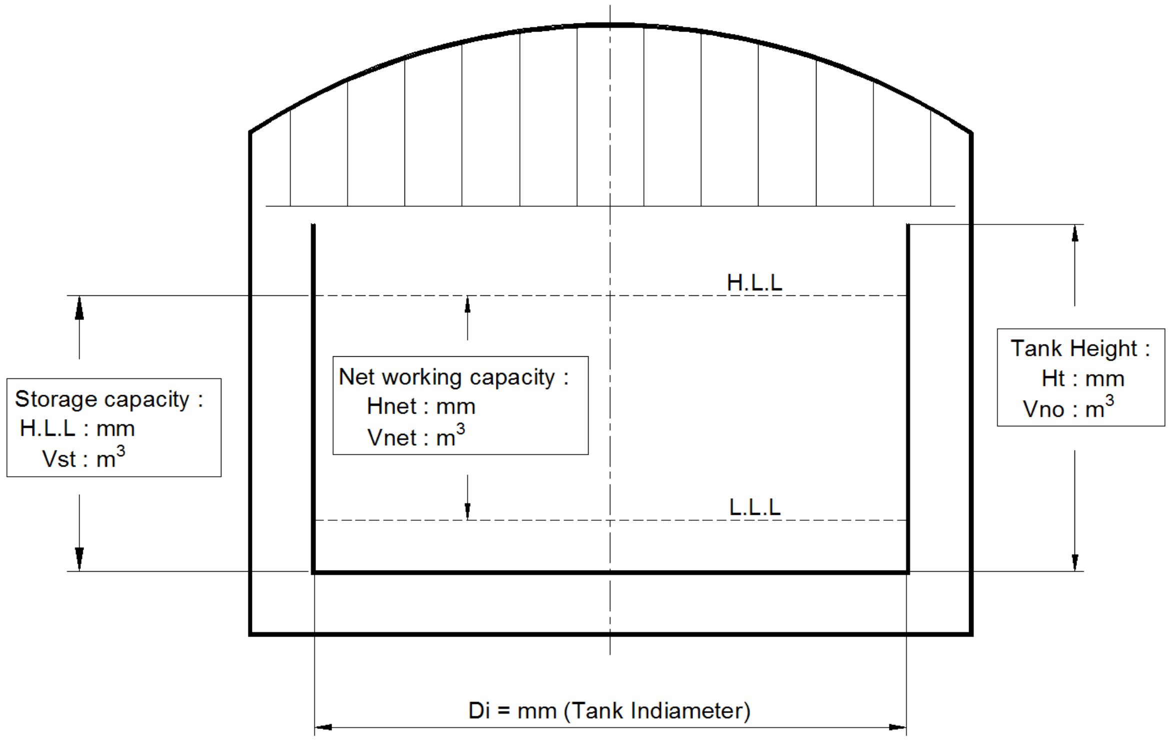
LIST OF CONTENTS

1. Tank Design Data

Description		Inner Tank		Outer tank	
Design Code		API 620, 11th ed. Add. 2 (2010), Appendix R			
Content		AMMONIA			
Content Specific Gravity		0.684			
Nominal capacity		16796 m^3	105645 BARREL		
Net working capacity		14641 m^3	92092 BARREL		
Storage capacity		15776 m^3	99225 BARREL		
Type of Roof		Suspended Deck		Dome roof	
Tank inside diameter		38000 mm	124.672 ft	40000 mm	131.234 ft
Tank Height		14810 mm	48.589 ft	16610 mm	54.495 ft
Design Liquid Level		13910 mm	45.636 ft	12600 mm	41.339 ft
High Liquid Level		13910 mm	45.636 ft		
Low Liquid Level		1000 mm	3.281 ft		
Design Temperature		-40 ℃	-40.0 °F	60 ℃	140 °F
Operating Temperature		-35 ℃	-31.0 °F	-35 ℃	-31 °F
Minimum Design Metal Temperature		-40 ℃	-40.0 °F	-40 ℃	-40 °F
Design pressure (Internal)		0 MPa	0 mbar.g	0.015 MPa	150 mbar.g
Design pressure (External)		0 MPa	0 mbar.g	0.0006 MPa	6 mbar.g
Operating pressure		0 MPa	0 mbar.g	0.005 MPa	50 mbar.g
Hydrostatic Test Level		13910 mm	45.636 ft	- mm	- ft
Pneumatic Test pressure		0 Pa	0 mbar.g	0.01875 MPa	187.5 mbar.g
Joint Efficiency		1.0		1.0	
Insulation		Yes (Cold)			
Max. Boil - off Rate		0.05 wt% per day			
Design Wind Speed(3-sec.gust)		ASCE7-10, Occupancy Category=III, Wind Speed=140 km/h (87.0 mi/h)			
Seismic		ASCE7-10, Risk Category=III			
Snow Load (Roof)		-		1.471 kpa	30.7 lb/ft^2
Material		**Inner Tank**		**Outer tank**	
Shell Plate		SA537-CL1+S5		SA537-CL1+S5	
Annular Plate		SA537-CL1+S5		SA537-CL1+S5	
Bottom Plate		SA516-60N+S5		SA516-60N+S5	
Roof	Type	Suspended Deck		Dome roof	
	Plate	SA516-60N+S5		SA516-70	
	Structure	A36		A36	
Wind Stiffener		-		SA537-CL1+S5	
Compression Ring		-		SA537-CL1+S5	
Corrosion Allowance		**Inner Tank**		**Outer tank**	
Shell Plate		3.0 mm	0.118 in	3.0 mm	0.118 in
Annular Plate		3.0 mm	0.118 in	3.0 mm	0.118 in
Bottom Plate		3.0 mm	0.118 in	3.0 mm	0.118 in
Suspended Deck		1.5 mm	0.059 in	0.0 mm	0.000 in
Roof	Plate	0.0 mm	0.000 in	3.0 mm	0.118 in
	Structure	0.0 mm	0.000 in	1.5 mm	0.059 in

2. TANK CAPACITY

2.1) SKETCH DRAWING



A. Design specification

Tank inside diameter (Inner tank)	Di	=	38000	mm	124.672	ft
Height from bottom to top	Ht	=	14810	mm	48.589	ft
High liquid level	H.L.L	=	13910	mm	45.636	ft
Low liquid level	L.L.L	=	1000	mm	3.281	ft
High liquid level from low liquid level	Hnet	=	12910	mm	42.356	ft

B. Nominal capacity

$Vno = \pi * Di^2 / 4 * Ht$ Vno = 16796 m^3 105645 BARREL

C. Net working capacity

$Vnet = \pi * Di^2 / 4 * (H.L.L - L.L.L)$ Vnet = 14641 m^3 92092 BARREL

D. Storage capacity

$Vst = \pi * Di^2 / 4 * H.L.L$ Vst = 15776 m^3 99225 BARREL

3. Inner Shell plate of calculation

3.1) Shell plate thickness at design condition (Material : SA537-CL1+S5)

Diameter of tank inside	D	=	**38000**	mm	38.000	m	1496.1	in
Height of tank	Ht	=	**14810**	mm	14.810	m	583.07	in
Design liquid level for shell th'k. calc.	D.L.L	=	**13910**	mm	13.910	m	45.64	ft
High liquid level	H.L.L	=	**13910**	mm	13.910	m	45.64	ft
Corrosion allowance	C.A	=	**3.0**	mm			0.118	in
Design specific gravity	G	=	**0.684**		684	kg/m^3	42.82	lb/ft^3
Tank radius	Rc = D/2	=	**19000**	mm	19.000	m	748.031	in
Cross-sectional area of the tank	At	=	**1134.1**	m^2			1757882	in^2
The total weight of that portion of the tank and its contents				W	=	See Below 3.1.1 Table		
Summation of the vertical components of the forces				F	=		0	lb
Joint efficiency of Shell Weld	E	=	**1.0**					
Tensile strength	Fu	=	482.633	Mpa			70000	psi
Yield strength	Fy	=	344.738	Mpa			50000	psi
Maximum allowable stress for simple tension of design liquid								
Sts_d = Min(Fu*0.3, Fy*0.6)	Sts_d	=	144.790	Mpa			21000	psi
Design internal pressure	Pg	=	0.00	mbar			0.000	psi
Liquid head pressure	P_L	=	See Below 3.1.1 Table(a)					
Total pressure	P	=	**Pg + P_L**					

3.1.1) Shell calculation

Shell Course No.	Width of Used Plate	Design Liquid Level (D.L.L)	P_L	P= Pg+P_L	W = contents weight	T1	T2	td		**Used th'k (tu)**	Weight
	mm	mm	psi	psi	lb	lb/in	lb/in	in	mm	**mm**	kg
6	2460	1560	1.518	1.518	0	567.6	1135.3	0.172	4.373	**10.0**	23060
5	2470	4030	3.921	3.921	-50839	1455.6	2932.8	0.258	6.547	**10.0**	23153
4	2470	6500	6.324	6.324	-101882	2343.5	4730.3	0.343	8.721	**11.0**	25469
3	2470	8970	8.727	8.727	-158032	3230.3	6527.9	0.429	10.896	**14.0**	32418
2	2470	11440	11.130	11.130	-229501	4113.9	8325.4	0.515	13.070	**16.0**	37051
1	2470	13910	13.533	13.533	-311185	4995.3	10122.9	0.600	15.244	**18.0**	41685
	14810 mm										182836

For cylindrical sidewalls of a vertical tank : as per API 620 5.10.2.5 c) Eqn. (10)(11),

$$T1 = \frac{Rc}{2}\left(P + \frac{W+F}{At}\right),\ T2 = P * Rc$$

T1 = Meridional (Longitudinal) unit force. (lb/in)

T2 = Latitudinal (Circumferential) unit force. (lb/in)

Required shell thickness calculation : as per API 620 5.10.3.2 Eqn. (16),

$$td = \frac{Max\ (T1, T2)}{Sts\_d * E} + C.A$$

td = Design thickness of shell. (mm)

tu = Used (Selected) thickness of shell. (mm)

3.2) Shell plate thickness at hydrostatic test condition (Material : SA537-CL1+S5)

Diameter of tank inside		D	=	**38000** mm	38.000	m	1496.1	in
Height of tank		Ht	=	**14810** mm	14.810	m	583.07	in
Hydro test level		H.T.L	=	**13910** mm	13.910	m	45.64	ft
Hydro specific gravity		SG	=	**1.000**	1000	kg/m^3	62.61	lb/ft^3
Tank radius		Rc = D/2	=	**19000** mm	19.000	m	748.031	in
Cross-sectional area of the tank		At	=	**1134.1** m^2			1757882	in^2
The total weight of that portion of the tank and its contents					W =	See Below 3.2.1 Table		
Summation of the vertical components of the forces					F =		0	lb
Tensile strength	(API 620 Table 5-1)	Fu	=	482.633 Mpa			70000	psi
Yield strength	(API 620 Table 5-1)	Fy	=	344.738 Mpa			50000	psi
Maximum allowable stress for tension (API 620 Table 5-1)								
Sts_d = Min(Fu*0.3, Fy*0.6)		Sts_d	=	144.790 Mpa			21000	psi
Maximum allowable stress for tension of hydro test				(API 620 R.6.1)				
Sts_t = Min(Fu*0.55, Fy*0.85)		Sts_t	=	265.448 Mpa			38500	psi
Pneumatic test pressure		Pt=Pg*1.25	=	0 mmAq	0.000	mbar	0.000	psi
Test Water (Liquid) head pressure		P_W	=	See Below 3.2.1 Table				
Total pressure		P	=	$Pt+P_W$ (As per design data sheet)				

3.2.1) Shell calculation

Shell Course No.	Width of Used Plate	Hydrostatic test Level (H.T.L)	P_W	P= $Pt+P_W$	W = contents weight	T1	T2	tt		**Used th'k (tu)**	Weight
	mm	mm	psi	psi	lb	lb/in	lb/in	in	mm	**mm**	kg
6	2460	1560	2.219	2.219	0	829.9	1659.8	0.043	1.095	**10.0**	23060
5	2470	4030	5.732	5.732	-50839	2133.1	4287.7	0.111	2.829	**10.0**	23153
4	2470	6500	9.245	9.245	-101882	3436.2	6915.7	0.180	4.563	**11.0**	25469
3	2470	8970	12.758	12.758	-158032	4738.2	9543.7	0.248	6.296	**14.0**	32418
2	2470	11440	16.272	16.272	-229501	6037.0	12171.6	0.316	8.030	**16.0**	37051
1	2470	13910	19.785	19.785	-311185	7333.6	14799.6	0.384	9.764	**18.0**	41685
	14810 mm										182836

For cylindrical sidewalls of a vertical tank : as per API 620 5.10.2.5 c) Eqn. (10)(11),

$$T1 = \frac{Rc}{2}\left(P + \frac{W+F}{At}\right),\ T2 = P * Rc$$

T1 = Meridional (Longitudinal) unit force. (lb/in)

T2 = Latitudinal (Circumferential) unit force. (lb/in)

Required shell thickness calculation : as per API 620 5.10.3.2 Eqn. (16),

$$tt = \frac{Max\,(T1,\ T2)}{Sts\_t}$$

tt = Hydrostatic test thickness (mm)

tu = Used (Selected) thickness of shell. (mm)

3.3) Summary of shell plate thickness

Shell Course No.	Width of Used Plate	Total Liquid height	Total hydro test height	At design (td)		At hydro test (tt)		Calc. thickness Max(td, tt)		**Used th'k (tu)**	Design or test condition
	mm	mm	mm	in	mm	in	mm	in	mm	**mm**	
6	2460	1560	1560	0.172	4.373	0.043	1.095	0.172	4.373	**10.0**	Design
5	2470	4030	4030	0.258	6.547	0.111	2.829	0.258	6.547	**10.0**	Design
4	2470	6500	6500	0.343	8.721	0.180	4.563	0.343	8.721	**11.0**	Design
3	2470	8970	8970	0.429	10.896	0.248	6.296	0.429	10.896	**14.0**	Design
2	2470	11440	11440	0.515	13.070	0.316	8.030	0.515	13.070	**16.0**	Design
1	2470	13910	13910	0.600	15.244	0.384	9.764	0.600	15.244	**18.0**	Design
	14810	mm									

3.4) Max. membrane stress check of shell plate for operating condition

1) Calculation formula

Maximum membrane stress for T2 (For vertical weld joint) : Sms1

$$Sms1 = \frac{T2}{tused - C.A * E}$$

Where,

T2	=	Latitudional unit force in wall of tank at the level under consideration (lb/in)			
C.A	=	Corrosion allowance	=	3.0 mm	0.118 in
E	=	Joint efficiency of shell weld	=	1.0	
tsued	=	Used shell plate thickness			

2) Calculation result (Inner shell at design condition)

Shell Course No.	Material	Used th'k (tu)		Vertical weld joint			
				T2	Sms1	Decision for Sms1	
		in	mm	lb/in	psi	psi	
6	SA537-CL1+S5	0.39	10.0	1135.28	4119.45	<	7000
5	SA537-CL1+S5	0.39	10.0	2932.81	10641.92	>	7000
4	SA537-CL1+S5	0.43	11.0	4730.34	15018.84	>	7000
3	SA537-CL1+S5	0.55	14.0	6527.87	15073.45	>	7000
2	SA537-CL1+S5	0.63	16.0	8325.40	16266.56	>	7000
1	SA537-CL1+S5	0.71	18.0	10122.93	17141.50	>	7000

Where,

Decision vaule of Sms1 : 0.1 times of specified minimum tensile strength

(by API 620 App. R.5.6.1 & R.5.6.2 & Figure R-2)

SA537-CL1+S5 70000 * 0.1 = 7000 psi

3) Decision of radiographic examination

(A) For vertical weld joint of 1st~5th course, Sms1 tensile stress is greater than specified minimum tensile strength of the plate material.

