
Mmax = 1,611.91 N.m

Sd = Ma / Sx-corr
Sd = 9,303,377.87 / 77,106.4264

Sd = 120.66 MPa

Sx-required = (Mmax / Sd) * 0.001
Sx-required = (1,611,909.3976 / 120.6563) * 0.001
Sx-required = 13.36 cm^3

Sx-corr >= Sx-required ==> PASS

Rafter Required Cross Sectional Area
Nmax = N-G-Max + N-Q-Max
Nmax = 2,331.9209 + 7,258.802
Nmax = 9,590.72 N

F-horizontal = Nmax * COS(Theta)
F-horizontal = 9,590.7228 * COS(9.4623)
F-horizontal = 9,460.23 N

Fa = Pa / A-corr
Fa = 141,773.9487 / 1,426.3731
Fa = 99.39 MPa

A-req = Nmax / Fa
A-req = 9,590.7228 / 99.3947
A-req = 96.49 mm^2

A-corr >= A-req ==> PASS

Rafter Required Radius of Gyration (Slenderness Check)
L = Member Unbraced Length (mm)
L/r = Slenderness Ratio
r = Governing Radius of Gyration (mm)
r-req = Required Radius of Gyration (mm)

L = 3,094.61 mm
r = 35.3 mm

As per API-650 5.10.3.2, Max Slenderness Ratio (max-ratio) = 200

L/r = L / r
L/r = 3,094.6054 / 35.296
L/r = 87.68

r-req = L / max-ratio
r-req = 3,094.6054 / 200
r-req = 15.47 mm

L/r <= 200 ==> PASS

Rafter Minimum Required Thickness
As per API-650 5.10.2.4, Minimum Nominal Thickness (t-min) = 4.3 mm
As per API-650 5.10.2.4, Minimum Corroded Thickness (t-min-corr) = 2.4 mm

tf >= t-min ==> PASS

tf-corr >= t-min-corr ==> PASS

tw >= t-min ==> PASS

tw-corr >= t-min-corr ==> PASS

Rafter Allowable Stress
fa = Nmax / A-corr
fa = 9,590.7228 / 1,426.3731
fa = 6.72 MPa

fbx = (Mmax / Sx-corr) * 1.0E-6
fbx = (1,611.9094 / 7.710642635473863E-5) * 1.0E-6
fbx = 20.9 MPa

stress-ratio = (fa / Fa) + (fbx / Sd)
stress-ratio = (6.7239 / 99.3947) + (20.905 / 120.6563)
stress-ratio = 0.24

stress-ratio <= 1

Rafter to Shell Clip - Bolts Design
Bolts-Qty = Bolts Total Quantity
Bolts-Qty-Req = Bolts Required Quantity
Clip-Load = Rafter Load on Clip (N)
clearance = Bolt Clearance (mm)
d = Bolt Diameter (mm)
hole-type = Bolt Hole Type
qty-horz = Horizontal Holes Quantity
qty-vert = Vertical Holes Quantity

Clip-Load = 9,590.72 N
clearance = 1.5 mm
d = 20.84 mm
hole-type = slot
qty-horz = 2
qty-vert = 1

Bolts-Qty = qty-horz * qty-vert
Bolts-Qty = 2 * 1
Bolts-Qty = 2

As per AISC Steel Construction Manual 13th Edition Table 7-4, Bolt Available Shear Strength (Y-bolt) = 27,445.53 N

Bolts-Qty-Req = CEILING((Clip-Load / Y-bolt))
Bolts-Qty-Req = CEILING((9,590.7228 / 27,445.5274))
Bolts-Qty-Req = 1 (Set to 2 since it cannot be less than 2)

Bolts-Qty >= Bolts-Qty-Req ==> PASS

Rafter to Center Ring Clip - Bolts Design
Bolts-Qty = Bolts Total Quantity
Bolts-Qty-Req = Bolts Required Quantity
Clip-Load = Rafter Load on Clip (N)
clearance = Bolt Clearance (mm)
d = Bolt Diameter (mm)
hole-type = Bolt Hole Type
qty-horz = Horizontal Holes Quantity
qty-vert = Vertical Holes Quantity

Clip-Load = 9,590.72 N
clearance = 2 mm
d = 16 mm
hole-type = round-hole
qty-horz = 2

qty-vert = 2

Bolts-Qty = qty-horz * qty-vert
Bolts-Qty = 2 * 2
Bolts-Qty = 4

As per AISC Steel Construction Manual 13th Edition Table 7-4, Bolt Available Shear Strength (Y-bolt) = 23,931.43 N

Bolts-Qty-Req = CEILING((Clip-Load / Y-bolt))
Bolts-Qty-Req = CEILING((9,590.7228 / 23,931.4323))
Bolts-Qty-Req = 1 (Set to 2 since it cannot be less than 2)

Bolts-Qty >= Bolts-Qty-Req ==> PASS

Center Ring (Crown Ring) Design

Center Ring Material Properties
Material (A36) = A36
Minimum Tensile Strength (Sut) = 400.0 MPa
Minimum Yield Strength (Sy) = 250.0 MPa

A = Cross sectional area (mm^2)
MA = Moment Between Forces per Roark's 7th Edition table 9.2 item 7 (N.mm)
MB = Moment at Forces per Roark's 7th Edition table 9.2 item 7 (N.mm)
N = Hoop Load per Roark's 7th Edition table 9.2 item 7 (N)
NF = Number of Load Points
SA = Total Stress Between Forces (MPa)
SB = Total Stress at Forces (MPa)
Sa = Allowable stress (MPa)
Sy = Elastic Section Modulus About y Axis (mm^3)
Theta = Half Angle Between Load Points (rad)
V = Radial Shear per Roark's 7th Edition table 9.2 item 7 (N)
W = Horizontal Force (N)
rc = Radius from Center (mm)

A = 2,664.55 mm^2
NF = 16
Sy = 29,607.62 mm^3
W = 9,460.23 N
rc = 277.5 mm

Theta = ((2 * pi) / NF) / 2
Theta = ((2 * pi) / 16) / 2
Theta = 0.2 rad

Sa = Fy * 0.6
Sa = 250.0 * 0.6
Sa = 150.0 MPa

Stress Between Load Points
MA = (W * (rc / 2)) * ((1 / SIN(Theta)) - (1 / Theta))
MA = (9,460.2307 * (277.5 / 2)) * ((1 / SIN(0.1963)) - (1 / 0.1963))
MA = 43,148.96 N.mm

N = (W / 2) * (1 / SIN(Theta))
N = (9,460.2307 / 2) * (1 / SIN(0.1963))
N = 24,245.77 N

SA = (MA / Sy) + (N / A)
SA = (43,148.9583 / 29,607.6184) + (24,245.7715 / 2,664.5525)

SA = 10.56 MPa

SA <= Sa ==> PASS

Stress at Load Points
MB = (W * (rc / 2)) * ((1 / Theta) - (1 / TAN(Theta)))
MB = (9,460.2307 * (277.5 / 2)) * ((1 / 0.1963) - (1 / TAN(0.1963)))
MB = 86,131.55 N.mm

V = (W / 2) * (1 / TAN(Theta))
V = (9,460.2307 / 2) * (1 / TAN(0.1963))
V = 23,779.9 N

SB = (MB / Sy) + (V / A)
SB = (86,131.5486 / 29,607.6184) + (23,779.8958 / 2,664.5525)
SB = 11.83 MPa

SB <= Sa ==> PASS

Outer Ring Design
A = Cross sectional area (mm^2)
MA = Moment Between Forces per Roark's 7th Edition table 9.2 item 7 (N.mm)
MB = Moment at Forces per Roark's 7th Edition table 9.2 item 7 (N.mm)
N = Hoop Load per Roark's 7th Edition table 9.2 item 7 (N)
NF = Number of Load Points
SA = Total Stress Between Forces (MPa)
SB = Total Stress at Forces (MPa)
Sa = Allowable stress (MPa)
Sy = Elastic Section Modulus About y Axis (mm^3)
Theta = Half Angle Between Load Points (rad)
V = Radial Shear per Roark's 7th Edition table 9.2 item 7 (N)
W = Horizontal Force (N)
rc = Radius from Center (mm)

A = 2,382.52 mm^2
NF = 16
Sy = 37,630.7 mm^3
W = 9,460.23 N
rc = 3,286.86 mm

Theta = ((2 * pi) / NF) / 2
Theta = ((2 * pi) / 16) / 2
Theta = 0.2 rad

Sa = Fy * 0.6
Sa = 250.0 * 0.6
Sa = 150.0 MPa

Stress Between Load Points
MA = (W * (rc / 2)) * ((1 / SIN(Theta)) - (1 / Theta))
MA = (9,460.2307 * (3,286.859 / 2)) * ((1 / SIN(0.1963)) - (1 / 0.1963))
MA = 511,079.43 N.mm

N = (W / 2) * (1 / SIN(Theta))
N = (9,460.2307 / 2) * (1 / SIN(0.1963))
N = 24,245.77 N

SA = (MA / Sy) + (N / A)
SA = (511,079.4304 / 37,630.6962) + (24,245.7715 / 2,382.518)
SA = 23.76 MPa

SA <= Sa ==> PASS

Stress at Load Points
MB = (W * (rc / 2)) * ((1 / Theta) - (1 / TAN(Theta)))
MB = (9,460.2307 * (3,286.859 / 2)) * ((1 / 0.1963) - (1 / TAN(0.1963)))
MB = 1,020,188.31 N.mm

V = (W / 2) * (1 / TAN(Theta))
V = (9,460.2307 / 2) * (1 / TAN(0.1963))
V = 23,779.9 N

SB = (MB / Sy) + (V / A)
SB = (1,020,188.3083 / 37,630.6962) + (23,779.8958 / 2,382.518)
SB = 37.09 MPa

SB <= Sa ==> PASS

Top Member Detail B Design Back

DLR = Nominal Weight of Roof Plates and Attached Structural (N)
DLS = Nominal Weight of Shell Plates and Framing (N)

DLS = Ws + W_framing
DLS = 76,467.5538 + 21,526.4179
DLS = 97,993.97 N

DLR = Wr + W_structural
DLR = 15,922.3485 + 1,803.4476
DLR = 17,725.8 N

Material Properties
Material (A36) = A36
Minimum Tensile Strength (Sut) = 400.0 MPa
Minimum Yield Strength (Sy) = 250.0 MPa

Compression Ring Detail b Properties
A_detail = Detail Total Area (mm^2)
A_roof = Contributing Roof Area (mm^2)
A_shell = Contributing Shell Area (mm^2)
I_shell = Contributing Shell Moment Of Inertia (mm^4)
R2 = Length of Normal to Head (mm)
Wc = Maximum Width of Participating Shell per API-650 Figure F-2 (mm)
Wh = Maximum Width of Participating Head per API-650 Figure F-2 (mm)

R2 = (ID / 2) / SIN(Theta)
R2 = (6,500 / 2) / SIN(9.4623)
R2 = 19,768.98 mm

Wh = 0.3 * SQRT((R2 * (th - CA-head)))
Wh = 0.3 * SQRT((19,768.9782 * (6 - 3)))
Wh = 73.06 mm

Wc = 0.6 * SQRT(((ID / 2) * (tc-nominal - CA-shell)))
Wc = 0.6 * SQRT(((6,500 / 2) * (6 - 3)))
Wc = 59.25 mm

Angle Size L130X130X12 Section Properties

Description	Variable	New	Corroded	Unit
Weight	W	23.5	17.41	kg/m
Cross Sectional Area	A	3,000	2,222.78	mm^2
Moment Of Inertia About X Axis	Ix	4,719,999.0	3,403,670.23	mm^4
Moment Of Inertia About Y Axis	Iy	4,719,999.0	3,403,670.23	mm^4
Section Modulus About X Axis	Sx	50,400	36,801.47	mm^3
Section Modulus About Y Axis	Sy	50,400	36,801.47	mm^3
Centroid X Coords	cx	36.4	36.4	mm
Centroid Y Coords	cy	36.4	36.4	mm
Angle Long Leg Length	L1-angle	130	127.0	mm
Angle Short Leg Length	L2-angle	130	127.0	mm
Angle Thickness	t-angle	12.0	9.0	mm

• Corrosion allowance, 1.5 mm, is applied to all sides of the structural member.

I_shell = ((Wc - h) * ((tc-nominal - CA-shell)^3)) / 12
I_shell = ((59.2453 - 6.0) * ((6 - 3)^3)) / 12
I_shell = 119.8 mm^4

A_shell = (Wc - h) * (tc-nominal - CA-shell)
A_shell = (59.2453 - 6.0) * (6 - 3)
A_shell = 159.74 mm^2

A_roof = Wh * (th - CA-head)
A_roof = 73.059 * (6 - 3)
A_roof = 219.18 mm^2

A_detail = A_shell + A_roof + A-corr
A_detail = 159.7358 + 219.1771 + 2,222.7823
A_detail = 2,601.7 mm^2

Stiffener and Shell Combined Section Properties

Description	Variable	Equation	Value	Unit
Shell centroid	d_shell	(tc-nominal - CA-shell) / 2	1.5	mm
Stiffener centroid	d_stiff	cy + (tc-nominal - CA-shell)	39.4	mm
moment of inertia of first body	I_1	Ic + (Area * (Distance^2))	6,854,228.5	mm^4
moment of inertia of second body	I_2	Ic + (Area * (Distance^2))	479.21	mm^4
Total area	A_sum	A_1 + A_2	2,382.52	mm^2
Sum of moments of inertia's	I_sum	I_1 + I_2	6,854,707.7	mm^4
Combined centroid	c_combined	((Centroid-1 * Area-1) + (Centroid-2 * Area-2)) / (Area-1 + Area-2)	36.86	mm
Combined moment of inertia	I_combined	Ic - (Area * (Distance^2))	3,617,852.88	mm^4
Distance from neutral axis to edge 1 (inside)	e1	c_combined	36.86	mm
Distance from neutral axis to edge 2 (outside)	e2	((tc-nominal - CA-shell) + L1-angle) - e1	96.14	mm
Combined stiffener shell section modulus	S	I / MAX(d-1 , d-2)	37,630.7	mm^3

Erection Requirement
As per API-650 5.1.5.9, Minimum Size of Top Corner Ring (Size-min) = L50x50x5
Minimum Section Modulus per Erection Requirement (Sx-min) = 3.05 cm^3

Sx >= Sx-min ==> PASS

Internal Pressure - Appendix F Requirements
A_actual = Area resisting compressive force (mm^2)
D = Tank nominal diameter (m)
DLR = Nominal weight of roof plates and attached structural (N)
DLS = Nominal weight of shell plates and framing (N)

Fp = Internal Pressure Combination Factor
Fy = Minimum specified yield-strength of the materials in the roof-to-shell junction (MPa)
ID = Tank inside diameter (m)
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 (N.m)
MDLR = Moment About the Shell-to-Bottom Joint from the Nominal Weight of the Roof Plate Plus any Structural Components Attached to the Roof (N.m)
MF = Moment About the Shell-to-Bottom Joint from Liquid Weight (N.m)
Mw = Wind Moment From Horizontal Plus Vertical Wind Pressures (N.m)
Mws = Wind Moment From Horizontal Wind Pressure (N.m)
P = Design pressure (kPa)
P_uplift = Uplift due to internal pressure per API-650 F.1.2 (N)
Theta angle = Angle between the roof and a horizontal plane at the roof-to-shell junction (deg)
W_add_DL = Additional dead load weight (N)
W_framing = Weight of framing supported by the shell and roof (N)
W_structural = Weight of roof attached structural (N)
Wr = Roof plates weight (N)
Ws = Shell plates weight (N)

