Tank design

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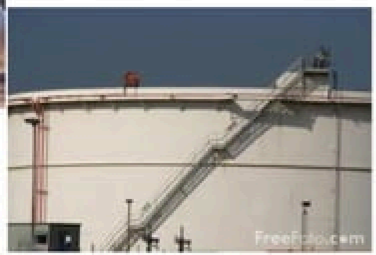
Tanks



Classification

- Open Top Tanks
- Fixed Roof Tanks
- Floating Roof Tanks

Open Top Tanks

- This type of tank has no roof.
- They shall not be used for petroleum product
- may be used for fire / cooling water.
- The product is open to the atmosphere; hence it is an atmospheric tank.

Fixed Roof Tanks

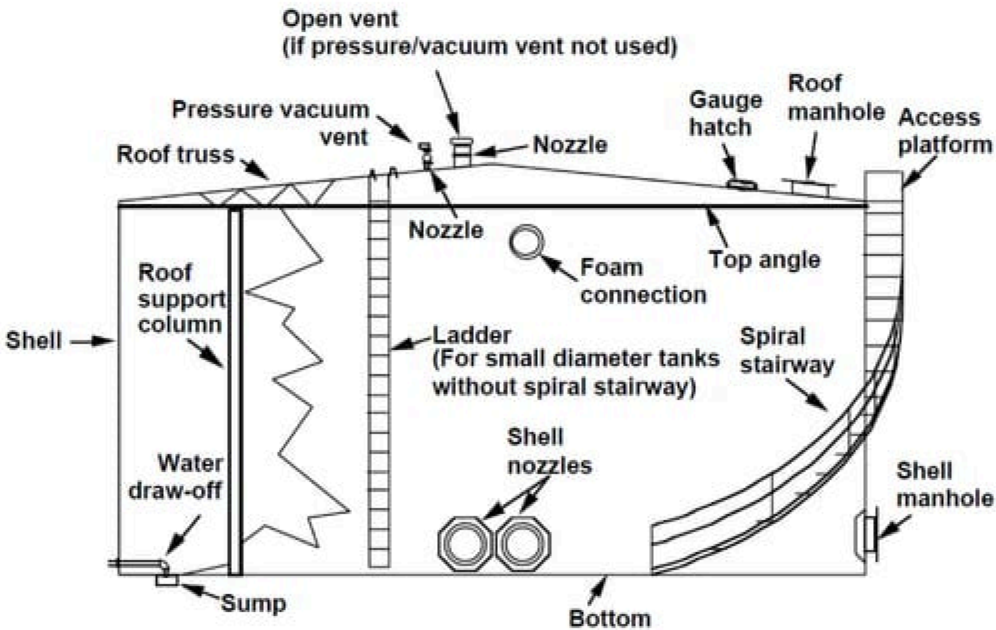
- Atmospheric tank (free vent)
- Low pressure tanks (approx. 2 Kpa g of internal pressure)
- High pressure tanks (approx. 5.6 Kpa g of internal pressure)

Fixed Roof Tanks

Dome

cone

Supported cone roof



A supported cone roof tank has a fixed roof in the shape of a cone that is supported by rafters on roof trusses.

The trusses are in turn supported by columns resting on the tank bottom.

Supported cone roof tanks are used when floating roof tanks are not required or are not more economical. Supported cone roof tanks can be larger in diameter than self-supporting.

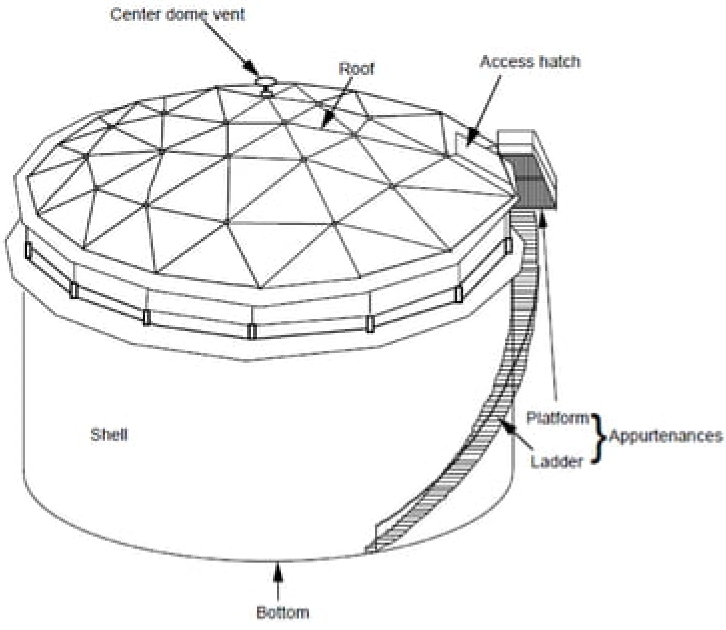
The supported cone roof tank cannot withstand any significant pressure or vacuum.