(B) For vertical weld joint of 6th course, Sms1 tensile stress is less than specified minimum tensile strength of the plate material.

Therefore, shell plate to be examined by radiographic examination according to API 620 Appendix R. Figure R-2 lower sketch.

4. Bottom plate and Annular plate of calculation

4.1)Bottom plate (API 620 SEC. 5.9.4.2)

1) Material of bottom plate		=	SA516-60N+S5				
Bottom plate corrosion allowance	C.A	=	0.118	inch	3.0	mm
Min. thickness: (API 620 SEC. 5.9.4.2 [1/4"])	tbm	=	0.250	inch	6.35	mm
2) Required bottom plate thickness	tbm + C.A	=	0.368	inch	9.350	mm
Used thickness of bottom plate	tb_used	=	$\boxed{0.394}$	inch	$\boxed{\mathbf{10.000}}$	mm

4.2) Annular plate (API 620 Table R-6)

1) Design condition

Annular plate material	MATERIAL	=	SA516-60N+S5			
Design specific gravity of liquid content	Gp	=	0.684			
Gravity of hydrostatic test	Gt	=	1.000			
Diameter of tank inside D= 38000 (mm)	D	=	124.7	ft	38.000	m
Nominal thickness for 1st shell course	t	=	0.709	inch	18.000	mm
Design required thickness for 1st shell course	td	=	0.600	inch	15.244	mm
Hydro-test required thickness for 1st shell course	tt	=	0.384	inch	9.764	mm
Design liquid level	Hd	=	45.64	ft	13.910	m

2) Maximum product stress

$$Sd = \frac{2.6 * D * Hd * Gp}{t}$$

Sd = 14278.13 psi = 98 Mpa

* Butt-welded annular bottom plates shall be used.

3) Annular plate thickness

Minimum annular plate thickness (0.25in)+C.A	tb_min	=	0.368	inch	9.35	mm
Used thickness of annular plate	tb	=	$\boxed{0.394}$	inch	$\boxed{\mathbf{10.00}}$	mm

- API 620 [TABLE R-6 Thickness Requirements[a] for the Annular Bottom plate] (tb : in)

Nominal Thickness of First Shell Course (in)	Design Stress[b] in First Shell Course (lbf/in.^{2})			
	≤ 20,000	22,000	24,000	26,000
≤ 0.75	1/4	1/4	1/4	1/4
> 0.75 to 1.00	1/4	1/4	1/4	5/16
> 1.00 to 1.25	1/4	1/4	5/16	3/8
> 1.25 to 1.50	1/4	9/32	3/8	7/16

4) Width of annular plate (API 620 R.3.5.1 and API 650 Appendix E.6.2.1.1.2)

Used annular plate thickness	tb	=	0.394	inch	10.00	mm
Design liquid level plus internal pressure head	H = Hd	=	45.636	ft	13.91	m
Design specific gravity of liquid	G	=	0.684			

4-1) Min. annular plate width(w)

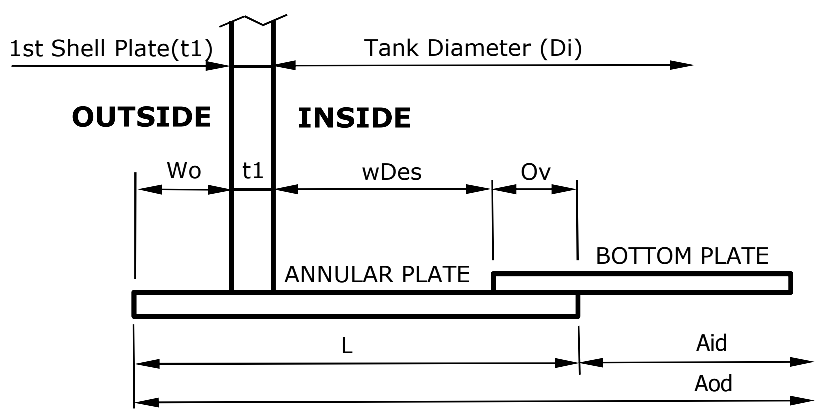
$$w = \frac{390 * tb}{(H * G)^{0.5}}$$

	w	=	27.5	inch	698.04	mm

(width between the inside of the shell and any lap welded joint in the reminder of the bottom)

4-2) Min. required annular plate width due to seismic	wSei	=	33.91	inch	861.3	mm
Min. radial width due to seismic (API 650 Appendix E.6.2.1.1.2-1a)			(Refer to Calculation 8.2.7)			
4-3) Annular plate width : wDes = Max. (w, wSei)		=	33.91	inch	861.3	mm
4-4) Min. annular plate width	Lmin = (Wo+t1+wDes+Ov)	=	39.70	inch	1008.3	mm
4-5) Used annular plate width	**L**	**=**	**39.76**	**inch**	**1010.0**	**mm**

5) Dimensions for annular plate (unit: mm)



* Tank inside diameter	Di	=	124.67	ft	38000	mm
* Length of annular outer dia. to shell outer diameter	Wo	=	2.52	inch	64.0	mm
* 1st shell course thickness (Uncorroded)	t1	=	0.71	inch	18.0	mm
* Annular plate inside diameter	Aid	=	118.58	ft	36144	mm
* Annular plate outside diameter	Aod	=	125.21	ft	38164	mm
* Overlap of annular plate and bottom plate	Ov	=	0.21	ft	65	mm

5. Inner tank shell stiffener calculation

Refer to Guide to STORAGE TANK & EQUIPMENT, Bob Long

The David Taylor model basin Formula is used to decide upon the pitching of the stiffeners on the tank shell. This is taken from the work of Windenburg and Trilling (Reference 18.4), some of which is based on test work carried out on behalf of the US Navy as far back as 1929.

5-1) The maximum height of unstiffened side wall (L_s) (equ. 18. 10)

$$L_s = D * \sqrt{\frac{t}{D}} \left[0.45 + \frac{2.42 * E \left(\frac{t}{D} \right)^2}{F * p \left(1 - \mu^2\right)^{0.75}} \right] = 365.28 \text{ in} \qquad 9278 \text{ mm}$$

Where,

p	=	External pressure or Insulation pressure from annular space (Min. value of STE's standard)	=	0.0725	psi	0.0005	Mpa
D	=	Inner tank diameter	=	1496.1	in	38000	mm
F	=	Factor of safety	=	2			
E	=	Modules of elasticity	=	2.886E+07	psi	199000	Mpa
t	=	thickness of the thinnest (top) shell course	=	0.3	in	7.0	mm
μ	=	Poisson's ratio	=	0.3			

No	Shell Thick.	Width of Used Plate	Corrosion Allowance	t_uniform	t_actual	Transposed Width
	tn(mm)	w(mm)	C.A(mm)	tu(mm)	ta(mm)	Wtr(mm)
6	10.0	2460	3.0	7.0	7.0	2460.0
5	10.0	2470	3.0	7.0	7.0	2470.0
4	11.0	2470	3.0	7.0	8.0	1769.0
3	14.0	2470	3.0	7.0	11.0	797.9
2	16.0	2470	3.0	7.0	13.0	525.5
1	18.0	2470	3.0	7.0	15.0	367.5
					Wtr =	8389.9 mm

5-2) The number of stiffeners required to stabilise the shell is given by : (equ. 18. 11)

$$N_{stiff.} = \frac{Wtr}{L_s} - 1$$

$$= \frac{8389.9}{9278} - 1 = -0.10 = \boxed{0 \text{ EA}}$$

6. Top girder calculation

Refer to Guide to STORAGE TANK & EQUIPMENT, Bob Long

The David Taylor model basin Formula is used to decide upon the pitching of the stiffeners on the tank shell. This is taken from the work of Windenburg and Trilling (Reference 18.4), some of which is based on test work carried out on behalf of the US Navy as far back as 1929.

6.1) Required moment of inertia (equ. 18. 13)

$$Iregd = \frac{F * p * La * D^3}{8 * E (N^2 - 1)} = 12.14 \ in^4 \qquad 5051728 \ mm^4$$

6.2) Calculate the number of buckling waves (min. N=2, Max.=10) (equ. 18. 12)

$$N^2 = \frac{0.663}{\frac{H}{D} \left(\frac{T_{av}}{D} \right)^{0.5}} = 104 \quad \leq \quad 100 \qquad N = \quad 10$$

Where,

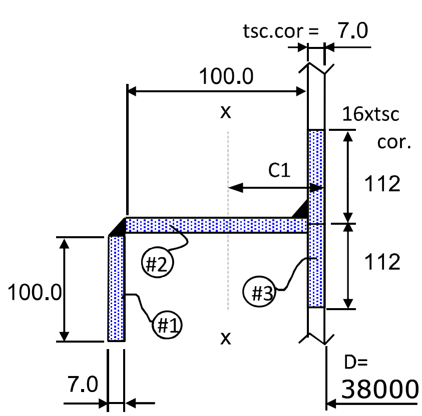
p	=	External pressure or Insulation pressure from annular space	=	0.0725	psi	0.0005	Mpa
		(Min. value of STE's standard)					
D	=	Inner tank diameter	=	1496.1	in	38000	mm
H	=	Inner tank height	=	583.1	in	14810	mm
L_a	=	Inner Stiffener height	=	571.3	in	14510	mm
F	=	Factor of safety	=	2.0			
E	=	Modules of elasticity	=	2.886E+07	psi	199000	Mpa
T_{av}	=	Average thickness of inner shell plate	=	0.4	in	10.2	mm

6.3) Calculated moment of inertia and cross sectional area

Available section modulus for top girder

Girder material and size (Material : SA537-CL1) L 100.0 * 100.0 * 10.0

Web plate length (#2)				=	100.0	mm
Toe plate length (#1)				=	100.0	mm
Web plate corroded thk, (#2)	10.0	-	3.0	=	7.0	mm
Toe plate corroded thk, (#1)	10.0	-	3.0	=	7.0	mm
Min. shell thickness where top girder located, tsc.cor				=	7.0	mm
Corrosion Allowance				=	3.0	mm



No.	A (mm^2)	Y (mm)	AY (mm^3)	h (mm)	$A.h^2$ (mm^4)	$I=(bd^3)/12$ (mm^4)	Un-corroded Weight (kg)
#1	700	110.5	77350	69.1	3346841	2859	
#2	700	57.0	39900	15.6	171364	583334	941.0
#3	1568	3.5	5488	37.9	2246801	6402	90061.0
Total	2968		122738		5765006	592595	91002.0

Where,

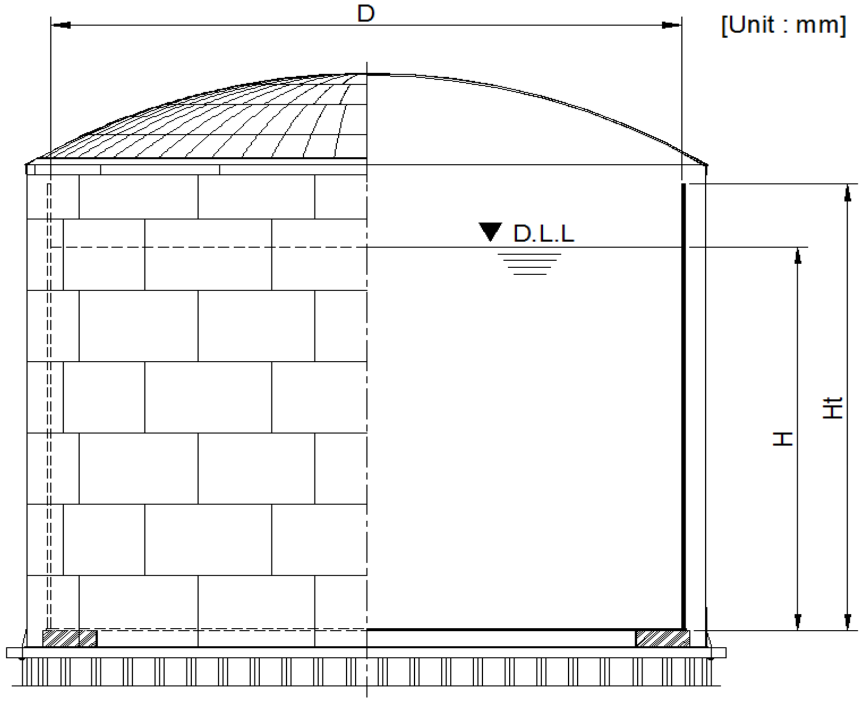
Neutral axis of combined section.	C1	=	41.4	mm
Moment of inertia of section.	Iact	=	6357601	mm^4
Section modulus available.	Za = Iact / C1	=	153737	mm^3
Required minimum section modulus.	Ireqd	=	5051728	mm^4

Ireqd < Iact , Therefore the top girder size is **Satisfactory.**

7. Tank stability check due to seismic : API 620 APPENDIX. L [CLE]

7.1) DESIGN CONDITION & DIMENSION

o DESIGN CODE : API 620 Appendix. L [CLE] and API 650 Appendix E and ASCE 7-10



Tank diameter	D =	38000	mm	=	124.672	ft
Tank height	Ht =	14810	mm	=	48.589	ft
1st shell course thickness	t =	18.00	mm	=	0.709	inch
Min. yield strength of 1st shell and annular plate	Fty =	344.7	Mpa	=	50.000	ksi
Product design stress	Sd =	144.8	Mpa	=	21.000	ksi
Tank elastic modulus	E =	199000	Mpa	=	29000	ksi
Shell weight (Excluded anchor strap weight)	Ws =	194.717	Ton	=	429.277	kips
Roof weight	Wr =	N/A	Ton	=	N/A	kips
Bottom weight	Wf =	93.506	Ton	=	206.146	kips
Specific gravity of content	G =	0.684				
Density of fulid	p =	684	kg/m^3	=	42.70	pcf
Design liquid level (H = D.L.L)	H =	13910	mm	=	45.636	ft
Contents weight	Wp =	10790	Ton	=	23788.51	kips
Corrosion allowance	C.A =	3.0	mm	=	0.118	inch
Design internal pressure	Pi =	0.00	mmAq	=	0.000	mbar
				=	0.000	bar

Importance factor classification.