A_actual = 2,601.7 mm^2
D = 6.5 m
DLR = 17,725.8 N
DLS = 97,993.97 N
Fp = 0.4
Fy = 250.0 MPa
ID = 6.5 m
MDL = 318,480.41 N.m
MDLR = 57,608.84 N.m
MF = 204,080.67 N.m
Mw = 114,229.16 N.m
Mws = 56,999.44 N.m
P = 0.0 kPa
Theta angle = 9.46 deg
W_add_DL = 0.0 N
W_framing = 21,526.42 N
W_structural = 1,803.45 N
Wr = 15,922.35 N
Ws = 76,467.55 N

P_uplift = P * pi * ((ID^2) / 4)
P_uplift = 0.0 * pi * ((6.5^2) / 4)
P_uplift = 0.0 N

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 (kPa)
P_max_internal = Maximum allowable internal pressure (kPa)

P_std = 18 kPa

P_F51 = ((Fy * TAN(Theta angle) * A_actual) / (200 * (D^2))) + ((0.00127 * DLR) / (D^2))
P_F51 = ((250.0 * TAN(9.4623) * 2,601.6952) / (200 * (6.5^2))) + ((0.00127 * 17,725.7962) / (6.5^2))
P_F51 = 13.36 kPa

P_max_internal = MIN(P_std , P_F51)
P_max_internal = MIN(18 , 13.3617)
P_max_internal = 13.36 kPa

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 (m)
D = Tank Nominal Diameter per API-650 5.6.1.1 Note 1 (m)
G = Product Design Specific Gravity
Gt = Hydrotest Specific Gravity
H = Shell height (m)
HL = Max Liquid Level (m)
Pe = Design External Pressure (kPa)
Pi = Design Internal Pressure (kPa)
Rwi = Impulsive Force Reduction Factor
V = Wind velocity (km/hr)
W-ins = Shell Insulation Weight (kg)
W-shell = Shell Nominal Weight (kg)
W-shell-corr = Shell Corroded Weight (kg)
d-ins = Insulation Density (kg/m^3)
h-min = Minimum Shell Course Height per API-650 5.6.1.2 (mm)
t-ins = Insulation Thickness (mm)

Ac = 0.21
Ai = 0.31
Av = 0.38
D = 6.5 m
G = 1
Gt = 1.02
H = 7.5 m
HL = 6.72 m
Pe = 0.0 kPa
Pi = 0.0 kPa
Rwi = 4
V = 112.32 km/hr
d-ins = 130 kg/m^3
h-min = 800 mm
t-ins = 0 mm

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

Rwi = Impulsive Force Reduction Factor

Rwi = 4

Course # 1 (bottom course) Design

CA = Corrosion allowance per API-650 5.3.2 (mm)
D1 = Shell Course Centerline Diameter (m)
H = Design Liquid Level per API-650 5.6.3.2 (m)
H' = Effective Design Liquid Level per API-650 F.2 (m)
H-max = Maximum Liquid Level for the Installed Thickness (m)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (m)
Ht' = Effective Hydrostatic Test Liquid Level per API-650 F.2 (m)
JE = Joint efficiency
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (kPa)
Rwi = Impulsive Force Reduction Factor
W-1 = Shell Course Nominal Weight (kg)

W-1-corr = Shell Course Nominal Weight (kg)
h1 = Course Height (m)
loc = Course Location (m)
t = Installed Thickness (mm)
t-min = Minimum Required Thickness (mm)
td = Course Design Thickness per A.4.1 (mm)
tt = Course Hydrostatic Test Thickness per A.4.1 (mm)

CA = 3 mm
H = 6.72 m
JE = 0.7
Ma = A36
Rwi = 4
h1 = 1.83 m
loc = 0 m
t = 8 mm

Shell Course Center of Gravity (CG-1) = 0.91 m

D1 = ID + t
D1 = 6.5 + 0.008
D1 = 6.51 m

W-1 = pi * Dc * t * h1 * d
W-1 = pi * 6.508 * 0.008 * 1.828 * 7,840
W-1 = 2,344.12 kg

W-1-corr = pi * Dc * (t - CA) * h1 * d
W-1-corr = pi * 6.508 * (0.008 - 0.003) * 1.828 * 7,840
W-1-corr = 1,465.07 kg

Material Properties
Material (A36) = A36
Minimum Tensile Strength (Sut) = 400.0 MPa
Minimum Yield Strength (Sy) = 250.0 MPa
As per API-650 A.4.1, Allowable Design Stress (Sd) = 145 MPa
As per API-650 A.4.1, Allowable Hydrostatic Test Stress (St) = 145 MPa
Permissible Design Metal Temperature (MDMT-permissible) = -30 °C

Thickness Required by Erection
As per API-650 5.6.1.1 NOTE 4, Thickness Required by Erection (t-erec) = 6 mm

Thickness Required by Design
H' = H
H' = 6.72
H' = 6.72 m

td = ((4.9 * D * (H' - 0.3) * SG) / (JE * Sd)) + CA
td = ((4.9 * 6.5 * (6.72 - 0.3) * 1) / (0.7 * 145)) + 3
td = 5.01 mm

Hydrostatic Test Required Thickness
Ht' = H
Ht' = 6.72
Ht' = 6.72 m

tt = (4.9 * D * (Ht' - 0.3) * SGt) / (JE * St)
tt = (4.9 * 6.5 * (6.72 - 0.3) * 1.025) / (0.7 * 145)
tt = 2.06 mm

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

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 6.72 m

Ni = 2.6 * Ai * G * (D^2)
Ni = 2.6 * 0.306 * 1 * (6.5^2)
Ni = 33.61 N/mm

Nc = (1.85 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (1.85 * 0.212 * 1 * (6.5^2) * COSH(((3.68 * (6.72 - 6.72)) / 6.5))) / COSH(((3.68 * 6.72) / 6.5))
Nc = 0.74 N/mm

Nh = 4.9 * (H - H_offset) * D * G
Nh = 4.9 * (6.72 - 0) * 6.5 * 1
Nh = 214.03 N/mm

S_T+ = Total Combined Hoop Stress per API 650 Sections E.6.1.4, EC.6.1.3 (MPa)
S_T- = Total Combined Hoop Stress per API 650 Sections E.6.1.4, EC.6.1.3 (MPa)

S_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
S_T+ = (214.032 + SQRT(((33.6141^2) + (0.7377^2) + (((0.3808 * 214.032) / 2.5)^2)))) / MAX((8 - 3) , 0.0001)
S_T+ = 52.17 MPa

S_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
S_T- = (214.032 - SQRT(((33.6141^2) + (0.7377^2) + (((0.3808 * 214.032) / 2.5)^2)))) / MAX((8 - 3) , 0.0001)
S_T- = 33.44 MPa

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 145) , (0.9 * 250.0 * 0.7))
Sd-seismic = 157.5 MPa

ts = ((SIGMAt+ * (tn - CA)) / S_membrane) + CA
ts = ((52.1729 * (8 - 3)) / 157.5) + 3
ts = 4.66 mm

Minimum Required Thickness
t-min = MAX(t-erec , td , tt , ts)
t-min = MAX(6 , 5.0146 , 2.0649 , 4.6563)
t-min = 6 mm

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (4.9 * D * SG)) + 0.3) + loc
H-max = ((((8 - 3) * 145 * 0.7) / (4.9 * 6.5 * 1)) + 0.3) + 0
H-max = 16.23 m

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(16.2341 , 0)
H-max-@-Pi = 16.23 m

Pi-max-@-H = MAX((((H-max - (H + loc)) * (9.8 * SG)) + P) , 0)
Pi-max-@-H = MAX((((16.2341 - (6.72 + 0)) * (9.8 * 1)) + 0.0) , 0)
Pi-max-@-H = 93.24 kPa

Course # 2 Design

CA = Corrosion allowance per API-650 5.3.2 (mm)
D2 = Shell Course Centerline Diameter (m)
H = Design Liquid Level per API-650 5.6.3.2 (m)
H' = Effective Design Liquid Level per API-650 F.2 (m)
H-max = Maximum Liquid Level for the Installed Thickness (m)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (m)
Ht' = Effective Hydrostatic Test Liquid Level per API-650 F.2 (m)
JE = Joint efficiency
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (kPa)
Rwi = Impulsive Force Reduction Factor
W-2 = Shell Course Nominal Weight (kg)
W-2-corr = Shell Course Nominal Weight (kg)
h2 = Course Height (m)
loc = Course Location (m)
t = Installed Thickness (mm)
t-min = Minimum Required Thickness (mm)
td = Course Design Thickness per A.4.1 (mm)
tt = Course Hydrostatic Test Thickness per A.4.1 (mm)

CA = 3 mm
H = 4.89 m
JE = 0.7
Ma = A36
Rwi = 4
h2 = 1.83 m
loc = 1.83 m
t = 6 mm

Shell Course Center of Gravity (CG-2) = 2.74 m

D2 = ID + t
D2 = 6.5 + 0.006
D2 = 6.51 m

W-2 = pi * Dc * t * h2 * d
W-2 = pi * 6.506 * 0.006 * 1.828 * 7,840
W-2 = 1,757.55 kg

W-2-corr = pi * Dc * (t - CA) * h2 * d
W-2-corr = pi * 6.506 * (0.006 - 0.003) * 1.828 * 7,840
W-2-corr = 878.77 kg

Material Properties
Material (A36) = A36
Minimum Tensile Strength (Sut) = 400.0 MPa
Minimum Yield Strength (Sy) = 250.0 MPa
As per API-650 A.4.1, Allowable Design Stress (Sd) = 145 MPa
As per API-650 A.4.1, Allowable Hydrostatic Test Stress (St) = 145 MPa
Permissible Design Metal Temperature (MDMT-permissible) = -30 °C

Thickness Required by Erection
As per API-650 5.6.1.1, Thickness Required by Erection (t-erec) = 5 mm

Thickness Required by Design
H' = H
H' = 4.892
H' = 4.89 m

td = ((4.9 * D * (H' - 0.3) * SG) / (JE * Sd)) + CA
td = ((4.9 * 6.5 * (4.892 - 0.3) * 1) / (0.7 * 145)) + 3
td = 4.44 mm

Hydrostatic Test Required Thickness
Ht' = H
Ht' = 4.892
Ht' = 4.89 m

tt = (4.9 * D * (Ht' - 0.3) * SGt) / (JE * St)
tt = (4.9 * 6.5 * (4.892 - 0.3) * 1.025) / (0.7 * 145)
tt = 1.48 mm

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

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 4.89 m

Ni = 2.6 * Ai * G * (D^2)
Ni = 2.6 * 0.306 * 1 * (6.5^2)
Ni = 33.61 N/mm

Nc = (1.85 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (1.85 * 0.212 * 1 * (6.5^2) * COSH(((3.68 * (6.72 - 4.892)) / 6.5))) / COSH(((3.68 * 6.72) / 6.5))
Nc = 1.17 N/mm

Nh = 4.9 * (H - H_offset) * D * G
Nh = 4.9 * (4.892 - 0) * 6.5 * 1
Nh = 155.81 N/mm

S_T+ = Total Combined Hoop Stress per API 650 Sections E.6.1.4, EC.6.1.3 (MPa)
S_T- = Total Combined Hoop Stress per API 650 Sections E.6.1.4, EC.6.1.3 (MPa)

S_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
S_T+ = (155.8102 + SQRT(((33.6141^2) + (1.1692^2) + (((0.3808 * 155.8102) / 2.5)^2)))) / MAX((6 - 3) , 0.0001)
S_T+ = 65.66 MPa

S_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
S_T- = (155.8102 - SQRT(((33.6141^2) + (1.1692^2) + (((0.3808 * 155.8102) / 2.5)^2)))) / MAX((6 - 3) , 0.0001)
S_T- = 38.22 MPa

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 145) , (0.9 * 250.0 * 0.7))
Sd-seismic = 157.5 MPa

ts = ((SIGMAt+ * (tn - CA)) / S_membrane) + CA
ts = ((65.6583 * (6 - 3)) / 157.5) + 3
ts = 4.25 mm

Minimum Required Thickness
t-min = MAX(t-erec , td , tt , ts)
t-min = MAX(5 , 4.4409 , 1.477 , 4.2506)
t-min = 5 mm

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (4.9 * D * SG)) + 0.3) + loc
H-max = ((((6 - 3) * 145 * 0.7) / (4.9 * 6.5 * 1)) + 0.3) + 1.828
H-max = 11.69 m

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(11.6884 , 0)
H-max-@-Pi = 11.69 m

Pi-max-@-H = MAX((((H-max - (H + loc)) * (9.8 * SG)) + P) , 0)
Pi-max-@-H = MAX((((11.6884 - (4.892 + 1.828)) * (9.8 * 1)) + 0.0) , 0)
Pi-max-@-H = 48.69 kPa

Course # 3 Design
CA = Corrosion allowance per API-650 5.3.2 (mm)
D3 = Shell Course Centerline Diameter (m)
H = Design Liquid Level per API-650 5.6.3.2 (m)
H' = Effective Design Liquid Level per API-650 F.2 (m)
H-max = Maximum Liquid Level for the Installed Thickness (m)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (m)
Ht' = Effective Hydrostatic Test Liquid Level per API-650 F.2 (m)
JE = Joint efficiency
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (kPa)
Rwi = Impulsive Force Reduction Factor
W-3 = Shell Course Nominal Weight (kg)
W-3-corr = Shell Course Nominal Weight (kg)
h3 = Course Height (m)
loc = Course Location (m)
t = Installed Thickness (mm)
t-min = Minimum Required Thickness (mm)
td = Course Design Thickness per A.4.1 (mm)
tt = Course Hydrostatic Test Thickness per A.4.1 (mm)

CA = 3 mm
H = 3.06 m
JE = 0.7
Ma = A36
Rwi = 4
h3 = 1.83 m
loc = 3.66 m
t = 6 mm

Shell Course Center of Gravity (CG-3) = 4.57 m

D3 = ID + t
D3 = 6.5 + 0.006
D3 = 6.51 m

W-3 = pi * Dc * t * h3 * d
W-3 = pi * 6.506 * 0.006 * 1.828 * 7,840
W-3 = 1,757.55 kg

W-3-corr = pi * Dc * (t - CA) * h3 * d
W-3-corr = pi * 6.506 * (0.006 - 0.003) * 1.828 * 7,840
W-3-corr = 878.77 kg

Material Properties

Material (A36) = A36
Minimum Tensile Strength (Sut) = 400.0 MPa
Minimum Yield Strength (Sy) = 250.0 MPa
As per API-650 A.4.1, Allowable Design Stress (Sd) = 145 MPa
As per API-650 A.4.1, Allowable Hydrostatic Test Stress (St) = 145 MPa
Permissible Design Metal Temperature (MDMT-permissible) = -30 °C

Thickness Required by Erection
As per API-650 5.6.1.1, Thickness Required by Erection (t-erec) = 5 mm

Thickness Required by Design
H' = H
H' = 3.064
H' = 3.06 m

td = ((4.9 * D * (H' - 0.3) * SG) / (JE * Sd)) + CA
td = ((4.9 * 6.5 * (3.064 - 0.3) * 1) / (0.7 * 145)) + 3
td = 3.87 mm

Hydrostatic Test Required Thickness
Ht' = H
Ht' = 3.064
Ht' = 3.06 m

tt = (4.9 * D * (Ht' - 0.3) * SGt) / (JE * St)
tt = (4.9 * 6.5 * (3.064 - 0.3) * 1.025) / (0.7 * 145)
tt = 0.89 mm

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

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 3.06 m

Ni = 5.22 * Ai * G * (D^2) * ((Y / (0.75 * D)) - (0.5 * ((Y / (0.75 * D))^2)))
Ni = 5.22 * 0.306 * 1 * (6.5^2) * ((3.064 / (0.75 * 6.5)) - (0.5 * ((3.064 / (0.75 * 6.5))^2)))
Ni = 29.09 N/mm

Nc = (1.85 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (1.85 * 0.212 * 1 * (6.5^2) * COSH(((3.68 * (6.72 - 3.064)) / 6.5))) / COSH(((3.68 * 6.72) / 6.5))
Nc = 2.97 N/mm