Importance factor	(by API 620 L.4.4.2 3))	=	**1.0**
Soil site class		=	**C**

Spectral response acceleration parameter for Short and 1-Second Periods:

Spectral acceleration param. (0.2 sec period)	S_S =	1.540	g	
Spectral acceleration param. (1 sec period)	S1 =	0.315	g	
Regional-dependent transition long-period	TL =	6.000	sec	
Seismic peak ground acceleration	Sp =	0.616		Sp = SS / 2.5, Sp=S1 / 1.25

Site coefficient for Short and 1-Second Periods:

Acceleration-based site coefficient	F_a =	1.000	g
Velocity-based site coefficient	F_v =	1.500	g

MCE Spectral Response Accelerations for Short and 1-Second Periods:

MCE spectral response acceleration param	S_{MS} =	1.540	$S_{MS} = F_a S_s$	ASCE 7-10
MCE spectral response acceleration param	S_{M1} =	0.473	$S_{M1} = F_v S_1$	ASCE 7-10

MCE : Maximum Considered Earthquake

2) Design Spectral Response Accelerations for Short and 1-Second Periods: (5% damped)

Scaling factor	(by API 620 App. L.4.4.2 1))	Q =	1.000		
Design spectral response acceleration param.		S_{DS} =	1.540	g	S_{DS} = Q * SM_S
Design spectral response acceleration param.		S_{D1} =	0.473	g	S_{D1} = Q * SM_1
	T0 = 0.2 * SD1 / SDS	T0 =	0.061	sec	ASCE 7-10
	Ts = SD1 / SDS	Ts =	0.307	sec	ASCE 7-10
Regional-dependent transition long-period		T_L =	6.000	sec	

Structural Period of Vibration (including sloshing): (using API 650 Appendix E)

Coefficient of impulsive natural period	Ci =	6.883		Ci = from API 650 Appendix E, Fig. E-1
Coefficient of sloshing period	Ks =	0.618		Ks =0.578 / SQRT(TANH(3.68 * H/D))
Impulsive natural period	Ti =	0.245	sec.	
Convective (Sloshing) period	Tc =	6.863	sec.	
Short period (Design)	Ts =	0.307	sec	

Where, Ti(sec) = Max{ $(1/2000^{0.5})$ * (Ci * H / $(t/D)^{0.5}$) * $(p/E)^{0.5}$, 0.128 } — API 650 Appendix E.4.5.1-1a

Tc(sec) = 1.8 * Ks * SQRT(D) — API 650 Appendix E4.5.2-a

Ts(sec) = SD1 / SDS — ASCE 7-10

3) Design Spectral Response Accelerations of Tank (Impulsive method)

Force reduction factor (impulsive mode)	Rwi =	2.50		
Force reduction factor (convective mode)	Rwc =	1.50		
Coefficient to adjust the spectral acceleration.	K =	1.5		API 620 Appendix. L.4.2
Impulsive spectral acceleration parameter.	Ai =	0.6160	g	
Convective spectral acceleration parameter.	Ac =	0.0602	g	
Vertical earthquake acceleration parameter.	Av =	0.7238	g	Av = 0.47 * S_{DS}

Where,

Impulsive spectral acceleration parameter, A_i:

$$A_i = S_{DS}\left(\frac{I}{R_{wi}}\right) = 2.5QF_aS_0\left(\frac{I}{R_{wi}}\right)$$

However, $A_i \geq 0.007$

and, for $S_1 \geq 0.6$:

$$A_i \geq 0.5S_1\left(\frac{I}{R_{wi}}\right) = 0.625S_P\left(\frac{I}{R_{wi}}\right)$$

Convective spectral acceleration parameter, A_c:

When, $T_C \leq T_L$ $$A_c = KS_{D1}\left(\frac{1}{T_c}\right)\left(\frac{I}{R_{wc}}\right) = 2.5KQF_aS_0\left(\frac{T_s}{T_c}\right)\left(\frac{I}{R_{wc}}\right) \leq A_i$$

When, $T_C > T_L$ $$A_c = KS_{D1}\left(\frac{T_L}{T_c^2}\right)\left(\frac{I}{R_{wc}}\right) = 2.5KQF_aS_0\left(\frac{T_sT_L}{T_c^2}\right)\left(\frac{I}{R_{wc}}\right) \leq A_i$$

API 620 Table L-1R, Appendix R tanks

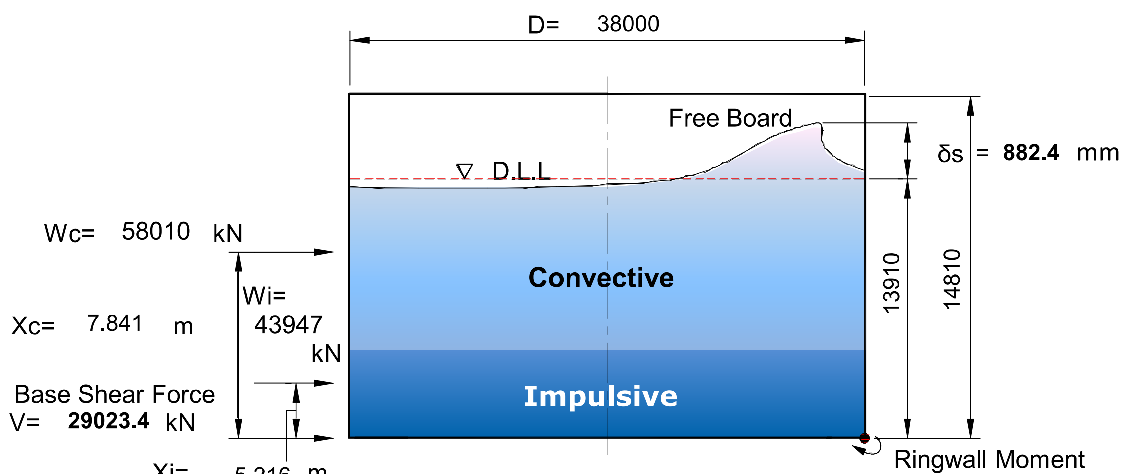
Inner Tank :		
Anchorage system	Rwi	Rwc
Self - anchored	2.25	1.5
Mech. - anchored	**2.5**	**1.5**

4) Seismic base shear force and sliding resistance

Total Base Shear Force at design(SRSS)	**V =**	**2959.6**	ton	**29023.4**	kN
Sliding Resistance	Vs =	**3148.5**	ton	**30876.0**	kN

Therefore , The tank is no Sliding. Self-Anchored (V < Vs)

Where,		CASE = D/H = 2.732	> 1.333
Short period (Design)	Ts =	0.307	sec., Ts = SD1/SDS, ASCE 7-10 seismic design criteria
Impulsive natural period coefficient	Ci =	6.883	(API 650 E, Fig. E-1) H/D= 13.91/38= 0.366
Impulsive natural period	Ti =	0.245	sec., Ti = $1/(2000^{0.5})$*Ci*H*SQRT(p/E)/SQRT(t/D)
Convective (Sloshing) period	Tc =	6.860	sec., Tc =1.8 * Ks * SQRT(D)
Effective impulsive portion, liquid weight	Wi =	4481	ton 43947 KN Wi = TANH(0.866*D/H)/(0.866*D/H)*Wp
Effective convective portion, liquid weight	Wc =	5915	ton 58010 KN Wc = (0.23*D/H*TANH(3.67*H/D))*Wp
Design base shear force (Impulsive components)	Vi =	2938.1	ton Vi = Ai * (Wr+Ws+Wf+Wi)
Design base shear force (Convective components)	Vc =	356.0	ton Vc = Ac * Wc
Total base shear force at design (SRSS)	V =	2959.6	ton V = SQRT(Vi^2 + Vc^2)
SRSS : Square Root of the Sum of the Squares			
Friction coefficient for tank sliding	μ =	0.40	
Sliding resistance	Vs =	3148.48	ton Vs = μ * (Wr+Ws+Wf+Wp) (1.0-0.4Av)
Local shear transfer force (kg/cm)	Vmax =	495.82	kg/cm Vmax = 2V / πD API 650 E7.7-1



Seismic Moment and Force Diagram

5) Overturning Moment

(Note: Mrw is the ringwall overturning moment at top of foundation.)

Center of action for ring wall overturning moment	CASE :	D/H = 2.732		> 1.333	
Height of tank shell's center of gravity (included top girder)	Xs =	6671.6	mm	6.672	m
Height of roof appurtenances center of gravity	Xr =	N/A	mm	N/A	m
Height of impulsive mode (for RINGWALL moment)	Xi =	5216	mm	5.216	m
Height of convective mode (for RINGWALL moment)	Xc =	7841	mm	7.841	m
Height of impulsive mode (for SLAB momentt)	Xis =	15008	mm	15.008	m
Height of convective mode (for SLAB moment)	Xcs =	13278	mm	13.278	m
Overturning RINGWALL moment	**Mrw =**	**15454107**	**kg.m**	**151553**	**KN-m**
Overturning SLAB moment	**Ms =**	**42493549**	**kg.m**	**416719**	**KN-m**

Where,

Mrw = SQRT[Ai * (Wi * Xi + Ws * Xs + Wr * Xr)]^2 + (Ac * Wc * Xc)^2]

Ms = SQRT[Ai * (Wi * Xis + Ws * Xs + Wr * Xr)]^2 + (Ac * Wc * Xcs)^2]

6) Anchorage Ratio

$$J = \frac{\mathbf{Mrw}}{D^2[wt(1-0.4Av) + wa - 0.4wint]} = \boxed{2.342}$$

API 650 Appendix E (Table E-6) Anchorage Ratio Criteria

J ≤ 0.785	No calculated uplift under the design seismic overturning moment. The tank is self-anchored.	
0.785 < J ≤ 1.54	Tank is uplifting, but the tank is stable for the design load providing the shell compression. requirements are satisfied. Tank is self-anchored.	
J > 1.54	Tank is not stable and cannot be self-anchored for the design load. Modify the annular ring if L < 0.035D is not controlling or add mechanical anchorage.	O

Where,

Vertical earthquake acceleration parameter	Av =	0.724		Av = 0.47 * SDS
Effective specific gravity	Ge =	0.486		Ge = G * (1 - 0.4Av)
Shell and roof weight acting at base of shell	Wt =	1631.1	kg/m	Wt = Ws / πD + wrs
Roof load acting on the shell, including - 10% of the specified snow load	wrs =	0.0	kg/m	wrs = Wr / πD
Force resisting uplift in annular region	wa =	**3411.3**	kg/m	33453.8 N/m

99 * ta * SQRT(Fy * H * Ge) ≤ 201.1 * H * D * Ge (API 650 E6.2.1.1-1a)

wa = Min(3411.3 , 5267.6) kg/m

waMax = 5742*H*Ge*Ls, Ls=0.035D waMax = 2374.8 kg/m (API 650 E6.2.1.1-2a)

Calculated design uplift load due to product pressure per unit circumferential length

wint = πD^2 / 4 * Pi / πD = (D / 4) * Pi wint = 0.0 kg/m

Internal Design Pressure Pi = 0.0 mmAq 0.00 kPa 0.0000 bar

Mechanical Anchorage required check by Seismic : YES	API 650 Appendix E.6.2.1.1.1

7) Annular Ring Requirement

Min. radial width (API 650 Appendix E.6.2.1.1.2-1a) L = 0.01723*ta*SQRT(Fy/(H*Ge)) L = 861.3 mm

The maximum width of annulus for determining the resisting force, 0.035 D (per API 650 E6.2.1.1.2-1a)

Annular plate limit width L Max. = 1330.0 mm L Max. = 0.035D

Annular plate thickness. Corr. Allowance:

10.0 - 3.0 = ta= 7.0 mm

Min. specified yield strength of annular plate Fy = 344.7 Mpa (SA537-CL1 API 620 Table 5-1)

8) Uplift force calculation due to seismic loading.

: (Only Mechanically anchored Tanks)

WAB = (1.273Mrw / D²) - wt(1-0.4Av) WAB= 12465.2 kg/m = 122.2 KN/m

WAB : Calculated design uplift load on anchors per unit circumferential length.

Wint : Calculated design uplift load wint= 0.0 kg/m = 0.0 KN/m

due to design internal pressure per unit circumferential length.

Tse : Load per anchorage Tse = πD * WAB / N Tse= 26.6 Ton = 260.6 KN

Anchor quantity : 56 Sets

9) Shell-Membrane Compression Stress (API 650 Appendix E.6.2.2)

Compression in Mechanically anchored Tanks

Maximum longitudinal shell compression stress. (σc) When **J (2.342) > 1.54**

x	Un-anchored tanks	When J ≤ 0.785	σc =	1.048	kg/mm²	10.28	Mpa
x	Un-anchored tanks	When 0.785 < J ≤ 1.54	σc =	-0.742	kg/mm²	-7.28	Mpa
O	Mechanically anchored	When J >1.54	σc =	1.048	kg/mm²	10.28	Mpa

Allowable longitudinal shell-membrane compression stress (API 650 Appendix E.6.2.2.3)

When, $GHD^2/ts^2 \geq 44$ GHD^2/ts^2 = 61.06 m³/mm² ≥ 44m³/mm²

Fc = 83ts / D Fc = 32.763 Mpa 3.341 kg/mm²

Therefore,

Maximum stress σc (kg/mm²)		Allowable Stress Fc (kg/mm²)	
1.048	<	3.341	**Tank is stable by seismic.**

Specific gravity of content	G =	0.684	
Thk. of 1st shell course less corrosion allowance	ts = 18 - 3.0 =	15.0	mm
Min. specified yield strength of 1st shell course	Fty = 344.7 Mpa =	35.153	kg/mm²

Maximum longitudinal shell compression stress. (σc) :

1) for Self-Anchored Tanks, [API 650 Appendix E 6.2.2.1]

x When, J ≤ 0.785

$$\sigma_c = \left(w_t(1+0.4A_v)+\frac{1.273M_{rw}}{D^2}\right)\frac{1}{1000t_s} = 1.05 \text{ kg/mm}^2 \quad 10.28 \text{ MPa}$$

x When 0.785 < J ≤ 1.54

$$\sigma_c = \left(\frac{w_t(1+0.4A_v)+w_a}{0.607-0.18667[J]^{2.3}}-w_a\right)\frac{1}{1000t_s} = -0.74 \text{ kg/mm}^2 \quad -7.28 \text{ MPa}$$

2) for Mechanically-Anchored Tanks, [API 650 Appendix E 6.2.2.2]

O When J >1.54

$$\sigma_c = \left(w_t(1+0.4A_v)+\frac{1.273M_{rw}}{D^2}\right)\frac{1}{1000t_s} = 1.05 \text{ kg/mm}^2 \quad 10.28 \text{ MPa}$$

10) Sloshing height calculation (API 650 Appendix E.7.2.1)

Sloshing wave height above the product design height	δs=0.42 * D * Af + hs	δs =	1260.6	mm
When,	SUG = II AND SDS ≥ 0.33g Then	0.7δs =	882.4	mm
Freeboard height (Eng. Spec. 2UA-229-21-FE-DSH-23097)		δs =	600.0	mm
		Max(δs,0.7δs) =	**882.4**	**mm**
hs : Addition shell height required above the sloshing wave height. (by MOM)		hs =	300.0	mm
Af : Acceleration coefficient for sloshing wave height calculation.		Af =	0.0602	g
Where,	Seismic use group		II	
	Importance factor (by API 620 App. L.4.4.2 3))	I =	1.000	
	Coefficient to adjust the spectral acceleration.	K =	1.500	
	Design spectral response acceleration param.	S_{D1} =	0.473	
	Convective (Sloshing) period (API 650 App. E.4.5.2)	Tc =	6.863	sec
	Regional-dependent transition long-period	TL =	6.000	sec

11) Dynamic Hoop Stress Calculation (API 650 Appendix E 6.1.4)

When, D/H = 2.732 > 1.333 (=4/3)

No.	t	Y	Nh	Y< 0.75D	Ni	Nc	**σT**	**< or >**	**Sa**	**Check**
	mm	m	(N/mm)		(N/mm)	(N/mm)	**(Mpa)**		**(Mpa)**	
6	7.0	1.560	160.5	< 0.75D	196.44	96.67	**54.90**	**<**	**192.6**	**OK**
5	7.0	4.030	475.1	< 0.75D	459.73	80.02	**137.36**	**<**	**192.6**	**OK**
4	8.0	6.500	789.6	< 0.75D	664.52	67.96	**186.96**	**<**	**192.6**	**OK**
3	11.0	8.970	1104.2	< 0.75D	810.79	59.82	**179.80**	**<**	**192.6**	**OK**
2	13.0	11.440	1418.8	< 0.75D	898.55	55.11	**185.26**	**<**	**192.6**	**OK**
1	15.0	13.910	1733.4	< 0.75D	927.81	53.57	**185.97**	**<**	**192.6**	**OK**

Where,

t	=	Thickness of the shell under consideration (Corroded)		(mm)			
Y	=	Distance from liquid surface to analysis point (Positive down)		(m)			
Nh	=	Product hydrostatic membrane force in shell		(N/mm)			
Ni	=	Impulsive hoop membrane force in shell		(N/mm)			
Nc	=	Convective hoop membrane force in shell		(N/mm)			
σT	=	Total combined hoop stress in shell		(Mpa)			
		$\sigma T = \sigma h \pm \sigma s = \{Nh \pm [Ni^2 + Nc^2 + (Av * Nh / 2.5)^2]^{0.5}\} / t$					
G	=	Specific gravity	0.684				
D	=	Tank Diameter	38.000	m			
H	=	Height of product liquid	13.910	m			
Ai	=	Impulsive spectral acceleration parameter	0.616				
Ac	=	Convective spectral acceleration parameter	0.060				
Av	=	Vertical earthquake acceleration parameter	0.724				
E	=	Joint efficiency	1.0				
Fty	=	Min. reduced yield strength of bottom shell course	344.7	Mpa		50000	psi
Sd	=	Product design stress	144.8	Mpa		21000	psi
Sa	=	Allowable stress (API 650 Appendix E.6.2.4)	192.6	Mpa		27930	psi
		Sa=Min(0.8 * Fty * E , Sd * 1.33)					

8. Outer Shell plate of calculation

8.1) Shell plate thickness at design condition (Material : SA537-CL1+S5)

Diameter of tank inside	D	=	**40000**	mm	40.000	m	1574.8	in
Height of tank	Ht	=	**16610**	mm	16.610	m	653.94	in
Design liquid level for shell th'k. calc.	D.L.L	=	**12600**	mm	12.600	m	41.34	ft
High liquid level	H.L.L	=	**12600**	mm	12.600	m	41.34	ft
Corrosion allowance	C.A	=	**3.0**	mm			0.118	in
Design specific gravity	G	=	**0.684**		684	kg/m^3	42.82	lb/ft^3
Tank radius	Rc = D/2	=	**20000**	mm	20.000	m	787.402	in
Cross-sectional area of the tank	At	=	**1256.6**	m^2			1947791	in^2
The total weight of that portion of the tank and its contents					W	=	See Below 8.1.1 Table	
Summation of the vertical components of the forces					F	=	0	lb
Joint efficiency of Shell Weld	E	=	**1.0**					
Tensile strength	Fu	=	482.633	Mpa			70000	psi
Yield strength	Fy	=	344.738	Mpa			50000	psi
Maximum allowable stress for simple tension of design liquid								
Sts_d = Min(Fu*0.3, Fy*0.6)	Sts_d	=	144.790	Mpa			21000	psi
Design internal pressure	Pg	=	150.00	mbar			2.176	psi
Liquid head pressure	P_L	=	See Below 3.1.1 Table(a)					
Total pressure	P	=	**Pg + P_L**					

8.1.1) Shell calculation

Shell Course No.	Width of Used Plate	Design Liquid Level (D.L.L)	P_L	P= Pg+P_L	W = contents weight	T1	T2	td		**Used th'k (tu)**	Weight
	mm	mm	psi	psi	lb	lb/in	lb/in	in	mm	**mm**	kg
8	540	0	0.000	2.176	-213739	813.3	1713.0	0.200	5.072	**34.0**	18127
7	1250	0	0.000	2.176	-253702	805.2	1713.0	0.200	5.072	**10.0**	12334
6	2470	250	0.243	2.419	-280894	895.5	1904.6	0.209	5.304	**10.0**	24372
5	2470	2720	2.646	4.822	-334625	1830.7	3796.7	0.299	7.592	**10.0**	24372
4	2470	5190	5.049	7.225	-388356	2765.9	5688.8	0.389	9.881	**11.0**	26809
3	2470	7660	7.452	9.628	-447460	3700.0	7581.0	0.479	12.169	**14.0**	34124
2	2470	10130	9.855	12.031	-522690	4630.9	9473.1	0.569	14.458	**16.0**	39000
1	2470	12600	12.258	14.434	-608671	5559.6	11365.2	0.659	16.747	**18.0**	43878
	16610 mm										223016

For cylindrical sidewalls of a vertical tank : as per API 620 5.10.2.5 c) Eqn. (10)(11),

$$\mathbf{T1} = \frac{Rc}{2}\left(P + \frac{W+F}{At}\right),\ \mathbf{T2} = P * Rc$$

T1 = Meridional (Longitudinal) unit force. (lb/in)

T2 = Latitudinal (Circumferential) unit force. (lb/in)

Required shell thickness calculation : as per API 620 5.10.3.2 Eqn. (16),

$$\mathbf{td} = \frac{\text{Max (T1, T2)}}{\text{Sts\_d} * E} + C.A$$

td = Design thickness of shell. (mm)

tu = Used (Selected) thickness of shell. (mm)

8.2 Shell plate thickness at hydrostatic test condition (Material : SA537-CL1+S5)

Diameter of tank inside	D	=	**40000** mm	40.000 m	1574.8 in
Height of tank	Ht	=	**16610** mm	16.610 m	653.94 in
Hydro test level for shell th'k. calc.	H.T.L	=	**12600** mm	12.600 m	41.34 ft
Hydro specific gravity	SG	=	**1.000**	1000 kg/m^3	62.61 lb/ft^3
Tank radius	Rc = D/2	=	**20000** mm	20.000 m	787.402 in
Cross-sectional area of the tank	At	=	**1256.6** m^2		1947791 in^2

The total weight of that portion of the tank and its contents W = See Below 8.2.1 Table

Summation of the vertical components of the forces F = 0 lb

Tensile strength (API 620 Table 5-1)	Fu	=	482.633 Mpa		70000 psi
Yield strength (API 620 Table 5-1)	Fy	=	344.738 Mpa		50000 psi

Maximum allowable stress for tension (API 620 Table 5-1)

Sts_d = Min(Fu*0.3, Fy*0.6) Sts_d = 144.790 Mpa 21000 psi

Maximum allowable stress for tension of hydro test (API 620 R.6.1)

Sts_t = Min(Fu*0.55, Fy*0.85) Sts_t = 265.448 Mpa 38500 psi

Pneumatic test pressure Pt=Pg*1.25 = **1911.97** mmAq 187.500 mbar 2.719 psi

Test water (Liquid) head pressure P_W = See Below 3.2.1 Table

Total pressure P = $Pt+P_W$ (As per design data sheet)

8.2.1) Shell calculation

Shell Course No.	Width of Used Plate	Hydrostatic test Level (H.T.L)	P_W	$P=Pt+P_W$	W = contents weight	T1	T2	tt		**Used th'k (tu)**	Weight
	mm	mm	psi	psi	lb	lb/in	lb/in	in	mm	**mm**	kg
8	540	0	0.000	2.719	-213739	1027.4	2141.3	0.056	1.413	**34.0**	18127
7	1250	0	0.000	2.719	-253702	1019.4	2141.3	0.056	1.413	**10.0**	12334
6	2470	250	0.356	3.075	-280894	1153.9	2421.3	0.063	1.597	**10.0**	24372
5	2470	2720	3.869	6.588	-334625	2526.2	5187.6	0.135	3.422	**10.0**	24372
4	2470	5190	7.382	10.101	-388356	3898.4	7953.9	0.207	5.247	**11.0**	26809
3	2470	7660	10.895	13.615	-447460	5269.6	10720.1	0.278	7.073	**14.0**	34124
2	2470	10130	14.408	17.128	-522690	6637.6	13486.4	0.350	8.898	**16.0**	39000
1	2470	12600	17.921	20.641	-608671	8003.3	16252.7	0.422	10.723	**18.0**	43878
	16610 mm										223016

For cylindrical sidewalls of a vertical tank : as per API 620 5.10.2.5 c) Eqn. (10)(11),

$$T1 = \frac{Rc}{2}\left(P + \frac{W+F}{At}\right),\quad T2 = P * Rc$$

T1 = Meridional (Longitudinal) unit force. (lb/in)

T2 = Latitudinal (Circumferential) unit force. (lb/in)

Required shell thickness calculation : as per API 620 5.10.3.2 Eqn. (16),

$$tt = \frac{Max\,(T1, T2)}{Sts\_t}$$

tt = Hydrostatic test thickness (mm)

tu = Used (Selected) thickness of shell. (mm)

8.3) Summary of shell plate thickness

Shell Course No.	Width of Used Plate	Total Liquid height	Total hydro test height	At design (td)		At hydro test (tt)		Calc. thickness Max(td, tt)		**Used th'k (tu)**	Design or test condition
	mm	mm	mm	in	mm	in	mm	in	mm	**mm**	
8	540	0	0	0.200	5.072	0.056	1.413	0.200	5.072	**34.0**	Design
7	1250	0	0	0.200	5.072	0.056	1.413	0.200	5.072	**10.0**	Design
6	2470	250	250	0.209	5.304	0.063	1.597	0.209	5.304	**10.0**	Design
5	2470	2720	2720	0.299	7.592	0.135	3.422	0.299	7.592	**10.0**	Design
4	2470	5190	5190	0.389	9.881	0.207	5.247	0.389	9.881	**11.0**	Design
3	2470	7660	7660	0.479	12.169	0.278	7.073	0.479	12.169	**14.0**	Design
2	2470	10130	10130	0.569	14.458	0.350	8.898	0.569	14.458	**16.0**	Design
1	2470	12600	12600	0.659	16.747	0.422	10.723	0.659	16.747	**18.0**	Design
	16610 mm										

8.4) Max. membrane stress check of shell plate for operating condition

1) Calculation formula

Maximum membrane stress for T2 (For vertical weld joint) : Sms1

$$Sms1 = \frac{T2}{tused - C.A * E}$$

3

Where,

T2	:	Latitudional unit force in wall of tank at the level under consideration (lb/in)			
C.A	:	Corrosion allowance	=	3.0 mm	0.118 in
E	:	Joint efficiency of shell weld	=	1.0	
tsued	:	Used shell plate thickness			

2) Calculation result (Outer shell)

Shell Course No.	Material	Used th'k (tu)		Vertical weld joint			
				T2	Sms1	Decision for Sms1	
		in	mm	lb/in	psi	psi	
8	SA537-CL1+S5	1.34	34.0	1713.04	1403.59	<	7000
7	SA537-CL1+S5	0.39	10.0	1713.04	6215.90	<	7000
6	SA537-CL1+S5	0.39	10.0	1904.56	6910.81	<	7000
5	SA537-CL1+S5	0.39	10.0	3796.69	13776.57	>	7000
4	SA537-CL1+S5	0.43	11.0	5688.83	18062.03	>	7000
3	SA537-CL1+S5	0.55	14.0	7580.97	17505.14	>	7000
2	SA537-CL1+S5	0.63	16.0	9473.10	18508.99	>	7000
1	SA537-CL1+S5	0.71	18.0	11365.24	19245.14	>	7000

Where,

Decision vaule of Sms1 : 0.1 times of specified minimum tensile strength

(by API 620 App. R.5.6.1 & R.5.6.2 & Figure R-2)

SA537-CL1+S5 70000 * 0.1 = 7000 psi

3) Decision of radiographic examination

(A) For vertical weld joint of 1st~5th course, Sms1 tensile stress is greater than specified minimum tensile strength of the plate material.

(B) For vertical weld joint of 6th~8th course, Sms1 tensile stress is less than specified minimum tensile strength of the plate material.

Therefore, shell plate to be examined by radiographic examination according to API 620 Appendix R. Figure R-2 lower sketch.

9. Bottom plate and Annular plate of calculation

9.1) Bottom plate (API 620 SEC. 5.9.4.2)

1) Material of bottom plate = SA516-60N+S5

Bottom plate corrosion allowance	C.A	=	0.118	inch	3.0	mm
Min. thickness: (API 620 SEC. 5.9.4.2 [1/4"])	tbm	=	0.250	inch	6.35	mm

2) Required bottom plate thickness

Required bottom plate thickness	tbm + C.A	=	0.368	inch	9.350	mm
Used thickness of bottom plate	tb_used	=	0.394	inch	**10.000**	mm

9.2) Annular plate (API 620 Table R-6)

1) Design condition

Annular plate material	MATERIAL	=	SA516-60N+S5			
Design specific gravity of liquid content	Gp	=	0.684			
Gravity of hydrostatic test	Gt	=	1.000			
Diameter of tank inside D= 40000 (mm)	D	=	131.2	ft	40.000	m
Nominal thickness for 1st shell course	t	=	0.709	inch	18.000	mm
Design required thickness for 1st shell course	td	=	0.659	inch	16.747	mm
Hydro-test required thickness for 1st shell course	tt	=	0.422	inch	10.723	mm
Design liquid level	Hd	=	41.34	ft	12.600	m

2) Maximum product stress

$$Sd = \frac{2.6 * D * Hd * Gp}{t}$$

Sd = 13614.17 psi = 94 Mpa

* Butt-welded annular bottom plates shall be used

3) Annular plate thickness

Minimum annular plate thickness (0.25in)+C.A	tb_min	=	0.368	inch	9.35	mm
Used thickness of annular plate	tb	=	0.394	inch	**10.00**	mm

- API 620 [TABLE R-6 Thickness Requirements[a] for the Annular Bottom plate] (tb : in)

Nominal Thickness of First Shell Course (in)	Design Stress[b] in First Shell Course (lbf/in.^{2})			
	≤ 20,000	22,000	24,000	26,000
≤ 0.75	1/4	1/4	1/4	1/4
> 0.75 to 1.00	1/4	1/4	1/4	5/16
> 1.00 to 1.25	1/4	1/4	5/16	3/8
> 1.25 to 1.50	1/4	9/32	3/8	7/16

4) Width of annular plate (API 620 R.3.5.1 and API 650 Appendix E.6.2.1.1.2)

Used annular plate thickness	tb	=	0.394 inch	10.00 mm
Design liquid level plus internal pressure head	H = Hd	=	41.339 ft	12.60 m
Design specific gravity of liquid	G	=	0.684	

4-1) Min. annular plate width(w)

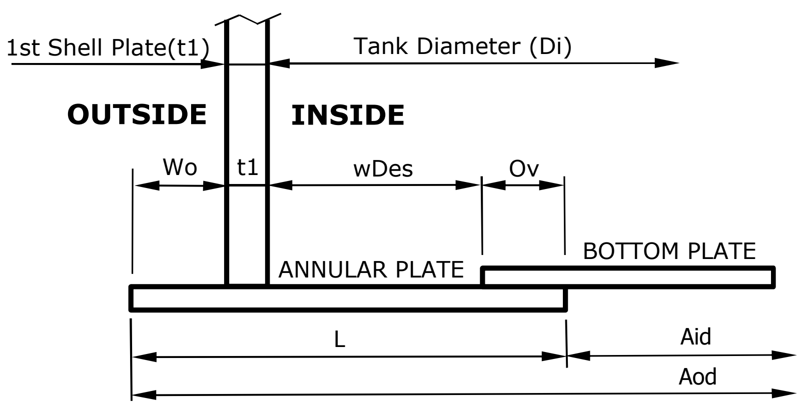
$$w = \frac{390 * tb}{(H * G)^{0.5}}$$

	w	=	28.9 inch	733.43 mm

(width between the inside of the shell and any lap welded joint in the reminder of the bottom)