Nh = 4.9 * (H - H_offset) * D * G
Nh = 4.9 * (3.064 - 0) * 6.5 * 1
Nh = 97.59 N/mm

S_T+ = Total Combined Hoop Stress per API 650 Sections E.6.1.4, EC.6.1.3 (MPa)
S_T- = Total Combined Hoop Stress per API 650 Sections E.6.1.4, EC.6.1.3 (MPa)

S_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
S_T+ = (97.5884 + SQRT(((29.0867^2) + (2.969^2) + (((0.3808 * 97.5884) / 2.5)^2)))) / MAX((6 - 3) , 0.0001)
S_T+ = 43.46 MPa

S_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
S_T- = (97.5884 - SQRT(((29.0867^2) + (2.969^2) + (((0.3808 * 97.5884) / 2.5)^2)))) / MAX((6 - 3) , 0.0001)

S_T- = 21.6 MPa

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 145) , (0.9 * 250.0 * 0.7))
Sd-seismic = 157.5 MPa

ts = ((SIGMAt+ * (tn - CA)) / S_membrane) + CA
ts = ((43.4626 * (6 - 3)) / 157.5) + 3
ts = 3.83 mm

Minimum Required Thickness
t-min = MAX(t-erec , td , tt , ts)
t-min = MAX(5 , 3.8673 , 0.889 , 3.8279)
t-min = 5 mm

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (4.9 * D * SG)) + 0.3) + loc
H-max = ((((6 - 3) * 145 * 0.7) / (4.9 * 6.5 * 1)) + 0.3) + 3.656
H-max = 13.52 m

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(13.5164 , 0)
H-max-@-Pi = 13.52 m

Pi-max-@-H = MAX((((H-max - (H + loc)) * (9.8 * SG)) + P) , 0)
Pi-max-@-H = MAX((((13.5164 - (3.064 + 3.656)) * (9.8 * 1)) + 0.0) , 0)
Pi-max-@-H = 66.61 kPa

Course # 4 Design
CA = Corrosion allowance per API-650 5.3.2 (mm)
D4 = Shell Course Centerline Diameter (m)
H = Design Liquid Level per API-650 5.6.3.2 (m)
H' = Effective Design Liquid Level per API-650 F.2 (m)
H-max = Maximum Liquid Level for the Installed Thickness (m)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (m)
Ht' = Effective Hydrostatic Test Liquid Level per API-650 F.2 (m)
JE = Joint efficiency
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (kPa)
Rwi = Impulsive Force Reduction Factor
W-4 = Shell Course Nominal Weight (kg)
W-4-corr = Shell Course Nominal Weight (kg)
h4 = Course Height (m)
loc = Course Location (m)
t = Installed Thickness (mm)
t-min = Minimum Required Thickness (mm)
td = Course Design Thickness per A.4.1 (mm)
tt = Course Hydrostatic Test Thickness per A.4.1 (mm)

CA = 3 mm
H = 1.24 m
JE = 0.7
Ma = A36
Rwi = 4
h4 = 1.0 m
loc = 5.48 m
t = 6 mm

Shell Course Center of Gravity (CG-4) = 5.98 m

D4 = ID + t
D4 = 6.5 + 0.006
D4 = 6.51 m

W-4 = pi * Dc * t * h4 * d
W-4 = pi * 6.506 * 0.006 * 1.0 * 7,840
W-4 = 961.46 kg

W-4-corr = pi * Dc * (t - CA) * h4 * d
W-4-corr = pi * 6.506 * (0.006 - 0.003) * 1.0 * 7,840
W-4-corr = 480.73 kg

Material Properties
Material (A36) = A36
Minimum Tensile Strength (Sut) = 400.0 MPa
Minimum Yield Strength (Sy) = 250.0 MPa
As per API-650 A.4.1, Allowable Design Stress (Sd) = 145 MPa
As per API-650 A.4.1, Allowable Hydrostatic Test Stress (St) = 145 MPa
Permissible Design Metal Temperature (MDMT-permissible) = -30 °C

Thickness Required by Erection
As per API-650 5.6.1.1, Thickness Required by Erection (t-erec) = 5 mm

Thickness Required by Design
H' = H
H' = 1.236
H' = 1.24 m

td = ((4.9 * D * (H' - 0.3) * SG) / (JE * Sd)) + CA
td = ((4.9 * 6.5 * (1.236 - 0.3) * 1) / (0.7 * 145)) + 3
td = 3.29 mm

Hydrostatic Test Required Thickness
Ht' = H
Ht' = 1.236
Ht' = 1.24 m

tt = (4.9 * D * (Ht' - 0.3) * SGt) / (JE * St)
tt = (4.9 * 6.5 * (1.236 - 0.3) * 1.025) / (0.7 * 145)
tt = 0.3 mm

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

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 1.24 m

Ni = 5.22 * Ai * G * (D^2) * ((Y / (0.75 * D)) - (0.5 * ((Y / (0.75 * D))^2)))
Ni = 5.22 * 0.306 * 1 * (6.5^2) * ((1.236 / (0.75 * 6.5)) - (0.5 * ((1.236 / (0.75 * 6.5))^2)))
Ni = 14.94 N/mm

Nc = (1.85 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (1.85 * 0.212 * 1 * (6.5^2) * COSH(((3.68 * (6.72 - 1.236)) / 6.5))) / COSH(((3.68 * 6.72) / 6.5))
Nc = 8.24 N/mm

Nh = 4.9 * (H - H_offset) * D * G

Nh = 4.9 * (1.236 - 0) * 6.5 * 1
Nh = 39.37 N/mm

S_T+ = Total Combined Hoop Stress per API 650 Sections E.6.1.4, EC.6.1.3 (MPa)
S_T- = Total Combined Hoop Stress per API 650 Sections E.6.1.4, EC.6.1.3 (MPa)

S_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
S_T+ = (39.3666 + SQRT(((14.9414^2) + (8.243^2) + (((0.3808 * 39.3666) / 2.5)^2)))) / MAX((6 - 3) , 0.0001)
S_T+ = 19.15 MPa

S_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
S_T- = (39.3666 - SQRT(((14.9414^2) + (8.243^2) + (((0.3808 * 39.3666) / 2.5)^2)))) / MAX((6 - 3) , 0.0001)
S_T- = 7.09 MPa

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 145) , (0.9 * 250.0 * 0.7))
Sd-seismic = 157.5 MPa

ts = ((SIGMAt+ * (tn - CA)) / S_membrane) + CA
ts = ((19.1513 * (6 - 3)) / 157.5) + 3
ts = 3.36 mm

Minimum Required Thickness
t-min = MAX(t-erec , td , tt , ts)
t-min = MAX(5 , 3.2937 , 0.3011 , 3.3648)
t-min = 5 mm

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (4.9 * D * SG)) + 0.3) + loc
H-max = ((((6 - 3) * 145 * 0.7) / (4.9 * 6.5 * 1)) + 0.3) + 5.484
H-max = 15.34 m

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(15.3444 , 0)
H-max-@-Pi = 15.34 m

Pi-max-@-H = MAX((((H-max - (H + loc)) * (9.8 * SG)) + P) , 0)
Pi-max-@-H = MAX((((15.3444 - (1.236 + 5.484)) * (9.8 * 1)) + 0.0) , 0)
Pi-max-@-H = 84.52 kPa

Course # 5 Design
CA = Corrosion allowance per API-650 5.3.2 (mm)
D5 = Shell Course Centerline Diameter (m)
H = Design Liquid Level per API-650 5.6.3.2 (m)
H' = Effective Design Liquid Level per API-650 F.2 (m)
H-max = Maximum Liquid Level for the Installed Thickness (m)
H-max-@-Pi = Maximum Liquid Level for the Installed Thickness @ Design Internal Pressure (m)
Ht' = Effective Hydrostatic Test Liquid Level per API-650 F.2 (m)
JE = Joint efficiency
Ma = Course Material
Pi-max-@-H = Maximum Allowable Internal Pressure for the Installed Thickness @ Design Liquid Level (kPa)
Rwi = Impulsive Force Reduction Factor
W-5 = Shell Course Nominal Weight (kg)
W-5-corr = Shell Course Nominal Weight (kg)
h5 = Course Height (m)
loc = Course Location (m)
t = Installed Thickness (mm)

t-min = Minimum Required Thickness (mm)
td = Course Design Thickness per A.4.1 (mm)
tt = Course Hydrostatic Test Thickness per A.4.1 (mm)

CA = 3 mm
H = 0.24 m
JE = 0.7
Ma = A36
Rwi = 4
h5 = 1.02 m
loc = 6.48 m
t = 6 mm

Shell Course Center of Gravity (CG-5) = 6.99 m

D5 = ID + t
D5 = 6.5 + 0.006
D5 = 6.51 m

W-5 = pi * Dc * t * h5 * d
W-5 = pi * 6.506 * 0.006 * 1.016 * 7,840
W-5 = 976.84 kg

W-5-corr = pi * Dc * (t - CA) * h5 * d
W-5-corr = pi * 6.506 * (0.006 - 0.003) * 1.016 * 7,840
W-5-corr = 488.42 kg

Material Properties
Material (A36) = A36
Minimum Tensile Strength (Sut) = 400.0 MPa
Minimum Yield Strength (Sy) = 250.0 MPa
As per API-650 A.4.1, Allowable Design Stress (Sd) = 145 MPa
As per API-650 A.4.1, Allowable Hydrostatic Test Stress (St) = 145 MPa
Permissible Design Metal Temperature (MDMT-permissible) = -30 °C

Thickness Required by Erection
As per API-650 5.6.1.1, Thickness Required by Erection (t-erec) = 5 mm

Thickness Required by Design
H' = H
H' = 0.236
H' = 0.24 m

Design liquid level is below the design point under consideration

td = ((4.9 * D * (H' - 0.3) * SG) / (JE * Sd)) + CA
td = ((4.9 * 6.5 * (0.236 - 0.3) * 1) / (0.7 * 145)) + 3
td = 2.98 mm

Hydrostatic Test Required Thickness
Ht' = H
Ht' = 0.236
Ht' = 0.24 m

Hydrotest Design liquid level is below the design point under consideration

tt = (4.9 * D * (Ht' - 0.3) * SGt) / (JE * St)
tt = (4.9 * 6.5 * (0.236 - 0.3) * 1.025) / (0.7 * 145)
tt = -0.02 (Set to 0 mm since it cannot be less than 0)

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

As per API 650 Section E.6.1.4, Shell Course Liquid Surface to Analysis Point Distance (Y) = 0.24 m

Ni = 5.22 * Ai * G * (D^2) * ((Y / (0.75 * D)) - (0.5 * ((Y / (0.75 * D))^2)))
Ni = 5.22 * 0.306 * 1 * (6.5^2) * ((0.236 / (0.75 * 6.5)) - (0.5 * ((0.236 / (0.75 * 6.5))^2)))
Ni = 3.19 N/mm

Nc = (1.85 * Ac * G * (D^2) * COSH(((3.68 * (H - Y)) / D))) / COSH(((3.68 * H) / D))
Nc = (1.85 * 0.212 * 1 * (6.5^2) * COSH(((3.68 * (6.72 - 0.236)) / 6.5))) / COSH(((3.68 * 6.72) / 6.5))
Nc = 14.5 N/mm

Nh = 4.9 * (H - H_offset) * D * G
Nh = 4.9 * (0.236 - 0) * 6.5 * 1
Nh = 7.52 N/mm

S_T+ = Total Combined Hoop Stress per API 650 Sections E.6.1.4, EC.6.1.3 (MPa)
S_T- = Total Combined Hoop Stress per API 650 Sections E.6.1.4, EC.6.1.3 (MPa)

S_T+ = (Nh + SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
S_T+ = (7.5166 + SQRT(((3.188^2) + (14.5002^2) + (((0.3808 * 7.5166) / 2.5)^2)))) / MAX((6 - 3) , 0.0001)
S_T+ = 7.47 MPa

S_T- = (Nh - SQRT(((Ni^2) + (Nc^2) + (((Av * Nh) / 2.5)^2)))) / MAX((t - CA) , 0.0001)
S_T- = (7.5166 - SQRT(((3.188^2) + (14.5002^2) + (((0.3808 * 7.5166) / 2.5)^2)))) / MAX((6 - 3) , 0.0001)
S_T- = -2.46 MPa

Sd-seismic = MIN((1.33 * Sd) , (0.9 * Fy * E))
Sd-seismic = MIN((1.33 * 145) , (0.9 * 250.0 * 0.7))
Sd-seismic = 157.5 MPa

ts = ((SIGMAt+ * (tn - CA)) / S_membrane) + CA
ts = ((7.4691 * (6 - 3)) / 157.5) + 3
ts = 3.14 mm

Minimum Required Thickness
t-min = MAX(t-erec , td , tt , ts)
t-min = MAX(5 , 2.9799 , 0 , 3.1423)
t-min = 5 mm

Rating of Installed Thickness
H-max = ((((t - CA) * Sd * JE) / (4.9 * D * SG)) + 0.3) + loc
H-max = ((((6 - 3) * 145 * 0.7) / (4.9 * 6.5 * 1)) + 0.3) + 6.484
H-max = 16.34 m

H-max-@-Pi = MAX(H-max , 0)
H-max-@-Pi = MAX(16.3444 , 0)
H-max-@-Pi = 16.34 m

Pi-max-@-H = MAX((((H-max - (H + loc)) * (9.8 * SG)) + P) , 0)
Pi-max-@-H = MAX((((16.3444 - (0.236 + 6.484)) * (9.8 * 1)) + 0.0) , 0)
Pi-max-@-H = 94.32 kPa

Shell Design Summary Results

W-ins = t-ins * d-ins * pi * (OD + t-ins) * H
W-ins = 0.0 * 130 * pi * (6.516 + 0.0) * 7.5
W-ins = 0.0 kg

W-shell-corr = W-1-corr + W-2-corr + W-3-corr + W-4-corr + W-5-corr
W-shell-corr = 1,465.0744 + 878.7745 + 878.7745 + 480.73 + 488.4217
W-shell-corr = 4,191.78 kg

W-shell = W-1 + W-2 + W-3 + W-4 + W-5
W-shell = 2,344.119 + 1,757.549 + 1,757.549 + 961.4601 + 976.8434
W-shell = 7,797.52 kg

CG-shell = ((CG-1 * W-1) + (CG-2 * W-2) + (CG-3 * W-3) + (CG-4 * W-4) + (CG-5 * W-5)) / W-shell
CG-shell = ((0.914 * 2,344.119) + (2.742 * 1,757.549) + (4.57 * 1,757.549) + (5.984 * 961.4601) + (6.992 * 976.8434)) / 7,797.5204
CG-shell = 3.54 m

Shell Design Summary

Course	Height (m)	Material	CA (mm)	JE	Sy (mpa)	Sut (mpa)	Sd (mpa)	St (mpa)	t-erec (mm)
5	1.02	A36	3	0.7	250.0	400.0	145	145	5
4	1.0	A36	3	0.7	250.0	400.0	145	145	5
3	1.83	A36	3	0.7	250.0	400.0	145	145	5
2	1.83	A36	3	0.7	250.0	400.0	145	145	5
1	1.83	A36	3	0.7	250.0	400.0	145	145	6

Shell Design Summary (continued)

Course	t-design (mm)	t-test (mm)	t-seismic (mm)	t-ext (mm)	t-min (mm)	t-installed (mm)	Status	H-max-@-Pi (m)	Pi-max-@-H (kPa)
5	2.98	0	3.14	N/A	5	6	PASS	16.34	94.32
4	3.29	0.3	3.36	N/A	5	6	PASS	15.34	84.52
3	3.87	0.89	3.83	N/A	5	6	PASS	13.52	66.61
2	4.44	1.48	4.25	N/A	5	6	PASS	11.69	48.69
1	5.01	2.06	4.66	N/A	6	8	PASS	16.23	93.24