4-2) Min. required annular plate width due to seismic	wSei	=	35.63 inch	905.0 mm
Min. radial width due to seismic (API 650 Appendix E.6.2.1.1.2-1a)			(Refer to Calculation 8.2.7)	
4-3) Annular plate width : wDes = Max. (w, wSei)		=	35.63 inch	905.0 mm
4-4) Mim. annular plate width	Lmin = (Wo+t1+wDes+Ov)	=	41.42 inch	1052.0 mm
4-4) Used annular plate width	**L**	**=**	**79.13 inch**	**2010.0 mm**

5) Dimensions for annular plate (unit: mm)



* Tank inside diameter	Di	=	131.23 ft	40000 mm
* Length of annular outer dia. to shell outer diameter	Wo	=	2.52 inch	64.0 mm
* 1st shell course thickness (Uncorroded)	t1	=	0.71 inch	18.0 mm
* Annular plate inside diameter	Aid	=	118.58 ft	36144 mm
* Annular plate outside diameter	Aod	=	131.77 ft	40164 mm
* Overlap of annular plate and bottom plate	Ov	=	0.21 ft	65 mm

10. Roof plate of calculation (API 620 SEC. 5.10.2.5 a) and 5.10.3.2)

Material of roof plate		=	SA516-70		
$T1 = Rs\ [(Pg + qzr) - Pc] * 0.5$	T1	=	1538.64 lb/in	27.48	kg/mm
$T2 = Rs\ (Pg + qzr) - T1$	T2	=	1694.12 lb/in	30.25	kg/mm
t req'd = T1 / (Sts * Eff) + C.A =	t req'd	=	0.327 in	8.317	mm
t req'd = T2 / (Sts * Eff) + C.A =	t req'd	=	0.349 in	8.855	mm
Therefore, roof plate used thickness		=	**0.35** in	**9.0**	mm

Where,

Pg	=	Internal pressure	=	2.176	lb/in^2	0.0015	kg/mm^2
qzr	=	Design wind pressure on horizontal projected areas	=	0.105	lb/in^2	0.0001	kg/mm^2
Rs	=	Dome roof radius	=	1417.323	in	36000	mm
Rc	=	Diameter of tank inside (Corroded)	=	787.520	in	20003	mm
Sts	=	Allowable stress	=	21000	lb/in^2	14.764	kg/mm^2
C.A	=	Corrosion allowance	=	0.118	in	3.0	mm
Eff	=	Joint efficiency of roof plate	=	0.35			
Pc	=	Equivalent pressure of total weight ($Wt / \pi * Rc^2$)	=	0.110	lb/in^2	0.000077	kg/mm^2
Wt	=	Roof plate weight	=	213739	lb	96950	kg

11. Intermediate Wind Girder & Compression ring Calculation

11.1) Maximum unstiffened shell height (H1, Hsafe)

API 620 5.10.6	API 650 Appendix V
$H_1 = 6(100t)\sqrt{\left(\frac{100t}{D}\right)^3}$ (ft)	$H_{safe} = \dfrac{(tsmin)^{2.5} * E}{15203 * D^{1.5} * Ps * \Psi}$ (m)
= 11.825 m = 38.795 ft	= 3.725 m = 12.221 ft

Un-stiffened height from top shell	(API 650 Appendix V)	Hsafe=	3.725 m	12.22 ft
Un-stiffened height from top shell	(API 650 5.10.6)	H_1=	11.825 m	38.80 ft
Design wind speed (3-sec. gust)	38.89 m/sec	V=	140.0 km/h	87.00 mph
Tank out-diameter	D= Di+2(AVG. Sh_Th'k.)	D=	40.014 m	131.28 ft
Tank in-diameter		Di=	40.000 m	131.23 ft
Insulation thickness of tank outside		Insu_Th'k =	0.00 mm	0.0000 in
Nominal thickness of thinnest shell course		tn =	10 mm	0.3937 in
Corrosion allowance		C.A =	3.0 mm	0.1181 in
Top shell course thickness (Corroded)		t = tn-CA =	7.00 mm	0.2756 in
Required minimum section modulus	API 650 5.9.7.6	Zr =	$D^2H1 / 17 (V/190)^2$	(cm³)

No	Shell Thick.	Width of Used Plate	t_uniform	t_actual (Corroded)	Transposed Width	Height From Shell Top	Stiff. Location from Bottom	Required Section Modulus	Height From Tank bottom
	tn(mm)	w(mm)	tu(mm)	ta(mm)	Wtr(mm)	mm	mm	Zr (cm3)	mm
8	34.0	540	7.0	31.0	13.1				
7	10.0	1250	7.0	7.0	1250.0				
6	10.0	2470	7.0	7.0	2470.0	3000	O	153.4	13610
5	10.0	2470	7.0	7.0	2470.0	6000	O	153.4	10610
4	11.0	2470	7.0	8.0	1769.0				
3	14.0	2470	7.0	11.0	797.9				
2	16.0	2470	7.0	13.0	525.5				
1	18.0	2470	7.0	15.0	367.5				
	Sum	16610	mm	Htr =	9663.0	mm			

Htr = 9.663 m

Quantity of Wind Stiffener

Hsafe = **3725** mm < Htr = **9663.0** mm   N = **2** EA

Since Hsafe < Hts   The intermediate wind girder is/are[2 ea] Required

11.2) Tank Design For External Pressure (Based on API650 Appendix V)

1) Design conditions Tank type = DRT

Tank out-diameter	D= Di+2(AVG. Sh_Th'k.)	D	=	40.014 m	131.3 ft
Tank height		H	=	16.610 m	54.49 ft
Design wind speed (3-sec. gust)	V = 38.89 m/sec	V	=	140.0 km/h	87.00 mph
Max. wind pressure	$W = 1.48 (V / 190)^2$	W	=	0.804 kPa	0.117 psi
Design external pressure	Pe = 61.18 kg/m^2	Pe	=	0.600 kPa	0.087 psi
Total external pressure	Ps = Max[Pe or (W + 0.4Pe)]	Ps	=	1.044 kPa	0.151 psi
Transformed shell height (See wind girder design on API650 .5.9.7)		HTS	=	9.663 m	31.70 ft
Shell thickness of thinnest shell course (Corroded)		tsmin	=	7.0 mm	0.276 inch
Corrosion allowance of shell and roof plate		C.A	=	3.0 mm	0.118 inch
Material of shell stiffener ring or wind girder / stiffeners		Matl	=	SA537-CL1+S5	
Design temperature		T	=	60.0 ℃	
Minimum yield strength of components		Fy	=	344.738 MPa	50000 psi
Yield strength reduction factor (At the Max. Design temp.)		Kr	=	1.000	
Reduced elastic modulus (as per Appendix M.2a Table)	EM Reduced factor = 1.00	E	=	199000 MPa	
Smallest the allowable compressive stress	Max(fc=0.4*Fy, 103)	fc	=	137.9 MPa	20000 psi

2) (API 650 Appendix V.8.1.1) Check for elastic buckling in the unstiffened cylindrical shell

$(D / tsmin)^{0.75} * [(HTS / D) * (Fy * Kr / E)^{0.5}] \geq 0.00675$

= **0.03716** ≥ **0.00675** **Satisfied**

3) (API 650 Appendix V.8.2.1.2) Max. height of unstiffened shell permitted, based on tsmin , Hsafe

$Hsafe1 = (tsmin)^{2.5} * E / [15203 * D^{1.5} * Ps * \Psi]$ Hsafe1 = 4.696 m 15.407 ft

Where, CASE 2) Ψ = (Pe + 0.70) / 0.95 = Ψ = 1.368

[When, Vacuum pressure(Pe) is greater than 0.25 kPa but less than or equal to 0.7 kPa]

$Hsafe2 = (tsmin)^{2.5} * E / [15203 * D^{1.5} * Pe * \Psi]$ Hsafe2 = 3.725 m 12.221 ft

Where, Ψ = 3 (Stability factor For vacuum pressure only)

Therefore, Hsafe = Min(Hsafe1, Hsafe2) **Hsafe** = 3.725 **m** 12.221 ft

4) (API 650 Appendix V.8.1.3) The minimum shell thickness required for a specified design external pressure

tsmin= 7.00 mm ≤ $47.07 (\Psi * HTS * Ps)^{0.4} * D^{0.6} / E^{0.4}$ = 9.34

Therefore, Shell stiffener ring is required due to the external pressure.

5) (API 650 Appendix V.8.2.1.3) Calculate the required number of intermediate stiffener , Ns

Ns + 1 = Hts / Hsafe = 2.5941 Ns = 1.5941 EA

* Installed quantity of shell stiffener ring Qty = 2 EA

6) (API 650 Appendix V.8.2.2.1) Calculate the number of buckling waves (Min. N=2, max=10)

$N^2 = SQRT\{ 445 * D^3 / (tsmin * HTS^2)\} =$ 208.85 ≤ 100 N = 10.00

7) (API 650 Appendix V.7) Total design external pressure loading, Pr (Refer to Roof Design Load)

Pr1 = DL + (Lr or S) + 0.4Pe =	364.5 kg/m^2	3.574 kPa	0.518 psi
Pr2 = DL + Pe + 0.4(Lr or S) =	311.2 kg/m^2	3.052 kPa	0.443 psi
Pr = The greater of (Pr1 or Pr2) =	364.473 kg/m^2	3.574 kPa	0.518 psi

Where,

DL = 190 kg/m^2 Lr = 97.649 kg/m^2 Pe = 61.183 kg/m^2 S = 150 kg/m^2

8) Top end stiffener calculation for external pressure (roof-to-shell junction)

Required cross-sectional area of the top end stiffener region , Areqd (top) : Appendix V.7.3.2

It is not self supporting roof. Thus, this calculation is not required.

9) Bottom end stiffener calculation for external pressure (Bottom-to-shell junction)

Required cross-sectional area of the bottom end stiffener region, Areqd (btm) : Appendix V.8.2.3.3.1

Areqd (btm) = V1 * D / 2f	=	179.63	mm^2	0.2784	in^2

Required cross-sectional area of bottom end stiffener, Astiff (btm)

Astiff (btm) = Areqd (btm) - tb * Xbtm - tsn * Xshell (Appendix V.8.2.3.3.2)	=	-5528.7	mm^2	-8.569	in^2

Less than Zero : thus, An additional stiffener is not necessary.

Required moment of inertia of the top end stiffener ring, Ireqd (btm) Appendix V.8.2.3.2

Ireqd (btm) = 37.5 * V1 * D^3 / E (N^2 - 1)	=	528.4	cm^4	12.696	in^4
Iact (btm) = Combined actual moment inertia of btm end stiff. region	=	7378.3	cm^4	177.26	in^4

Iact (btm) = 1/3 * (tsn * y^3+b * $(d-y)^3$ - (b-tsn) * $(d-y-tb)^3$) (Refer to API 650 Fig. V.1a)

Therefore, Iact(btm) > Ireqd(btm) **Satisfied !**

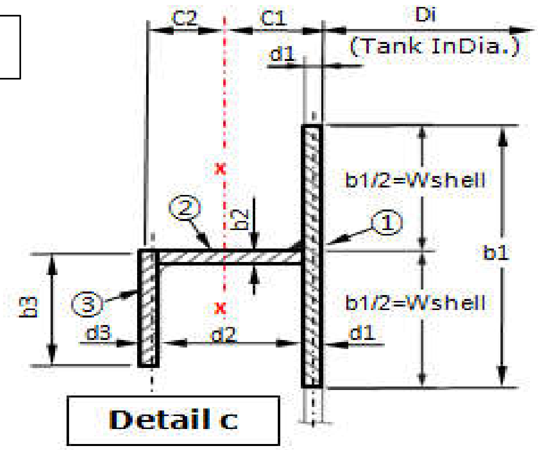
Where,

Xbtm	=	16 * tb (For bottom compression region)	=	112.0	mm	4.4094	in
Xshell	=	13.4 * SQRT(D * tsn) (For bottom comp. region)	=	328.3	mm	12.925	in
tsn	=	Nominal lowest shell course thickness (Corroded)	=	15.0	mm	0.5906	in
tb	=	Nominal bottom plate thickness (Corroded)	=	7.0	mm	0.2756	in
f	=	Smallest of the allowable tensile stresses of annular plate	=	482.6	MPa	70000	psi
V1	=	Radial load imposed on the stiffener by the shell					
	=	250 * Ps * H (Appendix V.8.2.3.1)	=	4333.3	N/m	296.93	lb/ft
y	=	Distance of neutral axis to Xshell	=	199.9	mm	7.8717	in
Wo	=	Lengh of annular out dia. to shell outer diameter	=	64.0	mm	2.5197	in
b	=	Xbtm + tsn + Wo	=	191.0	mm	7.5197	in
d	=	tb + Xshell	=	335.3	mm	13.2	in

11.3) Intermediate stiffener required moment of inertia and cross-sectional area check

API 650 Figure 5.24—Typical Stiffening-ring Sections for Tank Shells

 # 1



	SIZE:	L130 x 130 x 10	LENGTH:	127	m		Weight :	2492 kg
No.	**b** cm	**d** cm	**A** cm^2	**Y** cm	**AY** cm^3	**h** cm	**Ah^2** cm^4	**$Ig = bd^3/12$** cm^4
①	22.4	0.70	15.7	0.4	5.5	6.0	560.6	0.6
②	1.0	12.0	12.0	6.7	80.4	0.4	1.6	144.0
③	13.0	1.0	13.0	13.2	171.6	6.9	613.6	1.1
SUM	36.4	13.7	40.7	20.3	257.5	13.2	1175.9	145.7

C1 = AY / A =	C1 =	6.33	cm	API 650 Appendix V External Pressure Check			
C2 = Σ(d) - C1 =	C2 =	7.37	cm				
Astiff_act = A② + A③	Astiff_act=	25.00	cm^2	**> O.K**	Astiff_req	-25.36	cm^2
Iact = $\Sigma(Ah^2) + \Sigma(Ig)$ =	Iact=	1321.65	cm^4	**> O.K**	Ireqd	381.38	cm^4
Zact = Iact / Max(C1,C2)=	Zact=	179.32	cm^3	**> O.K**	Zreqd	153.40	cm^3

Required moment of inertia of the inertia of the intermediate stiffener, Ireqd (Appendix V.8.2.2.5)

Ireqd = 37.5 * Q * D^3 / E (N^2 - 1) Appendix V.8.2.3.2	**Ireqd**	=	381.38	cm^4	9.1626	in^4
Iact : Combined actual moment inertia of top end stiff. region	**Iact**	=	1321.65	cm^4	31.753	in^4

Therefore, Iact > Ireqd **Satisfied !**

Required total cross-sectional area of the intermediate stiffener , Areqd (Appendix V.8.2.2.6.1)

Areqd = Q * D / (2 * fc)	**Areqd**	=	608	mm^2	0.9422	in^2

Required cross-sectional area of the intermediate stiffener structural shape, Astiff_req (Appendix V.8.2.2.6.2)