Intermediate Stiffeners Design

Stiffeners Design For Wind Loading

D = Nominal Tank Diameter (m)
H1 = Maximum Unstiffened Transformed Shell Height per API-650 5.9.6.1 (m)
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 (kPa)
Pwv = Wind Pressure where Design Wind Speed V is Used per API-650 5.9.6.1 (kPa)
V = Wind velocity (km/hr)
ts_min = Thickness of the Thinnest Shell Course (mm)

D = 6.5 m
N = 4
V = 112.32 km/hr

Shell Courses Heights (W) = [1.83 1.83 1.83 1.0 1.02] m

ts_min = MIN(ts_1 , ts_2 , ts_3 , ts_4 , ts_5)
ts_min = MIN(8 , 6 , 6 , 6 , 6)
ts_min = 6 mm

Stiffeners Required Quantity

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

Transformed shell courses heights

Variable	Equation	Value	Unit		
Wtr_1	W_1 * SQRT(((t_min / ts_1)^5))	0.89	m	N/A	N/A
Wtr_2	W_2 * SQRT(((t_min / ts_2)^5))	1.83	m	N/A	N/A
Wtr_3	W_3 * SQRT(((t_min / ts_3)^5))	1.83	m	N/A	N/A
Wtr_4	W_4 * SQRT(((t_min / ts_4)^5))	1.00	m	N/A	N/A
Wtr_5	W_5 * SQRT(((t_min / ts_5)^5))	1.02	m	N/A	N/A

HTS = Wtr_1 + Wtr_2 + Wtr_3 + Wtr_4 + Wtr_5
HTS = 0.8905 + 1.828 + 1.828 + 1.0 + 1.016
HTS = 6.56 m

Pwv = 1.48 * ((V / 190)^2)
Pwv = 1.48 * ((112.32 / 190)^2)
Pwv = 0.52 kPa

Pwd = Pwv + 0.24
Pwd = 0.5172 + 0.24
Pwd = 0.76 kPa

H1 = 9.47 * ts_min * SQRT(((ts_min / D)^3)) * (1.72 / Pwd)
H1 = 9.47 * 6 * SQRT(((6 / 6.5)^3)) * (1.72 / 0.7572)
H1 = 114.46 m

Ns = CEILING(((HTS / Hsafe) - 1))
Ns = CEILING(((6.5625 / 114.464) - 1))
Ns = 0

N >= Ns ==> PASS

Stiffeners Design

Real Elevations

Stiffener #	Size	Elevation (ft)	Spacing below (ft)	Spacing above (ft)	Average Spacing Ls (ft)
1	L75X75X6	1.68	1.68	1.80	1.74
2	L75X75X6	3.48	1.80	1.80	1.80
3	L75X75X6	5.28	1.80	1.00	1.40
4	L75X75X6	6.28	1.00	1.22	1.11

Transformed Elevations

Stiffener #	Size	Transformed Elevation (ft)	Transformed Spacing below (ft)	Transformed Spacing above (ft)	Transformed Average Spacing (ft)
1	L75X75X6	0.82	0.82	1.72	1.27
2	L75X75X6	2.54	1.72	1.80	1.76
3	L75X75X6	4.34	1.80	1.00	1.40

4	L75X75X6	5.34	1.00	1.22	1.11

Stiffener #1 Design
Fy = Intermediate Wind Girder and Shell Yield Strength per API 650 5.9.6.6 (MPa)
Z_act = Stiffener Region Section Modulus per API-650 5.9.6.6.2 (cm^3)
Z_req = Intermediate Wind Girder Minimum Required Section Modulus per API-650 5.9.6.6 (cm^3)
h1 = Vertical Distance Between the Intermediate Stiffener and the Top Angle of the Shell or the Top Wind Girder of an Open-top Tank (m)

Z_act = 20.63 cm^3
h1 = 1.8 m

Shell Yield Strength (Fy_shell) = 250.0 MPa
Stiffener Yield Strength (Fy_stiffener) = 250.0 MPa

Fy = MIN(Fy_stiffener , Fy_shell)
Fy = MIN(250.0 , 250.0)
Fy = 250.0 (Set to 210 MPa since it cannot be greater than 210)

Z_req = ((6 * h1 * (D^2)) / (0.5 * Fy)) * (Pwd / 1.72)
Z_req = ((6 * 1.8 * (6.5^2)) / (0.5 * 210)) * (0.7572 / 1.72)
Z_req = 1.91 cm^3

Z_act >= Z_req

Stiffener #2 Design
Fy = Intermediate Wind Girder and Shell Yield Strength per API 650 5.9.6.6 (MPa)
Z_act = Stiffener Region Section Modulus per API-650 5.9.6.6.2 (cm^3)
Z_req = Intermediate Wind Girder Minimum Required Section Modulus per API-650 5.9.6.6 (cm^3)
h1 = Vertical Distance Between the Intermediate Stiffener and the Top Angle of the Shell or the Top Wind Girder of an Open-top Tank (m)

Z_act = 19.86 cm^3
h1 = 1.8 m

Shell Yield Strength (Fy_shell) = 250.0 MPa
Stiffener Yield Strength (Fy_stiffener) = 250.0 MPa

Fy = MIN(Fy_stiffener , Fy_shell)
Fy = MIN(250.0 , 250.0)
Fy = 250.0 (Set to 210 MPa since it cannot be greater than 210)

Z_req = ((6 * h1 * (D^2)) / (0.5 * Fy)) * (Pwd / 1.72)
Z_req = ((6 * 1.8 * (6.5^2)) / (0.5 * 210)) * (0.7572 / 1.72)
Z_req = 1.91 cm^3

Z_act >= Z_req

Stiffener #3 Design
Fy = Intermediate Wind Girder and Shell Yield Strength per API 650 5.9.6.6 (MPa)
Z_act = Stiffener Region Section Modulus per API-650 5.9.6.6.2 (cm^3)
Z_req = Intermediate Wind Girder Minimum Required Section Modulus per API-650 5.9.6.6 (cm^3)
h1 = Vertical Distance Between the Intermediate Stiffener and the Top Angle of the Shell or the Top Wind Girder of an Open-top Tank (m)

Z_act = 19.86 cm^3
h1 = 1.0 m

Shell Yield Strength (Fy_shell) = 250.0 MPa
Stiffener Yield Strength (Fy_stiffener) = 250.0 MPa

Fy = MIN(Fy_stiffener , Fy_shell)
Fy = MIN(250.0 , 250.0)
Fy = 250.0 (Set to 210 MPa since it cannot be greater than 210)

Z_req = ((6 * h1 * (D^2)) / (0.5 * Fy)) * (Pwd / 1.72)
Z_req = ((6 * 1.0 * (6.5^2)) / (0.5 * 210)) * (0.7572 / 1.72)
Z_req = 1.06 cm^3

Z_act >= Z_req

Stiffener #4 Design
Fy = Intermediate Wind Girder and Shell Yield Strength per API 650 5.9.6.6 (MPa)
Z_act = Stiffener Region Section Modulus per API-650 5.9.6.6.2 (cm^3)
Z_req = Intermediate Wind Girder Minimum Required Section Modulus per API-650 5.9.6.6 (cm^3)
h1 = Vertical Distance Between the Intermediate Stiffener and the Top Angle of the Shell or the Top Wind Girder of an Open-top Tank (m)

Z_act = 19.86 cm^3
h1 = 1.22 m

Shell Yield Strength (Fy_shell) = 250.0 MPa
Stiffener Yield Strength (Fy_stiffener) = 250.0 MPa

Fy = MIN(Fy_stiffener , Fy_shell)
Fy = MIN(250.0 , 250.0)
Fy = 250.0 (Set to 210 MPa since it cannot be greater than 210)

Z_req = ((6 * h1 * (D^2)) / (0.5 * Fy)) * (Pwd / 1.72)
Z_req = ((6 * 1.22 * (6.5^2)) / (0.5 * 210)) * (0.7572 / 1.72)
Z_req = 1.3 cm^3

Z_act >= Z_req

Intermediate Stiffeners Summary

Intermediate Stiffeners Summary Table

Stiffener #	Size	Elevation (m)	Z reqd (cm^3)	Z act (cm^3)	Weight (kg)
1	L75X75X6	1.68	1.91	20.63	143.45
2	L75X75X6	3.48	1.91	19.86	143.37
3	L75X75X6	5.28	1.06	19.86	143.37
4	L75X75X6	6.28	1.30	19.86	143.37

Flat Bottom: non Annular Plate Design

Back

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

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

CA = 3 mm
CA_1 = 3 mm
E = 0.7
Ma-bottom = A36
Ma_1 = A36
Sd_1 = 145 MPa
St_1 = 145 MPa
chime = 50 mm
tb = 10 mm
td_1 = 5.01 mm
ts_1 = 8 mm
tt_1 = 2.06 mm

Bottom Plates Material Properties
Material (A36) = A36
Minimum Tensile Strength (Sut-btm) = 400.0 MPa
Minimum Yield Strength (Sy-btm) = 250.0 MPa
Density (d-btm) = 7,840 kg/m^3
Permissible Design Metal Temperature (MDMT-permissible-btm) = -30 °C

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 = ((5.0146 - 3) / (8 - 3)) * 145
S1 = 58.42 MPa

As per API-650 5.5.1, first shell course material, A36, is in Group I; therefore, butt welded annular plates are not required

S2 = (tt_1 / ts_1) * St_1
S2 = (2.0649 / 8) * 145
S2 = 37.43 MPa

As per API-650 5.5.1, first shell course material, A36, is in Group I; therefore, butt welded annular plates are not required

S = MAX(S1 , S2)
S = MAX(58.422 , 37.4266)
S = 58.42 MPa

Bottom Weight
A-btm = Bottom Surface Area (m^2)
CA = Corrosion allowance (mm)
OD-btm = Bottom Outer Diameter (m)
Wb-pl = Bottom Plates Weight (kg)
Wb-pl-corr = Bottom Corroded Plates Weight (kg)
chime = Outside Projection (Chime Distance) (mm)
tb = Installed Thickness (mm)

CA = 3 mm
chime = 50 mm
tb = 10 mm

OD-btm = OD + (chime * 2)
OD-btm = 6.516 + (0.05 * 2)
OD-btm = 6.62 m

A-btm = pi * ((OD-btm / 2)^2)
A-btm = pi * ((6.616 / 2)^2)
A-btm = 34.38 m^2

Wb-pl = A-btm * tb * d-btm
Wb-pl = 34,378,021.1516 * 10 * 7.840000000000001E-6
Wb-pl = 2,695.24 kg

Wb-pl-corr = A-btm * (tb - CA) * d-btm
Wb-pl-corr = 34,378,021.1516 * (10 - 3) * 7.840000000000001E-6
Wb-pl-corr = 1,886.67 kg

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

Liquid Height to Pressure Conversion Factor (f) = 9.81

P-btm = (d-btm * 9.80665 * (tb - CA-btm) * (1 / 1.0E6)) + (Lmin * f * SG)
P-btm = (7,840 * 9.80665 * (10 - 3) * (1 / 1.0E6)) + (0.0 * 9.8064 * 1)
P-btm = 0.54 kPa

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

Bottom Required Thickness
As per API-650 5.4.1, Required Thickness by Erection (tb-erec) = 9 mm

tb-req = tb-erec
tb-req = 9
tb-req = 9 mm

tb >= tb-req ==> PASS

Bottom Outside Projection
As per API-650 5.4.2, Minimum Required Outside Projection (chime) = 50 mm

chime >= chime ==> PASS

Wind Moment (Per API-650 Section 5.11) Back

Wind Pressures per API-650 & ASCE7-10

PWR = Roof Design Wind Pressure per API-650 5.2.1.k (kPa)
PWS = Shell Design Wind Pressure per API-650 5.2.1.k (kPa)
V = Design Wind Velocity (3-sec gust) (kph)
Vs = Adjusted Design Wind Velocity (kph)

V = 144.0 kph

Wind Velocity per API-650 and ASCE7-10

Vs = 0.78 * V
Vs = 0.78 * 144.0
Vs = 112.32 kph

Roof Wind Pressure
PWR = 1.48 * ((Vs / 190)^2)
PWR = 1.48 * ((112.32 / 190)^2)
PWR = 0.52 kPa

Shell Wind Pressure
PWS = 0.89 * ((Vs / 190)^2)
PWS = 0.89 * ((112.32 / 190)^2)
PWS = 0.31 kPa

Wind Overturning and Sliding Stability

Ah = Roof Horizontal Projected Area (m^2)
Ah-total = Roof Horizontal Projected Area Including Insulation (m^2)
As = Shell Total Vertical Projected Area (m^2)
Av-roof = Roof Vertical Projected Area (m^2)
CA-btm = Corrosion Allowance of Bottom Plates Under the Shell (mm)
CA_1 = Bottom Shell Course Corrosion Allowance (mm)
CG-roof = Roof Center of Gravity (m)
COF = Maximum Allowable Sliding Friction Coefficient
D-outer = Tank Max Outer Diameter (m)
DLR = Nominal Weight of Roof Plates and Attached Structural (N)
DLS = Nominal Weight of Shell Plates and Framing (N)
F-friction = Friction Force (N)
F-wind = Sliding Force (N)
Fby = Yield Strength of Bottom Plates Under the Shell (MPa)
MDL = Moment About the Shell-To-Bottom Joint from the Nominal Weight of the Shell (N.m)
MDLR = Moment About the Shell-To-Bottom Joint from the Nominal Weight of the Roof Plate Plus any Attached Structural (N.m)
MF = Moment About the Shell-To-Bottom Joint From Liquid Weight (N.m)
MPi = Moment About the Shell-To-Bottom Joint From Design Internal Pressure per API-650 5.11.2.2 (N.m)
MWR = Roof Wind Overturning Moment per API-650 5.11.2.2 (N.m)
MWS = Shell Wind Overturning Moment per API-650 5.11.2.2 (N.m)
Mw = Overturning Moment About the Shell-To-Bottom Joint from Wind Pressures per API-650 5.11.2.2 (N.m)
Rh = Roof Horizontal Radius (m)
W-struct = Roof New Structure Weight (N)

W-struct-corr = Roof Corroded Structure Weight (N)
Wb-pl-corr = Bottom Corroded Plates Weight (N)
Wr-pl = Roof New Plates Weight (N)
Wr-pl-corr = Roof Corroded Plates Weight (N)
Ws-framing = Shell New Framing Weight (N)
Ws-framing-corr = Shell Corroded Framing Weight (N)
Ws-pl = Shell New Plates Weight (N)
Ws-pl-corr = Shell Corroded Plates Weight (N)
Ws-struct-corr = Roof Corroded Structure Weight Supported by Shell (N)
Xs = Moment Arm of Wind Force on Shell (m)
Xw = Moment Arm of Wind Force on Roof (m)
tb = Thickness of Bottom Plates Under the Shell (mm)
tr-ins = Roof Insulation Thickness (mm)
ts-ins = Shell Insulation Thickness (mm)
ts_1 = Bottom Shell Course Nominal Thickness (mm)
wL = Tank Content Resisting Weight per API-650 5.11.2.3 (N/m)
wind-uplift = Wind Uplift per API-650 5.2.1.k (kPa)

Ah = 34.05 m^2
Av-roof = 1.81 m^2
CA-btm = 3 mm
CA_1 = 3 mm
CG-roof = 0.18 m
COF = 0.4
DLR = 17,725.8 N
DLS = 97,993.97 N
Fby = 250.0 MPa
Rh = 3.29 m
W-struct = 12,507.52 N
W-struct-corr = 8,351.4 N
Wb-pl-corr = 18,501.87 N
Wr-pl = 15,922.35 N
Wr-pl-corr = 7,961.17 N
Ws-framing = 10,367.33 N
Ws-framing-corr = 9,144.84 N
Ws-pl = 76,467.55 N
Ws-pl-corr = 41,107.27 N
Ws-struct-corr = 7,027.01 N
tb = 10 mm
tr-ins = 0 mm
ts-ins = 0 mm
ts_1 = 8 mm

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 5.2.1.k.2

wind-uplift = PWR
wind-uplift = 0.5172
wind-uplift = 0.52 kPa

Overturning Moments

Xw = D / 2
Xw = 6.5 / 2
Xw = 3.25 m

Ah-total = pi * ((Rh + ts-ins)^2)
Ah-total = pi * ((3.292 + 0.0)^2)
Ah-total = 34.05 m^2

MPi = Pg * Ah * Xw
MPi = 0.0 * 34.0463 * 3.25
MPi = 0.0 N.m

MWR = wind-uplift * Ah-total * Xw
MWR = 517.2121 * 34.0463 * 3.25
MWR = 57,229.72 N.m

D-outer = OD + (2 * (ts-ins / 1000))
D-outer = 6.516 + (2 * (0 / 1000))
D-outer = 6.52 m

As = D-outer * H
As = 6.516 * 7.5
As = 48.87 m^2

Xs = H / 2
Xs = 7.5 / 2
Xs = 3.75 m

MWS = PWS * As * Xs
MWS = 311.0262 * 48.87 * 3.75
MWS = 56,999.44 N.m

Mw = MWR + MWS
Mw = 57,229.7159 + 56,999.4416
Mw = 114,229.16 N.m

Resistance to Overturning per API-650 5.11.2

MDL = (D / 2) * DLS
MDL = (6.5 / 2) * 97,993.9717
MDL = 318,480.41 N.m

MDLR = (D / 2) * DLR
MDLR = (6.5 / 2) * 17,725.7962
MDLR = 57,608.84 N.m

As per API-650 5.11.2.3, the corroded thickness of plates under the shell used in the liquid resisting weight calculation shall not be greater than first shell course corroded thickness

wL = MIN((70.4 * Lmax * D) , (59 * (ts_1 - CA_1) * SQRT((Fby * Lmax))))
wL = MIN((70.4 * 6.72 * 6.5) , (59 * (8 - 3) * SQRT((250.0 * 6.72))))
wL = 3,075.07 N/m

MF = (D / 2) * wL * pi * D
MF = (6.5 / 2) * 3,075.072 * pi * 6.5
MF = 204,080.67 N.m

An unanchored tank must meet the criteria from API-650 5.11.2.1
Criterion 1
((0.6 * Mw) + MPi) < ((MDL / 1.5) + MDLR)
((0.6 * 114,229.1575) + 0.0) < ((318,480.4079 / 1.5) + 57,608.8375)
68,537.4945 < 269,929.1095 ==> Tank is stable

Criterion 2
(Mw + (Fp * MPi)) < (((MDL + MF) / 2) + MDLR)
(114,229.1575 + (0.4 * 0.0)) < (((318,480.4079 + 204,080.6736) / 2) + 57,608.8375)
114,229.1575 < 318,889.3783 ==> Tank is stable

Criterion 3

(MWS + (Fp * MPi)) < ((MDL / 1.5) + MDLR)
(56,999.4416 + (0.4 * 0.0)) < ((318,480.4079 / 1.5) + 57,608.8375)
56,999.4416 < 269,929.1095 ==> Tank is stable

Resistance to Sliding per API-650 5.11.4

F-wind = PWS * As
F-wind = 311.0262 * 48.87
F-wind = 15,199.85 N

F-friction = COF * (Wr-pl-corr + W-struct-corr + Ws-pl-corr + Ws-framing-corr + Wb-pl-corr)
F-friction = 0.4 * (7,961.1743 + 8,351.3979 + 41,107.2712 + 9,144.8437 + 18,501.8712)
F-friction = 34,026.62 N

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

Anchorage Requirement

Tank anchorage due to wind is not required per API-650 5.11

Seismic Design Back

Site Ground Motion Design

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 (m)
Fa = Site Acceleration Coefficient
Fv = Site Velocity Coefficient
H = Maximum Design Product Level (m)
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
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
Ss = Spectral Response Acceleration Short Period
TL = Regional Dependent Transistion Period for Longer Period Ground Motion (sec)
Tc = Convective Natural Period per API 650 Section E.4.5.2 (sec)

Anchorage_System = MECHANICALLY-ANCHORED
D = 6.5 m
Fa = 1.02
Fv = 1.5
H = 6.72 m
I = 1.5
K = 1.5
Q = 0.67
Rwc = 2
Rwi = 4
S1 = 0.5
Seismic_Site_Class = SEISMIC-SITE-CLASS-D
Seismic_Use_Group = SEISMIC-USE-GROUP-III
Ss = 1.2
TL = 4 sec

SDS = Q * Fa * Ss
SDS = 0.6667 * 1.02 * 1.2
SDS = 0.82

SD1 = Q * Fv * S1
SD1 = 0.6667 * 1.5 * 0.5
SD1 = 0.5

Ks = 0.578 / SQRT(TANH(((3.68 * H) / D)))
Ks = 0.578 / SQRT(TANH(((3.68 * 6.72) / 6.5)))
Ks = 0.58

Tc = 1.8 * Ks * SQRT(D)
Tc = 1.8 * 0.5783 * SQRT(6.5)
Tc = 2.65 sec

Ai = SDS * (I / Rwi)
Ai = 0.816 * (1.5 / 4)
Ai = 0.31

Ai = MAX(Ai , 0.007)
Ai = MAX(0.306 , 0.007)
Ai = 0.31

Tc <= TL

Ac = K * SD1 * (1 / Tc) * (I / Rwc)
Ac = 1.5 * 0.5 * (1 / 2.6538) * (1.5 / 2)
Ac = 0.21

Ac-min = MIN(Ac , Ai)
Ac-min = MIN(0.212 , 0.306)
Ac-min = 0.21

Av = (2 / 3) * 0.7 * SDS
Av = (2 / 3) * 0.7 * 0.816
Av = 0.38

Vertical Ground Acceleration Coefficient Specified by user (Av) = 0.38

Af = K * SD1 * I * (1 / Tc)
Af = 1.5 * 0.5 * 1 * (1 / 2.6538)
Af = 0.28

As per API-650 E.4.6.1, for tanks falling in SUG III, the importance factor shall be set equal to 1 in the determination of sloshing wave height = for tanks falling in SUG III, the importance factor shall be set equal to 1 in the determination of sloshing wave height

Seismic Design

A = Roof Surface Area (m^2)
A-rs = Roof Area Supported by The Shell (m^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 (m^2)
Ai = Impulsive Design Response Spectrum Acceleration Coefficient
Anchorage_System = Anchorage System
Av = Vertical Ground Acceleration Coefficient
D = Nominal Tank Diameter (m)
DELTAs = Sloshing Wave Height Above Product Design Height per API 650 Section E.7.2 (m)
Event_Type = Event Type
Fa = Site Acceleration Coefficient
Fc = Allowable Longitudinal Shell Compression Stress per API 650 Section E.6.2.2.3 (MPa)
Freeboard = Actual Freeboard (m)
Freeboard_required = Minimum Required Freeboard per API-650 Table E.7 (m)
Fv = Site Velocity Coefficient
Fy = Yield Strength (MPa)
G = Specific Gravity
Ge = Effective Specific Gravity per API 650 Section E.2.2
H = Maximum Design Product Level (m)
H_shell = Shell height (m)
Hrcg = Top of Shell to Roof and roof appurtenances Center of Gravity (m)

I = Importance Factor
J = Anchorage Ratio per API 650 Section E.6.2.1.1.1
K = Spectral Acceleration Adjustment Coefficient
Ks = Sloshing Coefficient
MU = Friction Coefficient
Min_Anchor_Quantity = Minimum Anchor Quantity
Min_Anchor_Spacing = Minimum Anchor Spacing (m)
Mrw = Ringwall Overturning Moment per API 650 Section E.6.1.5 (N.m)
Ms = Slab Overturning Moment per API 650 Section E.6.1.5 (N.m)
Overturn_Stability_Ratio = Overturning Stability Ratio per API 650 Section E.6.2.3
P = Design Pressure (MPa)
Q = MCE to Design Level Scale Factor
S1 = Spectral Response Acceleration at a Period of One Second
SD1 = Design Spectral Response Acceleration at a Period of 1 Second
SDS = Design Spectral Response Acceleration at Short Period
Sb = Roof Balanced Snow Load (Pa)
Sc = Mechanically Anchored Maximum Longitudinal Shell Compression Stress per API 650 Section E.6.2.2.2 (MPa)
Seismic_Site_Class = Seismic Site Class
Seismic_Use_Group = Seismic Use Group
Ss = Spectral Response Acceleration Short Period
TL = Regional Dependent Transistion Period for Longer Period Ground Motion (sec)
Tc = Convective Natural Period (sec)
V = Total Design Base Shear per API 650 Section E.6.1 (N)
Vc = Design Base Shear for Convective Component per API 650 Section E.6.1 (N)
Vi = Design Base Shear for Impulsive Component per API 650 Section E.6.1 (N)
Vmax = Local Shear Transfer per API 650 Section E.7.7 (N/m)
Vs = Self Anchored Sliding Resistance Maximum Allowable Base Shear per API 650 Section E.7.6 (N)
W-struct = Roof Structure Weight (kg)
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 (N)
Wb-attachments = Bottom Attachments Weight (kg)
Wb-pl = Bottom Plates Weight (kg)
Wc = Convective Effective Weight per API 650 Section E.6.1.1 (N)
Weff = Total Effective Weight per API 650 Section E.6.1.1 (N)
Wf = Tank Bottom Total Weight (N)
Wfd = Tank Foundation Weight (N)
Wg = Soil Weight (N)
Wi = Impulsive Effective Weight per API 650 Section E.6.1.1 (N)
Wp = Tank Contents Total Weight (N)
Wr = Total Weight of Fixed Tank Roof including Framing, Knuckles, any Permanent Attachments and 10 % of the Roof Balanced Design Snow Load (N)
Wr-DL-add = Roof Additional Dead Weight (kg)
Wr-attachments = Roof Attachments Weight (kg)
Wr-pl = Roof Plates Nominal Weight (kg)
Wrs = Roof Load Acting on The Tank Shell Including 10 % of the Roof Balanced Design Snow Load (N)
Ws = Total Weight of Tank Shell and Appurtenances (N)
Ws-attachments = Shell Attachments Weight (kg)
Ws-framing = Shell Framing Weight (kg)
Ws-pl = Shell Plates Nominal Weight (kg)
Wss = Roof Structure Weight Supported by The Tank Shell (kg)
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 (m)
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 (m)
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 (m)
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 (m)
Xr = Height from tank shell bottom to the center of gravity of roof and roof appurtenances per API 650 Section E.6.1.2 (m)
Xs = Height from tank shell bottom to shell's center of gravity (m)
ca1 = Bottom Shell Course Corrosion Allowance (mm)
ca_bottom = Bottom Corrosion Allowance (mm)
hs = Additional Shell Height Required Above Sloshing Height (mm)
t_bottom = Bottom Plate Thickness (mm)
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 (mm)
tb-corr = Bottom Plates Corroded Thickness (mm)
ts1 = Bottom Shell Course Thickness (mm)
ts1_c = Shell Course 1 Corroded Thickness (mm)
wa = (N/m)
wa = Self Anchored Force Resisting Uplift per API 650 Section E.6.2.1.1 (N/m)
wa_max = Self Anchored Force Resisting Uplift Max Limit per API 650 Section E.6.2.1.1 (N/m)
wint = Calculated Design Uplift Due to Product Pressure (N/m)
wrs = Specified Tank Roof Load Acting on Tank Shell (N/m)
wt = Tank and Roof Weight Acting at base of Shell per API 650 Section E.6.2.1.1.1 (N/m)

A = 34.52 m^2
A-rs = 34.52 m^2
Ac = 0.21
Af = 0.28
Ah-shell = 34.05 m^2
Ai = 0.31
Anchorage_System = MECHANICALLY-ANCHORED
Av = 0.38
D = 6.5 m
Event_Type = MAXIMUM-CONSIDERED-EARTHQUAKE-MCE
Fa = 1.02
Fv = 1.5
Fy = 250.0 MPa
G = 1
H = 6.72 m
H_shell = 7.5 m
Hrcg = 0.18 m
I = 1.5
K = 1.5
Ks = 0.58
MU = 0.4
Min_Anchor_Quantity = 6
Min_Anchor_Spacing = 3 m
P = 0.0 MPa
Q = 0.67
S1 = 0.5
SD1 = 0.5
SDS = 0.82
Sb = 0.0 Pa
Seismic_Site_Class = SEISMIC-SITE-CLASS-D
Seismic_Use_Group = SEISMIC-USE-GROUP-III
Ss = 1.2
TL = 4 sec
Tc = 2.65 sec
W-struct = 1,275.41 kg
Wb-attachments = 0 kg
Wb-pl = 2,695.24 kg
Wfd = 0 N
Wg = 0 N
Wp = 2,186,787.3 N

Wr-DL-add = 0.0 kg
Wr-attachments = 183.9 kg
Wr-pl = 1,623.63 kg
Ws-attachments = 2,240.21 kg
Ws-framing = 1,057.17 kg
Ws-pl = 7,797.52 kg
Wss = 1,275.41 kg
Xs = 3.54 m
ca1 = 3 mm
ca_bottom = 3 mm
hs = 0 mm
t_bottom = 10 mm
ts1 = 8 mm

Wf = Wb-pl
Wf = 26,431.2445
Wf = 26,431.24 N

Wr = (Wr-pl + Wr-attachments + W-struct + Wr-DL-add) + (0.1 * Sb * Ah)
Wr = (15,922.3485 + 1,803.4476 + 12,507.5158 + 0.0) + (0.1 * 0.0 * 34.0463)
Wr = 30,233.31 N

Wrs = ((Wr-pl + Wr-attachments + Wr-DL-add) * (A-rs / A)) + Wss + (0.1 * Sb * Ah-shell)
Wrs = ((15,922.3485 + 1,803.4476 + 0.0) * (34.5159 / 34.5159)) + 12,507.5158 + (0.1 * 0.0 * 34.0463)
Wrs = 30,233.31 N

Ws = Ws-pl + Ws-framing + Ws-attachments
Ws = 76,467.5538 + 10,367.3292 + 21,968.9468
Ws = 108,803.83 N

W_T = Ws + Wr + Wp + Wf
W_T = 108,803.8298 + 30,233.3119 + 2,186,787.3013 + 26,431.2445
W_T = 2,352,255.69 N

Effective Weight of Product
Wi = (1.0 - (0.218 * (D / H))) * Wp
Wi = (1.0 - (0.218 * (6.5 / 6.72))) * 2,186,787.3013
Wi = 1,725,674.56 N

Wc = 0.23 * (D / H) * TANH(((3.67 * H) / D)) * Wp
Wc = 0.23 * (6.5 / 6.72) * TANH(((3.67 * 6.72) / 6.5)) * 2,186,787.3013
Wc = 486,002.74 N

Weff = Wi + Wc
Weff = 1,725,674.5624 + 486,002.7404
Weff = 2,211,677.3 N

Design Loads
Vi = Ai * (Ws + Wr + Wf + Wi)
Vi = 0.306 * (108,803.8298 + 30,233.3119 + 26,431.2445 + 1,725,674.5624)
Vi = 578,689.74 N

Vc = Ac * Wc
Vc = 0.212 * 486,002.7404
Vc = 103,032.58 N

V = SQRT(((Vi^2) + (Vc^2)))
V = SQRT(((578,689.7423^2) + (103,032.581^2)))
V = 587,790.38 N

Center of Action for Effective Lateral Forces
Xr = H_shell + Hrcg
Xr = 7.5 + 0.1829
Xr = 7.68 m

Xi = (0.5 - (0.094 * (D / H))) * H
Xi = (0.5 - (0.094 * (6.5 / 6.72))) * 6.72
Xi = 2.75 m

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 * 6.72) / 6.5)) - 1) / (((3.67 * 6.72) / 6.5) * SINH(((3.67 * 6.72) / 6.5))))) * 6.72
Xc = 5.03 m