Astiff_req = Areqd - 26.84 * tshell * (D * tshell)$^{0.5}$	**Astiff_req**	=	-2536	mm^2	-3.931	in^2
Astiff_act = A② + A③	**Astiff_act**	=	2500	mm^2	3.875	in^2

Therefore, Astiff_act > Astiff_req **Satisfied !**

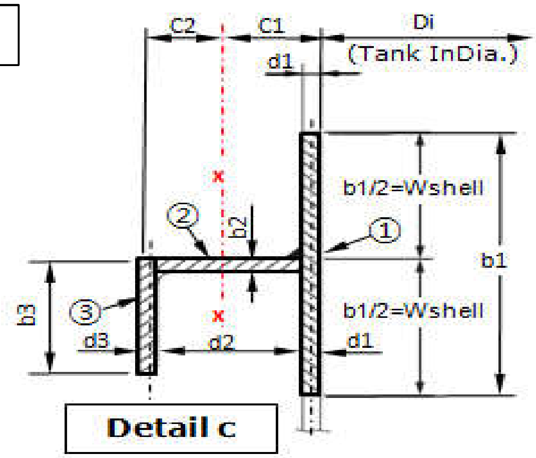
Where,

Radial load imposed on the stiffener , Q = 1000 * Ps * Ls =	Q	=	3131	N/m	214.52	lb/ft
Number of buckling waves (Min. N=2) (Appendix V.8.2.2.1)	N	=	10			
N^2 = SQRT[445 * D^3 / (tsmin * HTS^2)] = 208.85 ≤ 100	N^2	=	100			
Nominal tank diameter	D	=	40.0	m	131.2	ft
Elastic modulus at the Max. design Temp. (Appendix M.2a Table)	E	=	199000	MPa	28863	ksi
Allowable compressive stress Max(fc=0.4*Fy, 103)	fc	=	103.0	MPa	14.939	ksi
Yield strength of the component at the max. operating temperature	Fy	=	344.7	MPa	50	ksi

11.3) Intermediate stiffener required moment of inertia and cross-sectional area check

API 650 Figure 5.24—Typical Stiffening-ring Sections for Tank Shells

 # 2



	SIZE:	L130 x 130 x 10		LENGTH:	127	m	Weight :	2492 kg
No.	b cm	d cm	A cm^2	Y cm	AY cm^3	h cm	Ah^2 cm^4	$Ig = bd^3/12$ cm^4
①	22.4	0.70	15.7	0.4	5.5	6.0	560.6	0.6
②	1.0	12.0	12.0	6.7	80.4	0.4	1.6	144.0
③	13.0	1.0	13.0	13.2	171.6	6.9	613.6	1.1
SUM	36.4	13.7	40.7	20.3	257.5	13.2	1175.9	145.7

C1 = AY / A =	C1 =	6.33	cm	API 650 Appendix V External Pressure Check			
C2 = Σ(d) - C1 =	C2 =	7.37	cm				
Astiff_act = A② + A③	Astiff_act=	25.00	cm^2	> O.K	Astiff_req	-28.40	cm^2
Iact = $\Sigma(Ah^2) + \Sigma(Ig)$ =	Iact=	1321.65	cm^4	> O.K	Ireqd	190.69	cm^4
Zact = Iact / Max(C1,C2)=	Zact=	179.32	cm^3	> O.K	Zreqd	153.40	cm^3

Required moment of inertia of the inertia of the intermediate stiffener, Ireqd (Appendix V.8.2.2.5)

Ireqd = 37.5 * Q * D^3 / E (N^2 - 1) Appendix V.8.2.3.2	**Ireqd**	=	190.69	cm^4	4.5813	in^4
Iact : Combined actual moment inertia of top end stiff. region	**Iact**	=	1321.65	cm^4	31.753	in^4

Therefore, Iact > Ireqd **Satisfied !**

Required total cross-sectional area of the intermediate stiffener , Areqd (Appendix V.8.2.2.6.1)

Areqd = Q * D / (2 * fc)	**Areqd**	=	304	mm^2	0.4711	in^2

Required cross-sectional area of the intermediate stiffener structural shape, Astiff_req (Appendix V.8.2.2.6.2)

Astiff_req = Areqd - 26.84 * tshell * (D * tshell)$^{0.5}$	**Astiff_req**	=	-2840	mm^2	-4.402	in^2
Astiff_act = A② + A③	**Astiff_act**	=	2500	mm^2	3.875	in^2

Therefore, Astiff_act > Astiff_req **Satisfied !**

Where,

Radial load imposed on the stiffener , Q = 1000 * Ps * Ls =	Q	=	1565	N/m	107.26	lb/ft
Number of buckling waves (Min. N = 2) (Appendix V.8.2.2.1)	N	=	10			
N^2 = SQRT[445 * D^3 / (tsmin * HTS^2)] = 208.85 ≥ 100	N^2	=	100			
Nominal tank diameter	D	=	40.0	m	131.2	ft
Elastic modulus at the Max. design temp. (Appendix M.2a Table)	E	=	199000	MPa	28863	ksi
Allowable compressive stress Max(fc=0.4*Fy, 103)	fc	=	103.0	MPa	14.939	ksi
Yield strength of the component at the max. operating temperature	Fy	=	344.7	MPa	50	ksi

12 Compression-Ring Calculation (Based on API 620 11th Edi. 5.12.4)

1) Sketch drawing

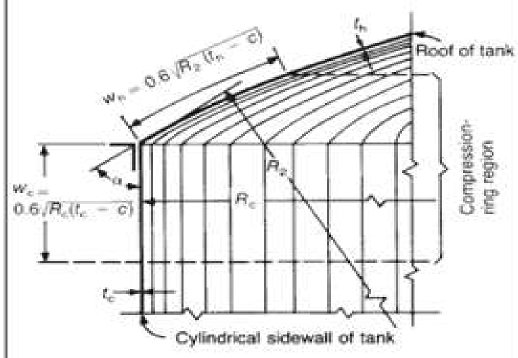


Figure 5-5 Compression-Ring Region

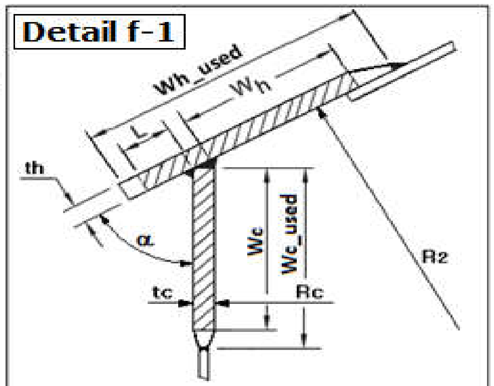


Figure 5-6 Pennissible and Non-pennissible Details of Construction for a Compression-ring Juncture

2) Loading weight

W = Total weight of roof plate and structure & accessory		W	=	2539.4	kN	570887.9	lbf
(Include roof platform & etc.)							
F = Summation weight of roof		F	=	0.0	kN	0.0	lbf
Wt = Total weight (Wt = W + F)		Wt	=	2539.4	kN	570887.9	lbf

3) Equivalent pressure of roof total weight

At = Cross sectional area of tank inside dia.	At = π * Rc^2	At	=	12566371	cm^2	1947791	$inch^2$
Pg = Internal design pressure		Pg	=	15.00	kPa	2.18	psi
qzr = Design wind pressure on horizontal projected areas		qzr	=	0.7	kPa	0.11	psi
Pc = Vertical unit pressure of roof weight	Pc = (W+F) / At	Pc	=	2.0	kPa	0.29	psi
P = Sum of total pressure	P = (Pg+qzr) - (W+F) / At	P	=	13.7	kPa	1.99	psi

4) Compression ring calculation

		Material	=	SA537-CL1+S5			
E = Joint efficiency of compression-ring		E	=	1.0			
Sts = Max. allowable tensile strength		Sts	=	144790	kPa	21000	psi
CA_sh = Corrosion allowance (Shell side)		C_sh	=	3.0	mm	0.12	inch
CA_rf = Corrosion allowance (Roof side)		C_rf	=	3.0	mm	0.12	inch
R2 = Dome roof radius		R2	=	36000	mm	1417.32	inch
Rc = Inside radius of tank shell		Rc	=	20000	mm	787.40	inch
tc = Compression ring thk. of top shell (Excl. CA)		tc	=	31.00	mm	1.22	inch
th = Compression ring thk. of roof end (Excl. CA)		th	=	31.00	mm	1.22	inch
Wc = Max. width of top shell	Wc = 0.6 * $(Rc * tc)^{0.5}$	Wc	=	472.44	mm	18.60	inch
Wh = Max. width of roof end	Wh = Min[32th, 0.6 $(R2 * th)^{0.5}$]	Wh	=	633.85	mm	24.95	inch
L = Projection length of roof compression-ring edge part		L	=	100.00	mm	3.94	inch
Where, Wh $\geq$ L $\leq$ 16th and Wh $\leq$ 32th		Wh : 32 * th	=	1088.00	mm	42.83	inch

5) Effective sectional area of compression ring

Aact = (Wh + L + tc) th + Wc * tc	**Aact**	**=**	**383.56**	**cm^2**	**59.45**	**$inch^2$**

6) Total circumferential force force in compression ring **(API 620 Para. 5.12.4.3)**

Q = T2 * Wh + T2s * Wc - T1 * Rc * Sin(α)			Q	=	3770.49	kN	847640.9	lbf
α = Angle (Refer to figure 5-6)	α =	56.25 deg	Sin(α)	=	0.83			
T1 = 0.5 * R2 [(Pg+qzr) - (W+F)/At]			T1	=	246.70	N/mm	1408.68	lbf/in
T2 = R2 (Pg+qzr) - T1			T2	=	319.45	N/mm	1824.09	lbf/in
T2s = P * Rc			T2s	=	274.11	N/mm	1565.20	lbf/in

7) Required cross sectional area

Areq = Max(Q / 15000, Q / (Sts * E)) = Max (56.51, 40.36)	**Areq**	**=**	**364.58**	**cm^2**	**56.51**	**$inch^2$**

8) Evaluation of Compression-ring sectional area

Areq (364.58 cm^2) < Aact (383.56 cm^2) **O.K**

9) Used thickness and used width dimension of Compression Ring

tc_used = Used thickness of top shell course	tc_used	=	34.0	mm	1.34	inch
th_used = Used thickness of roof end part	th_used	=	34.0	mm	1.34	inch
Wc_used = Design width of top shell course	Wc_used	=	540.0	mm	21.26	inch
Wh_used = Design width of roof end part	Wh_used	=	890.0	mm	35.04	inch
Atot_used = Total sectional area of used dimension	Atot_used	=	486.2	cm^2	75.36	$inch^2$

13. Tank stability check and loading data.

13.1) Tank stability check due to wind load.

1) Wind velocity pressure calculation: (ASCE 7-10)

qzs= 0.613 * Kzs * Kzt * Kd * V2 * Gf * Cf	(Shell)	qzs =	**684.72**	Pa	14.301	lb/ft^2
qzr = 0.613 * Kzr * Kzt * Kd * V2 * Gf * Cf	(Roof)	qzr =	**726.23**	Pa	15.168	lb/ft^2

Where, [V in m/sec]

Design wind speed (3-sec. gust)	V = 38.89 m/sec	=	140.0	km/h	87.00	mph
Kd = Wind directionality factor (When round, kd=0.95)		Kd =	0.95			
Kzs = Velocity pressure exposure coefficient (shell)		Kzs =	1.1433			
Kzr = Velocity pressure exposure coefficient (roof)		Kzr =	1.2126			
Terrain exposure category	α= 9.5	zg =	274.3	m	900.0	ft
Tank height + Foundation height		z(s) =	18.81	m	61.71	ft
Tank height + Roof height + Foundation height		z(r) =	24.88	m	81.62	ft
Kzt = Topographic factor defined		Kzt =	1.000			
EC =Exposure category : C	Occupancy category : III					
Gf = Gust effect factor		Gf =	0.85			
Cf = Force coefficient		Cf =	0.80			

2) Wind design on tanks (Overturning stability)

2-1) Wind load calculation

Design wind speed (3-sec. gust)		V	=	140.0	km/h
Tank out-diameter	D = Di + 2 * (AVG. Sh_thk.)	D	=	40.014	m
Tank shell height		Hts	=	16.610	m
Design liquid level		H	=	12.600	m
Roof radius	Roof type : Dome roof	Rr	=	36.000	m
Roof height	Roof slope : 1 : 0.9	Htr	=	6.0667	m
Design wind pressure on vertical projected areas		qzs	=	860.00	Pa
Design wind pressure on horizontal projected areas		qzr	=	726.23	Pa
Design internal pressure		Pi	=	15000	Pa
Operating pressure		Po	=	5000	Pa
Shell insulation thickness (Outer side)		Is	=	0.000	mm
Roof insulation thickness (Outer side)		Ir	=	0.000	mm
Up-lift force by internal pressure	$Fi = \pi * D^2 / 4 * Pi$	Fi	=	18862382	N

WDL : Shell (Roof) weight available to resist up-lift, less any corrosion allowance,

Ws = 223016(kg) - C.A:3.0mm * 7.85 * πDH =	173830	kg	Ws	=	1704690	N
Wr = Roof plate + Any attachment (With C.A)	81815	kg	Wr	=	802333	N
W_{DL} = Ws	173830	kg	W_{DL}	=	1704690	N

2-2) Project area of shell and roof

As = Project area of shell	As = (D + 2Is/1000) * Hts	As	=	664.63	m^2
Ar = Project area of circular segment of umbrella (Dome) roof		Ar	=	1257.49	m^2
sr = Roof plate thickness (With corroded), roof surface area	6.00	mm		762.37	m^2

2-3) Up-lift force by wind

Fr = Wind force of roof = Ar * qzr	Fr	=	93123	kg	913229	N

2-4) Base shear force by wind

Fs = Wind force of shell = As * qzs	**Fs**	**=**	58285	kg	**571578**	**N**

2-5) Moment calculation and overturning check for un-anchored tank

Mw = Overturning moment from horizontal plus vertical wind pressure

= Fs * Hts/2 + Fr * D/2	**Mw**	**=**	2347157	kg-m	**23017.7**	**kN-m**

Mpi = Moment about the shell-to-bottom joint from design internal pressure

= $(\pi D^2/4)$ * Pi * (D/2)	Mpi	=	38481644	kg-m	377376.0	kN-m

M_{DL} = Moment about the shell-to-bottom joint from the weight of the shell

= WDL * (D/2)	MDL	=	3477783	kg-m	34105.4	kN-m
Fp = Pressure combination factor : Max(Po/Pi, 0.4)	Fp	=	0.4			

MF = Moment about the shell-to-bottom joint from liquid

= $(\pi$D * wL) * (D/2)	MF	=	6983282	kg-m	68482.6	kN-m

MDLR = Moment about the shell-to-bottom joint from the weight of roof plate

plus any attached structural — MDLR = Wr * (D/2)	MDLR	=	1636860	kg-m	16052.1	kN-m

Mws = Overturning moment from horizontal wind pressure

= As * (Hts/2) * qzs	Mws	=	484055	kg-m	4747.0	kN-m
Wa = Liquid hold down weight — wa = π * D * wL	Wa	=	349045	kg	3423.0	kN

Where,

wL1 = 59 * tb * SQRT(Fby * H)	wL1	=	27.2	kN/m
wL2 = 140.8 * H * D	wL2	=	71.0	kN/m
wL = Min (wL1 or wL2)	wL	=	27.230	kN/m
ts1 = 1st course shell plate thickness (Corroded)	ts1	=	15.00	mm
tb = Annular plate thickness (Corroded)	tb	=	7.00	mm
Fby = Annular plate yield stress	Fby	=	345.0	Mpa

2-6) Overturning check for un-anchored tank

*** Check of unanchored tanks**

1) 0.6Mw + Mpi	=	391187	>	MDL / 1.5 + MDLR	=	38789	Anchorage shall be required.
2) Mw + Fp (Mpi)	=	173968	>	(MDL + MF) / 2 + MDLR	=	67346	Anchorage shall be required.
3) Mws+ Fp (Mpi)	=	155697	>	MDL / 1.5 + MDLR	=	38789	Anchorage shall be required.