Xis = (0.5 + (0.06 * (D / H))) * H
Xis = (0.5 + (0.06 * (6.5 / 6.72))) * 6.72
Xis = 3.75 m

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 * 6.72) / 6.5)) - 1.937) / (((3.67 * 6.72) / 6.5) * SINH(((3.67 * 6.72) / 6.5))))) * 6.72
Xcs = 5.1 m

Overturning Moment
Mrw = SQRT((((Ai * ((Wi * Xi) + (Ws * Xs) + (Wr * Xr)))^2) + ((Ac * (Wc * Xc))^2)))
Mrw = SQRT((((0.306 * ((1,725,674.5624 * 2.749) + (108,803.8298 * 3.5367) + (30,233.3119 * 7.6829)))^2) + ((0.212 * (486,002.7404 * 5.0268))^2)))
Mrw = 1,720,272.7 N.m

Ms = SQRT((((Ai * ((Wi * Xis) + (Ws * Xs) + (Wr * Xr)))^2) + ((Ac * (Wc * Xcs))^2)))
Ms = SQRT((((0.306 * ((1,725,674.5624 * 3.75) + (108,803.8298 * 3.5367) + (30,233.3119 * 7.6829)))^2) + ((0.212 * (486,002.7404 * 5.1016))^2)))
Ms = 2,231,817.76 N.m

Resistance to Design Loads
Ge = G * (1 - (0.4 * Av))
Ge = 1 * (1 - (0.4 * 0.3808))
Ge = 0.85

wrs = Wrs / (pi * D)
wrs = 30,233.3119 / (pi * 6.5)
wrs = 1,480.55 N/m

wt = (Ws / (pi * D)) + wrs
wt = (108,803.8298 / (pi * 6.5)) + 1,480.548
wt = 6,808.75 N/m

wint = P * 1000000 * ((pi * ((D^2) / 4)) / (pi * D))
wint = 0.0 * 1000000 * ((pi * ((6.5^2) / 4)) / (pi * 6.5))
wint = 0.0 N/m

Bottom Annular Plates Requirements
tb-corr = t_bottom - ca_bottom
tb-corr = 10 - 3
tb-corr = 7 mm

ts1_c = ts1 - ca1
ts1_c = 8 - 3
ts1_c = 5 mm

ta = MIN(tb-corr , ts1_c)
ta = MIN(7 , 5)
ta = 5 mm

wa_max = 201.1 * H * D * Ge
wa_max = 201.1 * 6.72 * 6.5 * 0.8477
wa_max = 7,446.06 N/m

wa = 99 * ta * SQRT((Fy * H * Ge))
wa = 99 * 5 * SQRT((250.0 * 6.72 * 0.8477))
wa = 18,679.95 N/m

wa > wa_max

wa = wa_max
wa = 7,446.0618
wa = 7,446.06 N/m

Tank Stability
J = Mrw / ((D^2) * (((wt * (1 - (0.4 * Av))) + wa) - (Fp * wint)))
J = 1,720,272.7023 / ((6.5^2) * (((6,808.7534 * (1 - (0.4 * 0.3808))) + 7,446.0618) - (0.4 * 0.0)))
J = 3.08

J > 1.54 ==> Tank is not stable, anchoring is required

Sc = ((wt * (1 + (0.4 * Av))) + ((1.273 * Mrw) / (D^2))) * (1 / (1000 * ts))
Sc = ((6,808.7534 * (1 + (0.4 * 0.3808))) + ((1.273 * 1,720,272.7023) / (6.5^2))) * (1 / (1000 * 5))
Sc = 11.94 MPa

Fc = (83 * (ts / (2.5 * D))) + (7.5 * SQRT((G * H)))
Fc = (83 * (5 / (2.5 * 6.5))) + (7.5 * SQRT((1 * 6.72)))
Fc = 44.98 MPa

Sc < Fc

Overturn_Stability_Ratio = (0.5 * D * (W_T + Wfd + Wg)) / Ms
Overturn_Stability_Ratio = (0.5 * 6.5 * (2,352,255.6877 + 0 + 0)) / 2,231,817.7627
Overturn_Stability_Ratio = 3.43

Overturn_Stability_Ratio >= 2.0 ==> PASS

Freeboard
DELTAs = 0.42 * D * Af
DELTAs = 0.42 * 6.5 * 0.2826
DELTAs = 0.77 m

Freeboard = H_shell - Lmax-operating
Freeboard = 7.5 - 6.72
Freeboard = 0.78 m [780.0 mm]

Freeboard_required = DELTAs
Freeboard_required = 0.7715
Freeboard_required = 0.77 m [771.5 mm]

Freeboard >= Freeboard_required ==> PASS

Sliding Resistance
Vs = MU * (Ws + Wr + Wf + Wp) * (1.0 - (0.4 * Av))
Vs = 0.4 * (108,803.8298 + 30,233.3119 + 26,431.2445 + 2,186,787.3013) * (1.0 - (0.4 * 0.3808))
Vs = 797,584.04 N

V <= Vs

Local Shear Transfer
Vmax = (2 * V) / (pi * D)
Vmax = (2 * 587,790.3798) / (pi * 6.5)
Vmax = 57,569.07 N/m

Anchor Bolt Design Back

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

Av = 0.38 g
Ca-anchor = 1.5 mm
D = 6.5 m
Dac = 6.68 m
Fp = 0.4
Fty = 250.0 MPa
H = 7.5 m
MWS = 56,999.44 N.m
Ma-anchor = A307-B
Mrw = 1,720,272.7 N.m

N = 12
OD = 6.52 m
P = 0.0 kPa
PWR = 0.52 kPa
Pt = 0.0 kPa
Wr-pl = 15,922.35 N
Wr-pl-corr = 7,961.17 N
Wrs-pl-corr = 7,961.17 N
Ws-framing = 10,367.33 N
Ws-framing-corr = 9,144.84 N
Ws-pl = 76,467.55 N
Ws-pl-corr = 41,107.27 N
Wss = 12,507.52 N
Wss-corr = 7,027.01 N
d = 30 mm
p = 2.86 mm
position_angles = [0 30 60 90 120 150 180 210 240 270 300 330] deg

Anchors Spacing Requirements

Max Allowable Spacing Between Anchors at Shell Outer Diameter per API-650 5.12.3
Max Allowable Spacing (max_allowable_spacing) = 3 m
Actual Spacing (actual_spacing) = 1.71 m

actual_spacing <= max_allowable_spacing ==> PASS

N-min = CEILING(((pi * OD) / 3))
N-min = CEILING(((pi * 6.516) / 3))
N-min = 7

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) = 1.75 m
Bolt loads will be based on equally spaced anchors.

Anchor Material Properties

Material (A307-B) = A307-B
Minimum Tensile Strength (Sut-anchor) = 415 MPa
Minimum Yield Strength (Sy-anchor) = 250 MPa
Minimum Yield Strength at Ambient Temperature (Sy-ambient-anchor) = 250 MPa

Fy = MIN(Sy-ambient-anchor , 380)
Fy = MIN(250 , 380)
Fy = 250 MPa

Fy-ambient = MIN(Sy-ambient-anchor , 380)
Fy-ambient = MIN(250 , 380)
Fy-ambient = 250 MPa

Uplift Load Cases per API-650 Table 5.21a

W1 = Ws-pl-corr + Ws-framing-corr + Wr-pl-corr
W1 = 41,107.2712 + 9,144.8437 + 7,961.1743
W1 = 58,213.29 N

W2 = Ws-pl-corr + Ws-framing-corr + Wrs-pl-corr + Wss-corr
W2 = 41,107.2712 + 9,144.8437 + 7,961.1743 + 7,027.0105
W2 = 65,240.3 N

W3 = Ws-pl + Ws-framing + Wr-pl + Wss
W3 = 76,467.5538 + 10,367.3292 + 15,922.3485 + 12,507.5158
W3 = 115,264.75 N

Uplift Case 1: Design Pressure Only
U = (P * (D^2) * 785) - W1
U = (0.0 * (6.5^2) * 785) - 58,213.2892
U = -58,213.29 (Set to 0 N since it cannot be less than 0)

Tb = U / N
Tb = 0 / 12
Tb = 0 N

Sd = (5 / 12) * Fy
Sd = (5 / 12) * 250
Sd = 104.17 MPa

A-s-r = Tb / Sd
A-s-r = 0 / 104.1667
A-s-r = 0.0 mm^2

P-attachment = 1.5 * Tb
P-attachment = 1.5 * 0
P-attachment = 0.0 N

Sd-shell = (2 / 3) * Fty
Sd-shell = (2 / 3) * 250.0
Sd-shell = 166.67 MPa

Uplift Case 2: Test Pressure Only
U = (Pt * (D^2) * 785) - W3
U = (0.0 * (6.5^2) * 785) - 115,264.7473
U = -115,264.75 (Set to 0 N since it cannot be less than 0)

Tb = U / N
Tb = 0 / 12
Tb = 0 N

Sd = (5 / 9) * Fy-ambient
Sd = (5 / 9) * 250
Sd = 138.89 MPa

A-s-r = Tb / Sd
A-s-r = 0 / 138.8889
A-s-r = 0.0 mm^2

P-attachment = 1.5 * Tb
P-attachment = 1.5 * 0
P-attachment = 0.0 N

Sd-shell = (5 / 6) * Fty
Sd-shell = (5 / 6) * 250.0
Sd-shell = 208.33 MPa

Uplift Case 3: Wind Load Only
U = ((PWR * (D^2) * 785) + ((4 * MWS) / D)) - W2
U = ((0.5172 * (6.5^2) * 785) + ((4 * 56,999.4416) / 6.5)) - 65,240.2998
U = -13,009.73 (Set to 0 N since it cannot be less than 0)

Tb = U / N
Tb = 0 / 12
Tb = 0 N

Sd = 0.8 * Fy
Sd = 0.8 * 250
Sd = 200.0 MPa

A-s-r = Tb / Sd
A-s-r = 0 / 200.0
A-s-r = 0.0 mm^2

P-attachment = 1.5 * Tb
P-attachment = 1.5 * 0
P-attachment = 0.0 N

Sd-shell = (5 / 6) * Fty
Sd-shell = (5 / 6) * 250.0
Sd-shell = 208.33 MPa

Uplift Case 4: Seismic Load Only
U = ((4 * Mrw) / D) - (W2 * (1 - (0.4 * Av)))
U = ((4 * 1,720,272.7023) / 6.5) - (65,240.2998 * (1 - (0.4 * 0.3808)))
U = 1,003,326.46 N

Tb = U / N
Tb = 1,003,326.458 / 12
Tb = 83,610.54 N

Sd = 0.8 * Fy
Sd = 0.8 * 250
Sd = 200.0 MPa

A-s-r = Tb / Sd
A-s-r = 83,610.5382 / 200.0
A-s-r = 418.05 mm^2

P-attachment = 3 * Tb
P-attachment = 3 * 83,610.5382
P-attachment = 250,831.61 N

Sd-shell = (5 / 6) * Fty
Sd-shell = (5 / 6) * 250.0
Sd-shell = 208.33 MPa

Uplift Case 5: Design Pressure + Wind Load
U = ((((Fp * P) + PWR) * (D^2) * 785) + ((4 * MWS) / D)) - W1
U = ((((0.4 * 0.0) + 0.5172) * (6.5^2) * 785) + ((4 * 56,999.4416) / 6.5)) - 58,213.2892
U = -5,982.72 (Set to 0 N since it cannot be less than 0)

Tb = U / N
Tb = 0 / 12
Tb = 0 N

Sd = (5 / 9) * Fy
Sd = (5 / 9) * 250
Sd = 138.89 MPa

A-s-r = Tb / Sd
A-s-r = 0 / 138.8889

A-s-r = 0.0 mm^2

P-attachment = 1.5 * Tb
P-attachment = 1.5 * 0
P-attachment = 0.0 N

Sd-shell = (5 / 6) * Fty
Sd-shell = (5 / 6) * 250.0
Sd-shell = 208.33 MPa

Uplift Case 6: Design Pressure + Seismic Load
U = ((Fp * P * (D^2) * 785) + ((4 * Mrw) / D)) - (W1 * (1 - (0.4 * Av)))
U = ((0.4 * 0.0 * (6.5^2) * 785) + ((4 * 1,720,272.7023) / 6.5)) - (58,213.2892 * (1 - (0.4 * 0.3808)))
U = 1,009,283.11 N

Tb = U / N
Tb = 1,009,283.1143 / 12
Tb = 84,106.93 N

Sd = 0.8 * Fy
Sd = 0.8 * 250
Sd = 200.0 MPa

A-s-r = Tb / Sd
A-s-r = 84,106.9262 / 200.0
A-s-r = 420.53 mm^2

P-attachment = 3 * Tb
P-attachment = 3 * 84,106.9262
P-attachment = 252,320.78 N

Sd-shell = (5 / 6) * Fty
Sd-shell = (5 / 6) * 250.0
Sd-shell = 208.33 MPa

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 (N)	Load per Anchor (N)	Anchor Allowable Stress (MPa)	Anchor Required Area (mm^2)	Anchor Bolt Required Diameter (mm)	Attachment Design Load (N)	Allowable Shell Stress at Anchor Attachment (MPa)
Design Pressure	0	0	104.17	0.0	6.51	0.0	166.67
Test Pressure	0	0	138.89	0.0	6.51	0.0	208.33
Wind Load	0	0	200.0	0.0	6.51	0.0	208.33
Seismic Load	1,003,326.46	83,610.54	200.0	418.05	29.58	250,831.61	208.33
Design Pressure + Wind	0	0	138.89	0.0	6.51	0.0	208.33

Design Pressure + Seismic	1,009,283.11	84,106.93	200.0	420.53	29.65	252,320.78	208.33

- Anchor Bolt Required Diameter = SQRT((A-s-r * (4 / pi))) + (1.22687 * p) + (Ca-anchor * 2)
- Governing Uplift Case = Design Pressure + Seismic
- Anchor Bolt Minimum Required Area = 420.53 mm^2

Bolt Required Diameter per ANSI B1.1

d-req = SQRT((A * (4 / pi))) + (1.22687 * n) + (Ca * 2)
d-req = SQRT((420.5346 * (4 / pi))) + (1.22687 * 2.86) + (1.5 * 2)
d-req = 29.65 mm

d >= d-req ==> PASS

A-s = (pi / 4) * ((d - (1.22687 * n))^2)
A-s = (pi / 4) * ((30 - (1.22687 * 2.86))^2)
A-s = 551.18 mm^2

Y-bolt = A-s * Sy-ambient-anchor
Y-bolt = 551.1776 * 250
Y-bolt = 137,794.4 N

Anchorage Summary

Required Number of Anchors = 7
Actual Number of Anchors = 12
Bolt Hole Circle Radius = 3.34 m
Required Bolt Diameter = 29.65 mm
Actual Bolt Diameter = 30 mm
Bolt Thread Pitch = 2.86 mm