THEREFORE, ANCHORAGE IS REQUIRED.

API 650 5.11 Wind Load on Tanks (Overturning Stability)

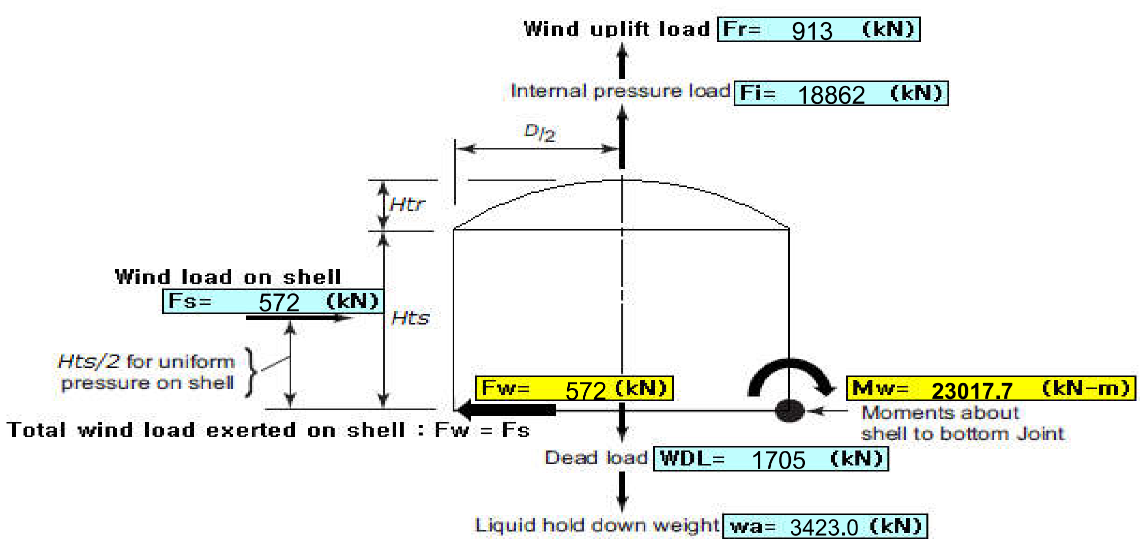
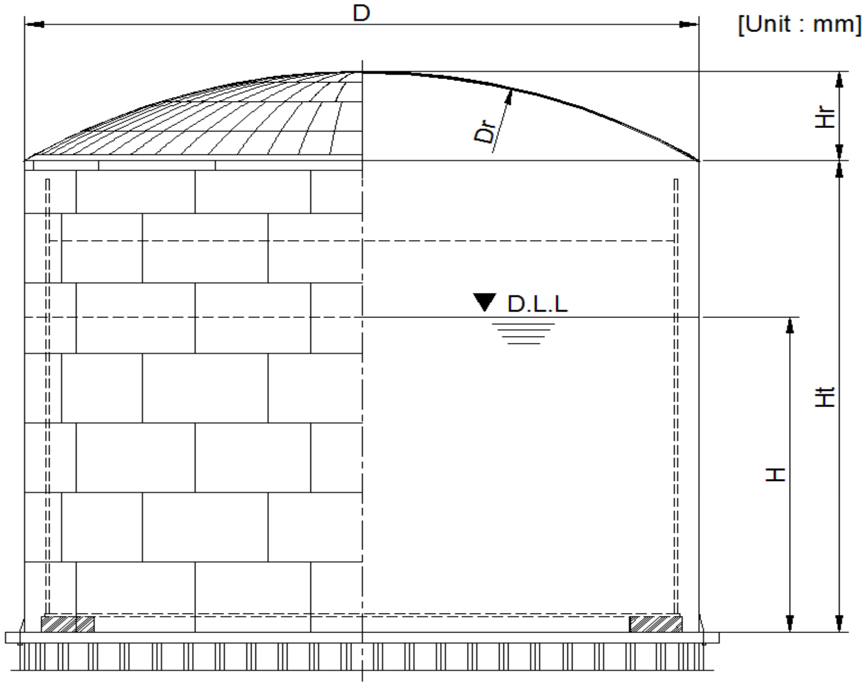


Figure 5.27—Overturning Check for Unanchored Tanks

13.2) Tank stability check due to seismic : API 620 APPENDIX. L [CLE]

1) DESIGN CONDITION & DIMENSION

o DESIGN CODE : API 620 APPENDIX. L [CLE] and API 650 Appendix E and ASCE 7-10



Roof type & slope		Dome roof				
Tank diameter	D =	40000	mm	=	131.234	ft
Tank height	Ht =	16610	mm	=	54.495	ft
Dome roof radius	Dr =	36000	mm	=	118.110	ft
Roof height	Hr =	6066.7	mm	=	19.904	ft
1st shell course thickness	t =	18.00	mm	=	0.709	inch
Min. yield strength of 1st shell and annular plate	Fty =	344.738	Mpa	=	50.000	ksi
Product design stress	Sd =	144.790	Mpa	=	21.000	ksi
Tank elastic modulus	E =	199000	Mpa	=	29000	ksi
Shell weight (Excluded anchor strap weight)	Ws =	265.669	Ton	=	585.700	kips
Roof weight	Wr =	258.950	Ton	=	570.888	kips
Bottom weight	Wf =	99.457	Ton	=	219.264	kips
Specific gravity of content	G =	0.684				
Density of fulid	p =	684	kg/m^3	=	42.70	pcf
Design liquid level (H = D.L.L)	H =	12600	mm	=	41.339	ft
Contents weight	Wp =	10830	Ton	=	23876.10	kips
Corrosion allowance	C.A =	3.0	mm	=	0.118	inch
Design internal pressure	Pi =	1529.57	mmAq	=	15.00	kPa
				=	0.150	bar

Importance factor classification.

Importance factor	(by API 620 App. L.4.4.2 3)	=	**1.00**
Soil site class		=	**C**

Spectral response acceleration parameter for short and 1-second periods:

Spectral acceleration param. (0.2 sec period)	S_S =	1.540	g	
Spectral acceleration param. (1 sec period)	S1 =	0.315	g	
Regional-dependent transition long-period	TL =	6.000	sec	
Seismic peak ground acceleration	Sp =	0.616		Sp = SS / 2.5, Sp=S1 / 1.25

Site coefficient for short and 1-second periods:

Acceleration-based site coefficient	F_a =	1.000	g	
Velocity-based site coefficient	F_v =	1.500	g	

MCE spectral response accelerations for short and 1-second periods:

MCE spectral response acceleration param	S_{MS} =	1.540	$S_{MS} = F_a S_s$	ASCE 7-10
MCE spectral response acceleration param	S_{M1} =	0.473	$S_{M1} = F_v S_1$	ASCE 7-10

MCE : Maximum Considered Earthquake

2) Design spectral response accelerations for short and 1-second periods: (5% damped)

Scaling factor	(by API 620 App. L.4.4.2 1))	Q =	1.000		
Design spectral response acceleration param.		S_{DS} =	1.540	g	SDS = Q * SMS
Design spectral response acceleration param.		S_{D1} =	0.473	g	SD1 = Q * SM1
	T0 = 0.2 * SD1 / SDS	T0 =	0.061	sec	ASCE 7-10
	Ts = SD1 / SDS	Ts =	0.307	sec	ASCE 7-10
Regional-dependent transition long-period		T_L =	6.000	sec	

Structural period of vibration (Including sloshing): (Using API 650 Appendix E)

Coefficient of impulsive natural period	Ci =	7.201		Ci = from API 650 Appendix E, Fig. E-1
Coefficient of sloshing period	Ks =	0.638		Ks =0.578 / SQRT(TANH(3.68 * H/D))
Impulsive natural period	Ti =	0.238	sec.	
Convective (Sloshing) period	Tc =	N/A	sec.	
Short period (Design)	Ts =	0.307	sec	

Where, Ti(sec) = Max{ $(1/2000^{0.5}) * (Ci * H / (t/D)^{0.5}) * (p/E)^{0.5}$, 0.128 } API 650 Appendix E.4.5.1-1a

Tc(sec) = 1.8 * Ks * SQRT(D) API 650 Appendix E4.5.2-a

Ts(sec) = SD1 / SDS ASCE 7-10

3) Design spectral response accelerations of Tank (Impulsive method)

Force reduction factor (Impulsive mode)	Rwi =	2.0		
Force reduction factor (Convective mode)	Rwc =	N/A		
Coefficient to adjust the spectral acceleration	K =	1.5		API 620 Appendix. L.4.2
Impulsive spectral acceleration parameter	Ai =	0.7700	g	
Convective spectral acceleration parameter	Ac =	N/A	g	
Vertical earthquake acceleration parameter	Av =	0.7238	g	Av = 0.47 * SDS

Where,

Impulsive spectral acceleration parameter, A_i:

$$A_i = S_{DS}\left(\frac{I}{R_{wi}}\right) = 2.5QF_aS_0\left(\frac{I}{R_{wi}}\right)$$

However, $A_i \geq 0.007$

and, for $S_1 \geq 0.6$:

$$A_i \geq 0.5S_1\left(\frac{I}{R_{wi}}\right) = 0.625S_P\left(\frac{I}{R_{wi}}\right)$$

Convective spectral acceleration parameter, A_c:

When, $T_C \leq T_L$ $$A_c = KS_{D1}\left(\frac{1}{T_c}\right)\left(\frac{I}{R_{wc}}\right) = 2.5KQF_aS_0\left(\frac{T_s}{T_c}\right)\left(\frac{I}{R_{wc}}\right) \leq A_i$$

When, $T_C > T_L$ $$A_c = KS_{D1}\left(\frac{T_L}{T_c^2}\right)\left(\frac{I}{R_{wc}}\right) = 2.5KQF_aS_0\left(\frac{T_sT_L}{T_c^2}\right)\left(\frac{I}{R_{wc}}\right) \leq A_i$$

API 620 Table L-1R, Appendix R tanks

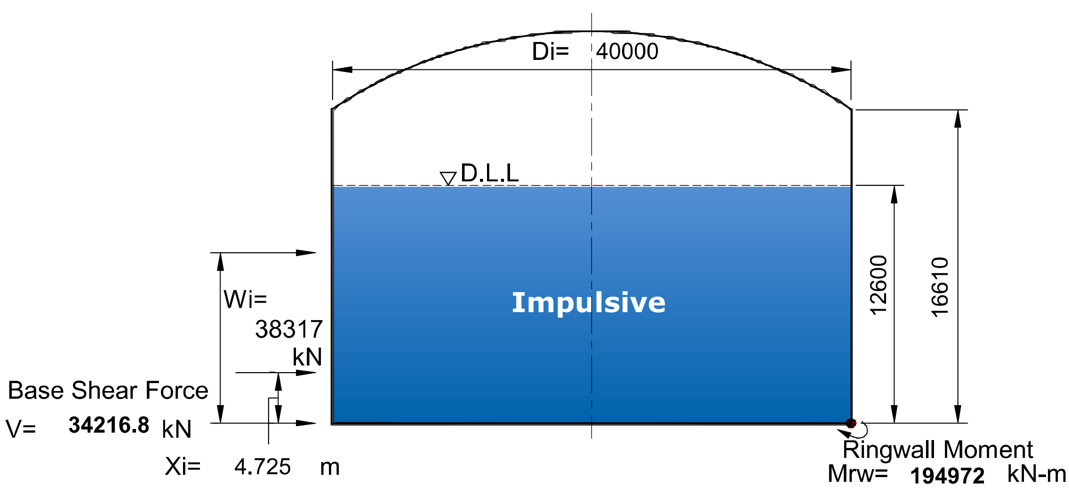
Outer Tank :		
Anchorage system	Rwi	Rwc
Self - anchored	2.0	N/A
Mech. - anchored	**2.0**	**N/A**

4) Seismic base shear force and sliding resistance

Total Base Shear Force at design (SRSS)	**V =**	**3489.1**	ton	**34216.8**	kN
Sliding Resistance	Vs =	**3255.2**	ton	**31922.7**	kN

Therefore , The tank is Sliding. Not Self-anchored (V > Vs)

Where,		CASE = D/H =	3.175 > 1.333	
Short period (Design)	Ts =	0.307	sec., Ts = SD1/SDS, ASCE 7-10 seismic design criteria	
Impulsive natural period coefficient	Ci =	7.201	(API 650 E, Fig. E-1) H/D= 12.6/40= 0.315	
Impulsive natural period	Ti =	0.238	sec., Ti = $1/(2000^{0.5})$*Ci*H*SQRT(p/E)/SQRT(t/D)	
Convective (Sloshing) period	Tc =	N/A	sec., Tc =1.8 * Ks * SQRT(D)	
Effective impulsive portion, liquid weight	Wi =	3907	ton 38317 KN	Wi = TANH(0.866*D/H)/(0.866*D/H)*Wp
Effective convective portion, liquid weight	Wc =	N/A	ton N/A KN	Wc = (0.23*D/H*TANH(3.67*H/D))*Wp
Design base shear force (Impulsive components)	Vi =	3489.1	ton Vi = Ai * (Wr+Ws+Wf+Wi)	
Design base shear force (Convective components)	Vc =	N/A	ton Vc = Ac * Wc	
Total base shear force at design (SRSS)	V =	3489.1	ton V = SQRT($Vi^2 + Vc^2$)	
SRSS : Square Root of the Sum of the Squares				
Friction coefficient for tank sliding	μ =	0.40		
Sliding resistance	Vs =	3255.21	ton Vs = μ * (Wr+Ws+Wf+Wp) * (1.0-0.4Av)	
Local shear transfer force (kg/cm)	Vmax =	555.31	kg/cm Vmax = 2V / πD API 650 E7.7-1	



Seismic Moment and Force Diagram

5) Overturning Moment

(Note: Mrw is the ringwall overturning moment at top of foundation.)