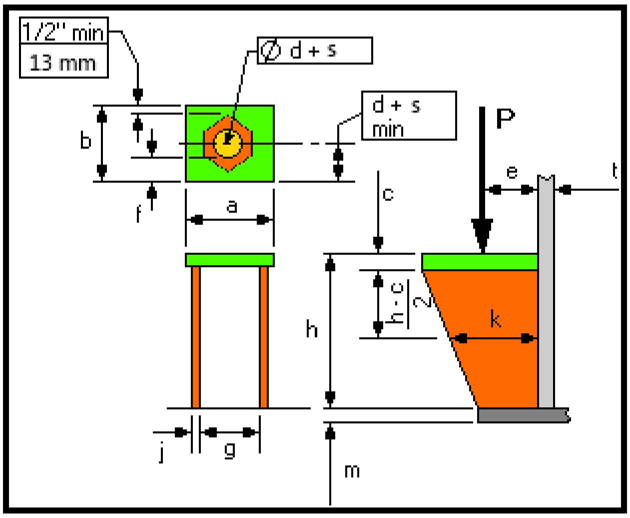
Anchor Chair Design Back

Anchor Chair Design per AISI Steel Plate Engineering Data-Volume 2 Part V

CA = Chair Corrosion Allowance (mm)
D = Tank Nominal Diameter (m)
Earthquakes-Considered = Earthquakes Considered
Et = Bottom Plates Thermal Expansion Coefficient per API-650 Table P.1a (mm/m.cdeg)
Ma-chair = Chair Material
R = Nominal Shell Radius (mm)
Ssw-chair = Chair Allowable Stress for Seismic or Wind Design per API-650 5.12.9 (MPa)
T = Difference Between the Ambient Temperature and the Maximum Design Temperature (°C)
V = Wind Velocity (kph)
Y-bolt = Anchor Bolt Yield Load (N)
a = Top Plate Width Along Shell (mm)
b = Top Plate Length (mm)
bmin = Top Plate Minimum Length (mm)
c = Top Plate Thickness (mm)
c-corr = Top Plate Corroded Thickness (mm)
d = Anchor Bolt Diameter (mm)
e = Anchor Bolt Eccentricity (mm)
emin = Minimum Calculated Eccentricity (mm)
emin-btm = Minimum Eccentricity Based on Bolt Clearance From Bottom Plates per API-650 5.12.4 (mm)
emin-req = Minimum Required Eccentricity (mm)
f = Top Plate Outside To Hole Edge Distance (mm)
fmin = Top Plate Outside to Hole Edge Minimum Distance (mm)
g = Vertical Plates Distance (mm)
gmin = Vertical Plates Minimum Distance (mm)
h = Chair Height (mm)
h-eff = Effective Chair Height (mm)
hmax = Chair Maximum Height (mm)
j = Vertical Plate Thickness (mm)
j-corr = Vertical Plate Corroded Thickness (mm)
jmin = Vertical Plate Minimum Thickness (mm)
k = Vertical Plates Average Width (mm)
m = Base or Bottom Plate Thickness (mm)
outside-projection = Bottom Outside Projection (mm)
t = Shell Thickness (mm)

CA = 1.5 mm
D = 6.5 m
Earthquakes-Considered = ASCE7-MAPPED-SS-AND-S1
Et = 1.2E-5 mm/m.cdeg
Ma-chair = A36
R = 3,250 mm
T = 12 °C
V = 112.32 kph

Y-bolt = 137,794.4 N
a = 180 mm
b = 180 mm
c = 20 mm
d = 30 mm
e = 82 mm
f = 76.0 mm
g = 90 mm
h = 305 mm
j = 14 mm
k = 115.62 mm
m = 10 mm
outside-projection = 50 mm
t = 8 mm



Anchor Chair Material Properties
Material (A36) = A36
Minimum Tensile Strength (Sut-chair) = 400.0 MPa
Minimum Yield Strength (Sy-chair) = 250.0 MPa
As per API-650 A.4.1, Allowable Design Stress (Sd-chair) = 145 MPa
As per API-650 A.4.1, Allowable Hydrostatic Test Stress (St-chair) = 145 MPa

Ssw-chair = 1.33 * Sd-chair
Ssw-chair = 1.33 * 145
Ssw-chair = 192.85 MPa

Size Requirements
c-corr = c - (2 * CA)
c-corr = 20 - (2 * 1.5)
c-corr = 17.0 mm

j-corr = j - (2 * CA)
j-corr = 14 - (2 * 1.5)
j-corr = 11.0 mm

Chair Minimum Height (hmin) = 305 mm

h >= hmin ==> PASS

hmax = 3 * a
hmax = 3 * 180
hmax = 540 mm

h-eff = MIN(hmax , h)
h-eff = MIN(540 , 305)
h-eff = 305 mm

emin = (0.886 * d) + 15
emin = (0.886 * 30) + 15
emin = 41.58 mm

emin-btm = (d / 2) + outside-projection + 3 + (500 * Et * D * T)
emin-btm = (30 / 2) + 50 + 3 + (500 * 1.2E-5 * 6.5 * 12)
emin-btm = 68.47 mm

emin-req = MAX(emin , emin-btm)
emin-req = MAX(41.58 , 68.468)
emin-req = 68.47 mm

e >= emin-req ==> PASS

gmin = d + 26
gmin = 30 + 26
gmin = 56 mm

g >= gmin ==> PASS

fmin = (d / 2) + 4
fmin = (30 / 2) + 4
fmin = 19 mm

f >= fmin ==> PASS

jmin = MAX(13 , (0.04 * (h-eff - c-corr)) , ((P-design / (172.3689 * k)) + (2 * CA)))
jmin = MAX(13 , (0.04 * (305 - 17.0)) , ((137,794.4014 / (172.3689 * 115.6217)) + (2 * 1.5)))
jmin = 13 mm

j >= jmin ==> PASS

bmin = emin + d + 7
bmin = 41.58 + 30 + 7
bmin = 78.58 mm

b >= bmin ==> PASS

Top Plate Minimum Required Thickness

Uplift Cases	P-chair (N)	P-design (N)	Sd-chair (MPa)	c-min (mm)	Status
Design Pressure	0.0	0.0	145	3.0	PASS
Test Pressure	0.0	0.0	145	3.0	PASS
Wind Load	0.0	0.0	192.85	3.0	PASS
Seismic Load	250,831.61	137,794.4	192.85	18.98	PASS

Design Pressure + Wind	0.0	0.0	192.85	3.0	PASS
Design Pressure + Seismic	252,320.78	137,794.4	192.85	18.98	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) = 18.98 mm

Top Plate Stress

Uplift Cases	P-chair (N)	P-design (N)	S-top-plate (MPa)	Sd-chair (MPa)	Stress Ratio	Status
Design Pressure	0.0	0.0	0.0	145	0.0%	PASS
Test Pressure	0.0	0.0	0.0	145	0.0%	PASS
Wind Load	0.0	0.0	0.0	192.85	0.0%	PASS
Seismic Load	250,831.61	137,794.4	170.33	192.85	88.32%	PASS
Design Pressure + Wind	0.0	0.0	0.0	192.85	0.0%	PASS
Design Pressure + Seismic	252,320.78	137,794.4	170.33	192.85	88.32%	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) = 170.33 MPa

Z = Chair Reduction Factor

Shell Stress at Anchor Attachment
Z = 26 / ((((0.177 * a * m) / SQRT((R * t))) * ((m / t)^2)) + 26)
Z = 26 / ((((0.177 * 180 * 10) / SQRT((3,250 * 8))) * ((10 / 8)^2)) + 26)
Z = 0.89

Uplift Cases	P-chair (N)	P-design (N)	S-Shell (MPa)	Sd-shell (MPa)	Stress Ratio	Status
Design Pressure	0.0	0.0	0.0	166.67	0.0%	PASS
Test Pressure	0.0	0.0	0.0	208.33	0.0%	PASS
Wind Load	0.0	0.0	0.0	208.33	0.0%	PASS
Seismic Load	250,831.61	137,794.4	191.2	208.33	91.78%	PASS
Design Pressure + Wind	0.0	0.0	0.0	208.33	0.0%	PASS
Design Pressure + Seismic	252,320.78	137,794.4	191.2	208.33	91.78%	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) = 191.2 MPa
- Governing Allowable Stress (Sd-Shell) = 208.33 MPa

Appuntenances Design Back

Plan View

LABEL	MARK	CUST. MARK	DESCRIPTION	OUTSIDE PROJ (mm)	INSIDE PROJ (mm)	ORIENT	RADIUS (mm)	REMARKS	REF DWG
Circular-Manway-MH2	RM01A		24" ROOF MANWAY	300	0	180 '	0		
Gooseneck-N4 (4")	RV01		4" GOOSENECK ROOF VENT	150	0	0 '	0		
Nozzle-N1 (3")	RN01A		3" ROOF NOZZLE	150	0	70 '	0		
Nozzle-N2 (3")	RN02A		3" ROOF NOZZLE	150	0	105 '	0		
Nozzle-N3 (3")	RN03A		3" ROOF NOZZLE	150	0	270 '	0		
Wingrail-0001	WR01A		WINGRAIL	--	--	211.52 '	3170		

Elevation View

LABEL	MARK	CUST. MARK	DESCRIPTION	OUTSIDE PROJ (mm)	INSIDE PROJ (mm)	ORIENT	ELEVATION (mm)	REMARKS	REF DWG
Anchor-Chair-Bolts	AC01A		ANCHOR CHAIRS	--	--	SEE TABLE	--		
Circular-Clean-Out-N3 (8")	CCD01A		CIRCULAR CLEAN OUT	200	0	145 '	110		
Double-Stringer-Stairway-0001	AS01A		DOUBLE STRINGER STAIRWAY (CW)	--	--	0 '	--		
MH1 (24")	SM01A		24" SHELL MANWAY	300	0	45 '	770	W/ DAVIT	
N5 (4")	SN01A		4" SHELL NOZZLE	175	0	315 '	250		
N6 (8")	SN02A		8" SHELL NOZZLE	200	0	10 '	250		
N7 (2")	SN03A		2" SHELL NOZZLE	150	0	325 '	250		

N8 (6")	SN04A		6" SHELL NOZZLE	200	0	75 '	7090	
N9 (6")	SN05A		6" SHELL NOZZLE	200	0	75 '	80	
Name-Plate	NP01A		STD API	--	--	0 '	1010	

Roof Nozzle: Nozzle-N1 (3")

Repad Design

(Per API-650 and other references below)

NOZZLE Description : 3 in SCH 40 TYPE RFSO
Material: A106-B

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 = 7.7273 m

ROOF PARAMETERS:
t-calc = 5 mm
t_cr = 3 mm (Roof t-act less C.A)
t_c = 6 mm
t_Basis = 5 mm
Repad Type: Circular
Repad Size (Do): 228.6 mm

(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 = 5 * 88.9
Required Area = 444.5 mm^2

Available Roof Area = (t_c - t_Basis) * D
Available Roof Area = (6 - 5) * 88.9
Available Roof Area = 88.9 mm^2

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 * (5.49 - 3)) + 6] * (5.49 - 3) * MIN((124.1/145) 1)
Available Nozzle Neck Area = 67.87 mm^2

A-rpr = (Required Area - Available Roof Area - Available Nozzle Neck Area)
A-rpr = 444.5 - 88.9 - 67.87
A-rpr = 287.73 mm^2

Since Nozzle size <= NPS 6 (per API-650 Table 5-14 Note a), t_rpr = 0

No Reinforcement Pad required.

Roof Nozzle: Nozzle-N2 (3")

Repad Design

(Per API-650 and other references below)

NOZZLE Description : 3 in SCH 40 TYPE RFSO
Material: A106-B

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 = 7.6526 m

ROOF PARAMETERS:
t-calc = 5 mm
t_cr = 3 mm (Roof t-act less C.A)
t_c = 6 mm
t_Basis = 5 mm
Repad Type: Circular
Repad Size (Do): 228.6 mm

(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 = 5 * 88.9
Required Area = 444.5 mm^2

Available Roof Area = (t_c - t_Basis) * D
Available Roof Area = (6 - 5) * 88.9
Available Roof Area = 88.9 mm^2

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 * (5.49 - 3)) + 6] * (5.49 - 3) * MIN((124.1/145) 1)
Available Nozzle Neck Area = 67.87 mm^2

A-rpr = (Required Area - Available Roof Area - Available Nozzle Neck Area)
A-rpr = 444.5 - 88.9 - 67.87
A-rpr = 287.73 mm^2

Since Nozzle size <= NPS 6 (per API-650 Table 5-14 Note a), t_rpr = 0

No Reinforcement Pad required.

Roof Nozzle: Nozzle-N3 (3")

Repad Design

(Per API-650 and other references below)

NOZZLE Description : 3 in SCH 40 TYPE RFSO
Material: A106-B

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 = 7.9274 m

ROOF PARAMETERS:
t-calc = 5 mm
t_cr = 3 mm (Roof t-act less C.A)
t_c = 6 mm
t_Basis = 5 mm
Repad Type: Circular
Repad Size (Do): 228.6 mm

(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 = 5 * 88.9
Required Area = 444.5 mm^2

Available Roof Area = (t_c - t_Basis) * D
Available Roof Area = (6 - 5) * 88.9
Available Roof Area = 88.9 mm^2

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 * (5.49 - 3)) + 6] * (5.49 - 3) * MIN((124.1/145) 1)
Available Nozzle Neck Area = 67.87 mm^2

A-rpr = (Required Area - Available Roof Area - Available Nozzle Neck Area)
A-rpr = 444.5 - 88.9 - 67.87
A-rpr = 287.73 mm^2

Since Nozzle size <= NPS 6 (per API-650 Table 5-14 Note a), t_rpr = 0

No Reinforcement Pad required.

Shell Nozzle: N5 (4")

Repad Design

NOZZLE Description : 4 in SCH 80 TYPE RFSO
Material: A106-B

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 = 0.25 m

COURSE PARAMETERS:
t-calc = 5.01 mm
t_cr = 2.01 mm (Course t-calc less C.A)
t_c = 5 mm (Course t less C.A.)
t_Basis = 2.01 mm
Repad Type: Dog House
Repad Size (Do): 305 mm

(SHELL NOZZLE REF. API-650 TABLE 5.6A, AND FOOTNOTE A OF TABLE 5-7)

Required Area = t_Basis * D
Required Area = 2.01 * 114.3
Required Area = 230.26 mm^2

Available Shell Area = (t_c - t_Basis) * D
Available Shell Area = (5 - 2.01) * 114.3
Available Shell Area = 341.24 mm^2

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 * (8.56 - 3)) + 5] * (8.56 - 3) * MIN((124.1/145) 1)
Available Nozzle Neck Area = 259.26 mm^2

A-rpr = (Required Area - Available Shell Area - Available Nozzle Neck Area)
A-rpr = 230.26 - 341.24 - 259.26
A-rpr = -370.23 mm^2

Since A-rpr <= 0, t_rpr = 0

No Reinforcement Pad required.

Shell Nozzle: N6 (8")

Repad Design

NOZZLE Description : 8 in SCH 80 TYPE RFSO
Material: A106-B

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 = 0.25 m

COURSE PARAMETERS:
t-calc = 5.01 mm
t_cr = 2.01 mm (Course t-calc less C.A)
t_c = 5 mm (Course t less C.A.)
t_Basis = 2.01 mm
Repad Type: Dog House
Repad Size (Do): 485 mm

(SHELL NOZZLE REF. API-650 TABLE 5.6A, AND FOOTNOTE A OF TABLE 5-7)

Required Area = t_Basis * D
Required Area = 2.01 * 219.08
Required Area = 441.34 mm^2

Available Shell Area = (t_c - t_Basis) * D
Available Shell Area = (5 - 2.01) * 219.08
Available Shell Area = 654.04 mm^2

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 * (12.7 - 3)) + 5] * (12.7 - 3) * MIN((124.1/145) 1)
Available Nozzle Neck Area = 727.28 mm^2

A-rpr = (Required Area - Available Shell Area - Available Nozzle Neck Area)
A-rpr = 441.34 - 654.04 - 727.28
A-rpr = -939.98 mm^2

Since A-rpr <= 0, t_rpr = 0

No Reinforcement Pad required.

Shell Nozzle: N7 (2")

Repad Design

NOZZLE Description : 2 in SCH 80 TYPE RFSO
Material: A106-B

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 = 0.25 m

COURSE PARAMETERS:
t-calc = 5.01 mm
t_cr = 2.01 mm (Course t-calc less C.A)
t_c = 5 mm (Course t less C.A.)

t_Basis = 2.01 mm
Repad Type: Circular
Repad Size (Do): 203 mm

(SHELL NOZZLE REF. API-650 TABLE 5.6A, AND FOOTNOTE A OF TABLE 5-7)

Required Area = t_Basis * D
Required Area = 2.01 * 60.32
Required Area = 121.53 mm^2

Available Shell Area = (t_c - t_Basis) * D
Available Shell Area = (5 - 2.01) * 60.32
Available Shell Area = 180.1 mm^2

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 * (5.54 - 3)) + 5] * (5.54 - 3) * MIN((124.1/145) 1)
Available Nozzle Neck Area = 65.92 mm^2

A-rpr = (Required Area - Available Shell Area - Available Nozzle Neck Area)
A-rpr = 121.53 - 180.1 - 65.92
A-rpr = -124.48 mm^2

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

No Reinforcement Pad required.

Shell Nozzle: N8 (6")

Repad Design

NOZZLE Description : 6 in SCH 80 TYPE RFSO
Material: A106-B

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 5 : Elevation = 7.09 m

COURSE PARAMETERS:
t-calc = 3.14 mm
t_cr = 0.14 mm (Course t-calc less C.A)
t_c = 3 mm (Course t less C.A.)
t_Basis = 0.14 mm
Repad Type: Circular
Repad Size (Do): 400 mm

(SHELL NOZZLE REF. API-650 TABLE 5.6A, AND FOOTNOTE A OF TABLE 5-7)

Required Area = t_Basis * D
Required Area = 0.14 * 168.27

Required Area = 23.94 mm^2

Available Shell Area = (t_c - t_Basis) * D
Available Shell Area = (3 - 0.14) * 168.27
Available Shell Area = 480.88 mm^2

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 * (10.97 - 3)) + 3] * (10.97 - 3) * MIN((124.1/145) 1)
Available Nozzle Neck Area = 475.87 mm^2

A-rpr = (Required Area - Available Shell Area - Available Nozzle Neck Area)
A-rpr = 23.94 - 480.88 - 475.87
A-rpr = -932.81 mm^2

Since A-rpr <= 0, t_rpr = 0

No Reinforcement Pad required.

Shell Nozzle: N9 (6")

Repad Design

NOZZLE Description : 6 in SCH 80 TYPE RFSO
Material: A106-B

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 = 0.08 m

COURSE PARAMETERS:
t-calc = 5.01 mm
t_cr = 2.01 mm (Course t-calc less C.A)
t_c = 5 mm (Course t less C.A.)
t_Basis = 2.01 mm
Repad Type: Dog House
Repad Size (Do): 400 mm

(SHELL NOZZLE REF. API-650 TABLE 5.6A, AND FOOTNOTE A OF TABLE 5-7)

Required Area = t_Basis * D
Required Area = 2.01 * 168.27
Required Area = 339 mm^2

Available Shell Area = (t_c - t_Basis) * D
Available Shell Area = (5 - 2.01) * 168.27
Available Shell Area = 502.38 mm^2

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 * (10.97 - 3)) + 5] * (10.97 - 3) * MIN((124.1/145) 1)

Available Nozzle Neck Area = 503.16 mm^2

A-rpr = (Required Area - Available Shell Area - Available Nozzle Neck Area)
A-rpr = 339 - 502.38 - 503.16
A-rpr = -666.53 mm^2

Since A-rpr <= 0, t_rpr = 0

No Reinforcement Pad required.

Shell Manway: MH1 (24")

Repad Design

MANWAY Description : 24 in Neck Thickness 8
Material: A36

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 = 0.77 m

COURSE PARAMETERS:
t-calc = 5.01 mm
t_cr = 2.01 mm (Course t-calc less C.A)
t_c = 5 mm (Course t less C.A.)
t_Basis = 2.01 mm
Repad Type: Circular
Repad Size (Do): 1257.3 mm

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

Required Area = t_Basis * D
Required Area = 2.01 * 625.6
Required Area = 1260.3 mm^2

Available Shell Area = (t_c - t_Basis) * D
Available Shell Area = (5 - 2.01) * 625.6
Available Shell Area = 1867.7 mm^2

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 * (8 - 3)) + 5] * (8 - 3) * MIN((160/145) 1)
Available Manway Neck Area = 250 mm^2

A-rpr = (Required Area - Available Shell Area - Available Manway Neck Area)
A-rpr = 1260.3 - 1867.7 - 250
A-rpr = -857.39 mm^2

Since A_rpr <= 0, t_rpr = 0

No Reinforcement Pad required.

Manway Neck Material Properties
Material (A36) = A36
As per API-650 A.4.1, Allowable Design Stress (Sd-neck) = 145 MPa
Permissible Design Metal Temperature (MDMT-permissible-neck) = -30 °C

Manway Repad Material Properties
Material (A36) = A36
Permissible Design Metal Temperature (MDMT-permissible-repad) = -30 °C

Cover Plate and Bolting Flange Design

CA-cover = Cover Plate and Bolting Flange Corrosion Allowance (mm)
Db = Bolt Circle Diameter (mm)
H = Design Liquid Level (m)
Ma-cover = Cover Plate Material
Ma-flange = Bolting Flange Material
SG = Product Specific Gravity
Sd = Allowable Stress per API-650 5.7.5.6 (MPa)
tc = Cover Plate Thickness (mm)
tc-design = Cover Plate Required Thickness per API-650 5.7.5.6 (mm)
tc-req = Cover Plate Minimum Required Thickness (mm)
tf = Bolting Flange Thickness (mm)
tf-design = Cover Plate Required Thickness per API-650 5.7.5.6 (mm)
tf-req = Bolting Flange Minimum Required Thickness (mm)

CA-cover = 3 mm
Db = 768.35 mm
H = 6.72 m
Ma-cover = A36
Ma-flange = A36
SG = 1
tc = 19 mm
tf = 16 mm

Water Density (Y) = 0.00981 MPa/m
As per API-650 5.7.5.6, Coefficient For Circular Plate (C) = 0.3

Cover Plate Material Properties and Required Thickness
Material (A36) = A36
Minimum Yield Strength (Sy-cover) = 250.0 MPa
Plate is impact tested

Sd = MIN(Sy-cover , 205) / 2 = 102.5 MPa

As per API-650 5.7.5.6, Cover Plate Erection Thickness (tc-erec) = 8 mm

tc-design = (Db * SQRT(((C * Y * H * MAX(SG , 1)) / Sd))) + CA-cover
tc-design = (768.35 * SQRT(((0.3 * 0.0098 * 6.72 * MAX(1 , 1)) / 102.5))) + 3
tc-design = 13.67 mm

tc-req = MAX(tc-erec , tc-design)
tc-req = MAX(8 , 13.6728)
tc-req = 13.67 mm

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

Bolting Flange Material Properties and Required Thickness
Material (A36) = A36

Minimum Yield Strength (Sy-flange) = 250.0 MPa
Permissible Design Metal Temperature (MDMT-permissible-flange) = -2.75 °C

As per API-650 5.7.5.6, Bolting Flange Erection Thickness (tf-erec) = 6 mm

tf-design = tc-design - 3
tf-design = 13.6728 - 3
tf-design = 10.67 mm

tf-req = MAX(tf-erec , tf-design)
tf-req = MAX(6 , 10.6728)
tf-req = 10.67 mm

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

Roof Manway: Circular-Manway-MH2

Repad Design

(Per API-650 Section 5.8.4 and other references below)
MANWAY Description : 24 in Neck Thickness 8
Material: A36

t_rpr = (Repad Required Thickness)
MOUNTED ON ROOF: Elevation = 7.7607 m

ROOF PARAMETERS:
t-calc = 5 mm
t_cr = 3 mm (Roof t-act less C.A)
t_c = 6 mm
t_Basis = 5 mm
Repad Type: Circular
Repad Size (Do): 1375 mm

(FOR ROOF MANWAY,REF. API-650 FIG 5-16, TABLE 5-13)

Required Area = t_Basis * D
Required Area = 5 * 625.6
Required Area = 3128 mm^2

Available Roof Area = (t_c - t_Basis) * D
Available Roof Area = (6 - 5) * 625.6
Available Roof Area = 625.6 mm^2

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 * (8 - 3)) + 6] * (8 - 3) * MIN((160/145) 1)
Available Manway Neck Area = 260 mm^2

A-rpr = (Required Area - Available Roof Area - Available Manway Neck Area)
A-rpr = 3128 - 625.6 - 260
A-rpr = 2242.4 mm^2

t_rpr = (A_rpr / (repad-min-OD - D)) + repad_CA

$t\_rpr = (2242.4 / (1{,}375 - 625.6)) + 3$
$t\_rpr = 5.99$ mm

Reinforcement Pad is required.
Based on Roof Manway Size of 24"
Repad Size (OD) Must be 1150 mm

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

Normal Venting

T = Product storage temperature (°C)
VIT = Required in-breathing flow rate due to thermal effects per API-2000 3.3.2.3.3 (m^3/hr)
VOT = Required out-breathing flow rate due to thermal effects per API-2000 3.3.2.3.2 (m^3/hr)
Vi = Total required in-breathing volumetric flow rate (m^3/hr)
Vip = Required in-breathing flow rate due to liquid movement per API-2000 3.3.2.2.2 (m^3/hr)
Vo = Total required out-breathing volumetric flow rate (m^3/hr)
Vop = Required out-breathing flow rate due to liquid movement per API-2000 3.3.2.2.1 (m^3/hr)
Vpe = Maximum emptying rate (m^3/hr)
Vpf = Maximum filling rate (m^3/hr)
Vtk = Tank capacity (m^3)
insulation_type = Insulation type
latitude = Latitude zone
vapor_pressure_type = Vapor pressure type

T = 32 °C
Vpe = 22.71 m^3/hr
Vpf = 22.71 m^3/hr
Vtk = 255.1 m^3
insulation_type = NO-INSULATION
latitude = BETWEEN-42-AND-58
vapor_pressure_type = HEXANE-OR-SIMILAR

In-breathing
Vip = Vpe
Vip = 22.7125
Vip = 22.71 m^3/hr

As per API-2000 Table-2, C factor (C) = 5

VIT = C * (Vtk^0.7) * 1
VIT = 5 * (255.0997^0.7) * 1
VIT = 241.92 m^3/hr

Vi = Vip + VIT
Vi = 22.7125 + 241.9173
Vi = 264.63 m^3/hr

Out-breathing
Vop = Vpf
Vop = 22.7125
Vop = 22.71 m^3/hr

As per API-2000 Table-1, Y factor (Y) = 0.25

VOT = Y * (Vtk^0.9) * 1
VOT = 0.25 * (255.0997^0.9) * 1
VOT = 36.64 m^3/hr

Vo = Vop + VOT
Vo = 22.7125 + 36.642
Vo = 59.35 m^3/hr

Emergency Venting

ATWS = Wetted surface area (m^2)
D = Tank diameter (m)
F = Environmental factor per API-2000 3.3.3.3.4
H = Tank height (m)
Pg = Design pressure (kPa)
insulation_type = Insulation type
q = Required emergency venting capacity per API-2000 Table 5 and 3.3.3.3.4 (m^3/hr)
vapor_pressure_type = Vapor pressure type

D = 6.5 m
H = 7.5 m
Pg = 0.0 kPa
insulation_type = NO-INSULATION
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 , 9.14)
ATWS = pi * 6.5 * MIN(7.5 , 9.14)
ATWS = 153.15 m^2

q = 16643.48 * F
q = 16643.48 * 1.0
q = 16,643.48 m^3/hr

Capacities and Weights Back

Capacity to Top of Shell (to Tank Height) : 248 M^3
Capacity to Design Liquid Level : 222 M^3
Capacity to Maximum Liquid Level : 222 M^3
Working Capacity (to Normal Working Level) : 0 M^3
Net working Capacity (Working Capacity - Min Capacity) : 0 M^3
Minimum Capacity (to Min Liq Level) : 0 M^3

Component	New Condition (N)	New Condition (Kg)	Corroded (N)	Corroded (Kg)
SHELL	76,468	7,798	41,108	4,192
ROOF	15,923	1,624	7,962	812
RAFTERS	11,184	1,141	7,028	717
GIRDERS	0	0	0	0
FRAMING	0	0	0	0
COLUMNS	0	0	0	0
TRUSS	0	0	0	0
STRUCTURE COMPONENTS	1,106	113	1,106	113
BOTTOM	26,432	2,696	18,502	1,887
STAIRWAYS	12,798	1,305	12,798	1,305
STIFFENERS	10,340	1,055	6,251	638
WIND GIRDERS	0	0	0	0
ANCHOR CHAIRS	2,060	210	2,060	210
APPURTENANCES	5,063	517	5,063	517
INSULATION	0	0	0	0
FLOATING ROOF	0	0	0	0
TOTAL	161,374	16,459	101,878	10,391

Weight of Tank, Empty : 16,459 Kg
Weight of Tank, Full of Product (Design SG = 1) : 239,449 Kg
Weight of Tank, Full of Water : 245,024 Kg
Net Working Weight, Full of Product (Design SG = 1) : 239,449.24 Kg
Net Working Weight Full of Water : 245,024 Kg

Foundation Area Req'd : 34.37 m^2
Foundation Loading, Empty : 4,694.1 N/m^2
Foundation Loading, Full of Product Design : 68,304.07 N/m^2
Foundation Loading, Full of Water : 69,894.39 N/m^2

SURFACE AREAS
Roof : 34.51 m^2
Shell : 153.15 m^2
Bottom : 34.37 m^2

Internal Pressure Moment : 0 N-m
Wind Moment : 114,229.15 N-m
Seismic Moment (Ringwall) : 1,720,272.7 N-m
Seismic Moment (Slab) : 2,231,817.76 N-m

MISCELLANEOUS ATTACHED ROOF ITEMS
MISCELLANEOUS ATTACHED SHELL ITEMS

Reactions on Foundation Back

Arss = Area of Tank Roof Supported by the Tank Shell (m^2)
Wrss = Weight of Tank Roof Supported by the Tank Shell (kg)
Ws = Weight of the Tank Shell and Shell Appurtenances (kg)
Wss = Roof Structure Weight Supported by The Tank Shell (kg)
yb = Bottom Plate Density (kg/m^3)
yw = Water Density (kg/m^3)

Arss = 34.52 m^2
Wss = 1,275.41 kg
yb = 7,840 kg/m^3
yw = 1,000 kg/m^3

Wrss = (Wr-pl + Wr-ins + Wr-attachments) + Wss
Wrss = (1,623.6277 + 0.0 + 183.9005) + 1,275.4117
Wrss = 3,082.94 kg

Ws = Ws-pl + Ws-ins + Ws-attachments + Ws-framing
Ws = 7,797.5204 + 0.0 + 2,240.2091 + 1,057.1734
Ws = 11,094.9 kg

Unfactored (Working Stress) Downward Reactions on Foundations

Load Case	Location	Equation	Value	Unit
Dead Load	Shell	(Ws + Wrss) / (pi * D)	6,808.75	N/m
Dead Load	Bottom	tb * yb * 9.806649999999999E-6	0.77	kPa
Internal Pressure	Bottom	P	0.0	kPa
Vacuum	Shell	(Pv * Arss) / (pi * D)	0.0	N/m
Hydrostatic Test	Bottom	Lmax * yw * (9.80665 / 1000)	65.9	kPa
Minimum Roof Live Load	Shell	(Lr * Arss) / (pi * D)	1,977.62	N/m
Seismic	Shell	((4 * (Mrw / D)) + (0.4 * (Ws + Wrss) * Av)) / (pi * D)	52,878.98	N/m
Seismic	Bottom	(32 * Ms) / (pi * (D^3) * 1000)	82.78	kPa
Snow	Shell	(S * Arss) / (pi * D)	0.0	N/m
Stored Liquid	Bottom	SG * Lmax * yw * (9.80665 / 1000)	65.9	kPa
Pressure Test	Bottom	Pt	0.0	kPa
Wind	Shell	(2 * (Hs^2) * PWS) / (pi * D)	1,713.51	N/m
• Seismic bottom reaction varies linearly from 32*Ms/(PI*D^3) at the tank shell to zero at the center of the tank				