Center of action for ring wall overturning moment	CASE : D/H =	3.175	>	1.333	
Height of tank shell's center of gravity (Included intermediate stiffener)	Xs =	7829.4	mm	7.829	m
Height of roof appurtenances center of gravity	Xr =	20384	mm	20.384	m
Height of impulsive mode (for RINGWALL moment)	Xi =	4725	mm	4.725	m
Height of convective mode (for RINGWALL moment)	Xc =	N/A	mm	N/A	m
Height of impulsive mode (for SLAB momentt)	Xis =	15887	mm	15.887	m
Height of convective mode (for SLAB moment)	Xcs =	N/A	mm	N/A	m
Overturning RINGWALL moment	**Mrw =**	**19881566**	**kg.m**	**194972**	**KN-m**
Overturning SLAB moment	**Ms =**	**53464688**	**kg.m**	**524309**	**KN-m**

Where, Mrw = SQRT[Ai * (Wi * Xi + Ws * Xs + Wr * Xr)]^2 + (Ac * Wc * Xc)^2]

Ms = SQRT[Ai * (Wi * Xis + Ws * Xs + Wr * Xr)]^2 + (Ac * Wc * Xcs)^2]

6) Anchorage Ratio

$$J = \frac{Mrw}{D^2[wt(1-0.4Av) + wa - 0.4wint]} = \boxed{131.437}$$

API 650 Appendix E (Table E-6) Anchorage Ratio Criteria

J ≤ 0.785	No calculated uplift under the design seismic overturning moment. The tank is self-anchored.	
0.785 < J ≤ 1.54	Tank is uplifting, but the tank is stable for the design load providing the shell compression. requirements are satisfied. Tank is self-anchored.	
J > 1.54	Tank is not stable and cannot be self-anchored for the design load. Modify the annular ring if L < 0.035D is not controlling or add mechanical anchorage.	O

Where,

Vertical earthquake acceleration parameter	Av =	0.724		Av = 0.47 * SDS	
Effective specific gravity	Ge =	0.486		Ge = G * (1 - 0.4Av)	
Shell and roof weight acting at base of shell	Wt =	4174.8	kg/m	Wt = Ws / πD + wrs	
Roof load acting on the shell, including - 10% of the specified snow load	wrs =	2060.7	kg/m	wrs = Wr / πD	
Force resisting uplift in annular region	wa =	**3246.7**	kg/m	31839.6	N/m
99 * ta * SQRT(Fy * H * Ge) ≤		201.1 * H * D * Ge		(API 650 E6.2.1.1-1a)	
wa = Min(	**3246.7** ,	5022.6	**) kg/m**		
waMax = 5742*H*Ge*Ls, Ls=0.035D	waMax =	2151.2	kg/m	(API 650 E6.2.1.1-2a)	

Calculated design uplift load due to product pressure per unit circumferential length

wint = $\pi D^2/4$ * Pi/πD = (D/4) * Pi	wint =	15295.7	kg/m				
Internal design pressure	Pi =	1529.6	mmAq	15.00	kPa	0.1500	bar

Mechanical Anchorage required check by Seismic :	**YES**	API 650 Appendix E.6.2.1.1.1
Mechanical Anchorage required check by Wind :	**YES**	API 650 5.11.2.1 (See. 8.1 Wind stability check)

7) Annular Ring Requirement

Min. radial width (API 650 Appendix E.6.2.1.1.2-1a) L = 0.01723 * ta * SQRT(Fy/(H*Ge)) L = 905.0 mm

The maximum width of annulus for determining the resisting force, 0.035 D (per API 650 E6.2.1.1.2-1a)

Annular plate limit width L Max. = 1400.0 mm L Max. = 0.035D

Annular plate thickness. Corr. allowance:

10.0 - 3.0 = ta= 7.0 mm

Min. specified yield strength of annular plate Fy = 344.7 Mpa (SA537-CL1 API 620 Table 5-1)

8) Uplift force calculation due to seismic loading. : (Only Mechanically anchored Tanks)

WAB = (1.273Mrw / D²) - wt(1-0.4Av)	WAB=	12852	kg/m	=	126.0	KN/m
WAB : Calculated design uplift load on anchors per unit circumferential length.						
Wint : Calculated design uplift load due to design internal pressure per unit circumferential length	wint=	15295.7	kg/m	=	150.0	KN/m
Tse : Load per anchorage Tse = πD * WAB / N	Tse=	28.84	Ton	=	282.8	KN
Anchor quantity : 56 Sets						

9) Shell-Membrane Compression Stress (API 650 Appendix E.6.2.2)

Compression in Mechanically anchored Tanks

Maximum longitudinal shell compression stress. (σc) When **J (131.437) > 1.54**

x	Un-anchored tanks	When J ≤ 0.785	σc =	1.413	kg/mm²	13.86	Mpa
x	Un-anchored tanks	When 0.785 < J ≤ 1.54	σc =	-0.216	kg/mm²	-2.12	Mpa
O	Mechanically anchored	When J >1.54	σc =	1.413	kg/mm²	13.86	Mpa

Allowable longitudinal shell-membrane compression stress (API 650 Appendix E.6.2.2.3)

When, $GHD^2/ts^2 \geq 44$ GHD^2/ts^2 = 61.29 m³/mm² ≥ 44 m³/mm²

Fc = 83ts / D Fc = 31.125 Mpa 3.174 kg/mm^2

Therefore,

Maximum stress σc (kg/mm²)		Allowable Stress Fc (kg/mm²)
1.413	<	3.174

Tank is stable by seismic.

Specific gravity of content	G =	0.684	
Thk. of 1st shell course less corrosion allowance	ts = 18 - 3.0 =	15.0	mm
Min. specified yield strength of 1st shell course	Fty = 344.7 Mpa =	35.153	kg/mm²

Maximum longitudinal shell compression stress. (σc) :

1) for Self-Anchored Tanks, [API 650 Appendix E 6.2.2.1]

x When, J ≤ 0.785

$$\sigma_c = \left(w_t(1+0.4A_v) + \frac{1.273M_{rw}}{D^2}\right)\frac{1}{1000t_s}$$

1.41 kg/mm² 13.86 MPa

x When 0.785 < J ≤ 1.54

$$\sigma_c = \left(\frac{w_t(1+0.4A_v)+w_a}{0.607-0.18667[J]^{2.3}} - w_a\right)\frac{1}{1000t_s}$$

-0.22 kg/mm² -2.12 MPa

2) for Mechanically-Anchored Tanks, [API 650 Appendix E 6.2.2.2]

O When J >1.54

$$\sigma_c = \left(w_t(1+0.4A_v) + \frac{1.273M_{rw}}{D^2}\right)\frac{1}{1000t_s}$$

1.41 kg/mm² 13.86 MPa

10) Dynamic Hoop Stress Calculation (API 650 Appendix E 6.1.4)

When, D/H = 3.175 > 1.333 (=4/3)

No.	t	Y	Nh	Y< 0.75D	Ni	Nc	**σT**	**< or >**	**Sa**	**Check**
	mm	m	(N/mm)		(N/mm)	(N/mm)	**(Mpa)**		**(Mpa)**	
8	31.0	0.000	-40.2	< 0.75D	0.0	N/A	**-0.92**	**<**	**192.6**	**OK**
7	7.0	0.000	-40.2	< 0.75D	0.0	N/A	**-4.08**	**<**	**192.6**	**OK**
6	7.0	0.250	-6.7	< 0.75D	43.9	N/A	**5.31**	**<**	**192.6**	**OK**
5	7.0	2.720	324.4	< 0.75D	429.9	N/A	**109.22**	**<**	**192.6**	**OK**
4	8.0	5.190	655.6	< 0.75D	730.2	N/A	**176.26**	**<**	**192.6**	**OK**
3	11.0	7.660	986.7	< 0.75D	944.7	N/A	**179.43**	**<**	**192.6**	**OK**
2	13.0	10.130	1317.8	< 0.75D	1073.4	N/A	**189.00**	**<**	**192.6**	**OK**
0	15.0	12.600	1649.0	< 0.75D	1116.3	N/A	**190.87**	**<**	**192.6**	**OK**

Where,

t	=	Thickness of the shell under consideration (Corroded)		(mm)		
Y	=	Distance from liquid surface to analysis point (Positive down)		(m)		
Nh	=	Product hydrostatic membrane force in shell		(N/mm)		
Ni	=	Impulsive hoop membrane force in shell		(N/mm)		
Nc	=	Convective hoop membrane force in shell		(N/mm)		
σT	=	Total combined hoop stress in shell		(Mpa)		
		$\sigma T = \sigma h \pm \sigma s = \{Nh \pm [Ni^2 + (Av * Nh / 2.5)^2]^{0.5}\} / t$				
G	=	Specific gravity	0.684			
D	=	Tank diameter	40.000	m		
H	=	Height of product liquid	12.600	m		
Ai	=	Impulsive spectral acceleration parameter	0.770			
Ac	=	Convective spectral acceleration parameter	N/A			
Av	=	Vertical earthquake acceleration parameter	0.724			
E	=	Joint efficiency	1.0			
Fty	=	Min. reduced yield strength of bottom shell course	344.738	Mpa	50000	psi
Sd	=	Product design stress	144.790	Mpa	21000	psi
Sa	=	Allowable stress (API 650 Appendix E.6.2.4)	192.571	Mpa	27930	psi

Sa=Min(0.8 * Fty * E, Sd * 1.33)

14. Maximum shell compressive (Buckling) stress calculation

14.1) Buckling check of Shell course (Case A. Uncorroded condition)

(API650 Appendix E 6.2.2)

Shell course	Shell height	Ts	Each Shell weight	Wt= (Ws+Wr) / πD	Mrw (Each shell)	D.L.L	σc maximum stress		Fc Allowable stress	Buckling check
No.	mm	mm	kg	kg/m	kg-m	mm	kg/mm^2		kg/mm^2	
8	540	34.0	18127	2264	4068190	0	0.1811	<	2.8776	OK
7	1250	10.0	12334	2362	4122730	0	0.6327	<	0.8464	OK
6	2470	10.0	24372	2556	4522570	250	0.6895	<	1.1626	OK
5	2470	10.0	24372	2750	7473412	2720	0.9493	<	1.8895	OK
4	2470	11.0	26809	2964	10477799	5190	1.1053	<	2.3720	OK
3	2470	14.0	34124	3235	13533173	7660	1.0671	<	2.9355	OK
2	2470	16.0	39000	3545	16656405	10130	1.1140	<	3.3673	OK
1	2470	18.0	43878	3895	19881566	12600	1.1578	<	3.7686	OK
Total	16610		223016							

Where,

Wt	=	Tank and roof weight acting at base of shell (kg/m)						
Ws	=	Shell weight (Ws = Wo + Accumulated shell weight)	=	230461	kg	=	508079	lb
Wo	=	Shell attachment weight (Excluded anchor strap weight)	=	7445	kg	=	16413	lb
Wr	=	Roof weight	=	258950	kg	=	570888	lb
D	=	Tank diameter	=	40000	mm	=	1574.8	in
R	=	Outer tank radius	=	20000	mm	=	787.4	in
Mrw	=	Overturning ringwall moment	=	19881566	kg·m	=	194971560	N·m
H	=	Maximum design product level	=	12600	mm	=	496.06	in
G	=	Design specific gravity	=	0.684				
Av	=	Vertical earthquake acceleration parameter	=	0.724	g			
σc	=	Maximum longitudinal shell compression stress (kg/mm^2)						
Fc	=	Allowable longitudinal shell-membrane compression stress (kg/mm^2)						
Ts	=	Shell thickness (Uncorroded)						

14.2) Buckling check of Shell course (Case B. Corroded condition)

(API650 Appendix E 6.2.2)

Shell course	Shell height	Ts (t-Ca)	Each Shell weight	Wt= (Ws+Wr) / πD	Mrw (Each shell)	D.L.L	σc maximum stress		Fc Allowable stress	Buckling check
No.	mm	mm	kg	kg/m	kg-m	mm	kg/mm^2		kg/mm^2	
8	540	31.0	16526	2016	4068190	0	0.1883	<	2.6237	OK
7	1250	7.0	8633	2085	4122730	0	0.8527	<	1.4811	OK
6	2470	7.0	17059	2221	4522570	250	0.9231	<	1.4811	OK
5	2470	7.0	17059	2356	7473412	2720	1.2835	<	1.6356	OK
4	2470	8.0	19496	2512	10477799	5190	1.4469	<	2.1181	OK
3	2470	11.0	26809	2725	13533173	7660	1.2983	<	2.6816	OK
2	2470	13.0	31686	2977	16656405	10130	1.3147	<	3.1134	OK
1	2470	15.0	36562	3268	19881566	12600	1.3355	<	3.5147	OK
Total	16610		173830							

Where,

Wt	=	Tank and roof weight acting at base of shell (kg/m)						
Ws	=	Shell weight (Ws = Wo + Accumulated shell weight)	=	180009	kg	=	396853	lb
Wo	=	Shell attachment weight (Excluded anchor strap weight)	=	6179	kg	=	13623	lb
Wr	=	Roof weight	=	230655	kg	=	508507	lb
D	=	Tank diameter	=	40000	mm	=	1574.8	in
R	=	Outer tank radius	=	20000	mm	=	787.4	in
Mrw	=	Overturning ringwall moment	=	19881566	kg·m	=	194971560	N·m
H	=	Maximum design product level	=	12600	mm	=	496.06	in
Ca	=	Corrosion allowance	=	3.0	mm	=	0.12	in
G	=	Design specific gravity	=	0.684				
Av	=	Vertical earthquake acceleration parameter	=	0.724	g			
σc	=	Maximum longitudinal shell compression stress (kg/mm^2)						
Fc	=	Allowable longitudinal shell-membrane compression stress (kg/mm^2)						
Ts	=	Shell thickness (Corroded)						

15. Weight Summary (Inner tank)

ITEM NO. : 2-TK-5101

Description	Weight (Kg)	Weight (N)
1) Shell		
Shell plate	182836	1793009
Top gider	1881	18446
Shell nozzle	0	0
Internal ladder supported by shell	8000	78453
Stairway, platform, accessory	2000	19613
Internal heating coil & support	0	0
Anchor strap	7000	68647
Others	0	0
Sub-Total	**201717**	**1978168**
2) Bottom		
Annular plate	9254	90754
Bottom plate	84252	826230
Others	0	0
Sub-Total	**93506**	**916984**
EMPTY WEIGHT	**295,223**	**2,895,152**
WEIGHT OF LIQUID CONTENT	**10,790,469**	**105,818,349**
WEIGHT OF WATER (TEST CONDITION)	**15,775,539**	**154,705,189**

16. Weight Summary (Outer tank)

ITEM NO. : 2-TK-5101

Description	Weight (Kg)	Weight (N)
1) Shell		
Shell plate & compression ring	223016	2187040
Compression ring	35208	345273
Intermediate wind girder	3445	33784
Shell nozzle	4000	39227
Stairway, platform, accessory	0	0
External ladder	0	0
Internal ladder supported by shell	0	0
Water spray	0	0
Internal heating coil & support	0	0
Roof handrail supported by shell	0	0
Anchor strap	7000	68647
Others	0	0
Sub-Total	**272669**	**2673971**
2) Bottom		
Annular plate	18913	185471
Bottom plate	80544	789865
Drain pipe w/sump	0	0
Bottom side heating coil & support	0	0
Others	0	0
Sub-Total	**99457**	**975336**
3) Roof		
Roof plate	96950	950759
Column	0	0
Rafter & girder	40000	392266
Gondora Ring beam	8000	78453
Walk way & handrail	10000	98067
Roof gauging platform	10000	98067
Water spray system	0	0
Suspended deck	79000	774725
Roof nozzle	10000	98067
Top disc., column base & clip	0	0
Others	5000	49033
Sub-Total	**258950**	**2539437**
4) Shell & Bottom & Roof insulation		
Shell side	8185	80267
Bottom side	339717	3331486
Roof side	10000	98067
Sub-Total	**357902**	**98067**
EMPTY WEIGHT	**988,978**	**6,286,811**
TOTAL EMPTY WEIGHT	**1,284,201**	**9,181,963**
OPERATING WEIGHT	**12,074,670**	**118,412,063**
HYDRO. TEST WEIGHT	**17,059,740**	**167,298,903**