Without proper venting, vapor pressure changes sufficient to damage the roof or shell may result from daily temperature fluctuations, normal filling and emptying cycles

The roof must be equipped with an open vent, a pressure-actuated vent, or a "frangible joint".

A frangible joint is a weak welded seam at the roof-to-shell junction. The weld is designed to fail before any major rupture can occur in the tank's shell.

Self-Supporting Fixed Roof Tank



The roof of a self-supporting, fixed roof tank is supported completely from the shell without supplementary structural members.

The roof may be either conical or dome.

A dome-shaped roof can support itself at a larger diameter than a cone-shaped roof.

Self-supporting, fixed roof tanks are practical only where relatively small fixed roof tanks are required.

It has same characteristics and usages as the supported cone roof tank

Floating Roof Tanks

External Floating roof

where the roof floats on the product in an open tank and the roof is open to atmosphere.

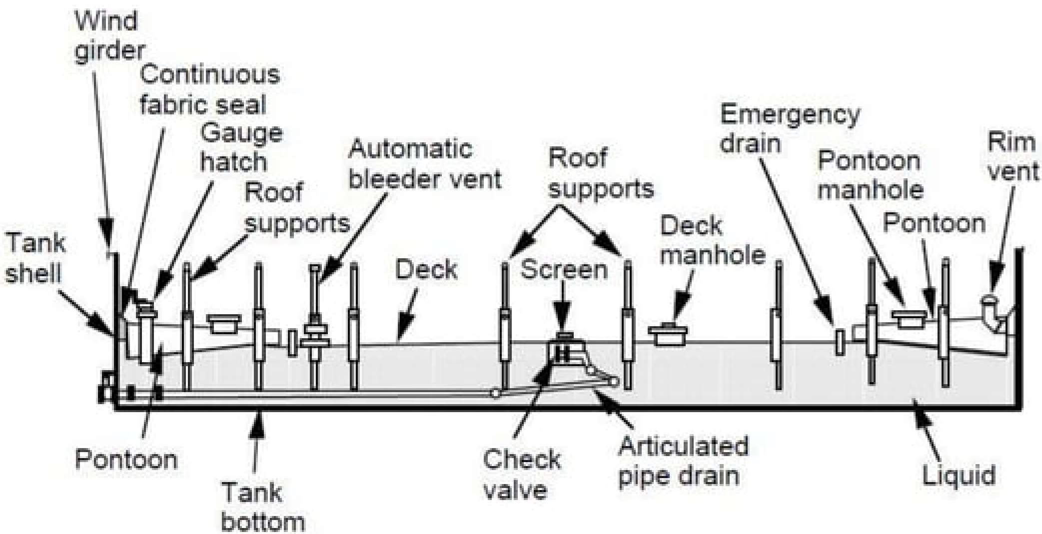
usage

floating roof tanks must be used to store petroleum products with flash points below 54°C (130°F) or if the flash point is less than 8°C (15°F) higher than the storage temperature.

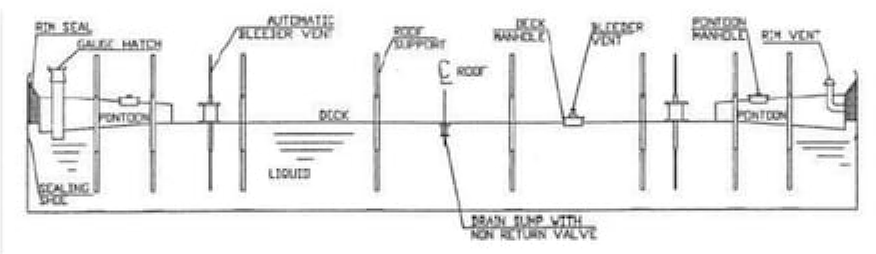
Examples of these products are gasoline and naphtha.

floating roof tanks should not to be used to store products that tend to boil under atmospheric conditions.

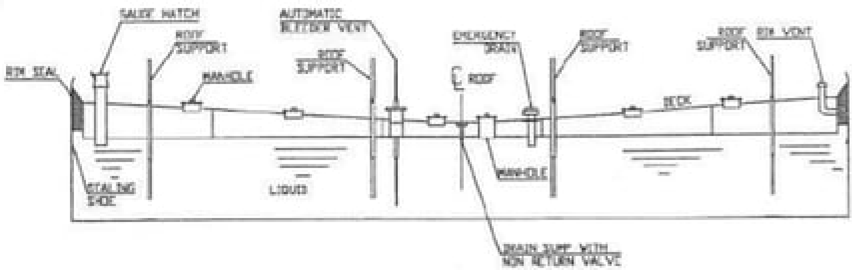
Single deck floating roof



Single deck floating roof



Double Deck Floating Roof



Internal floating roof

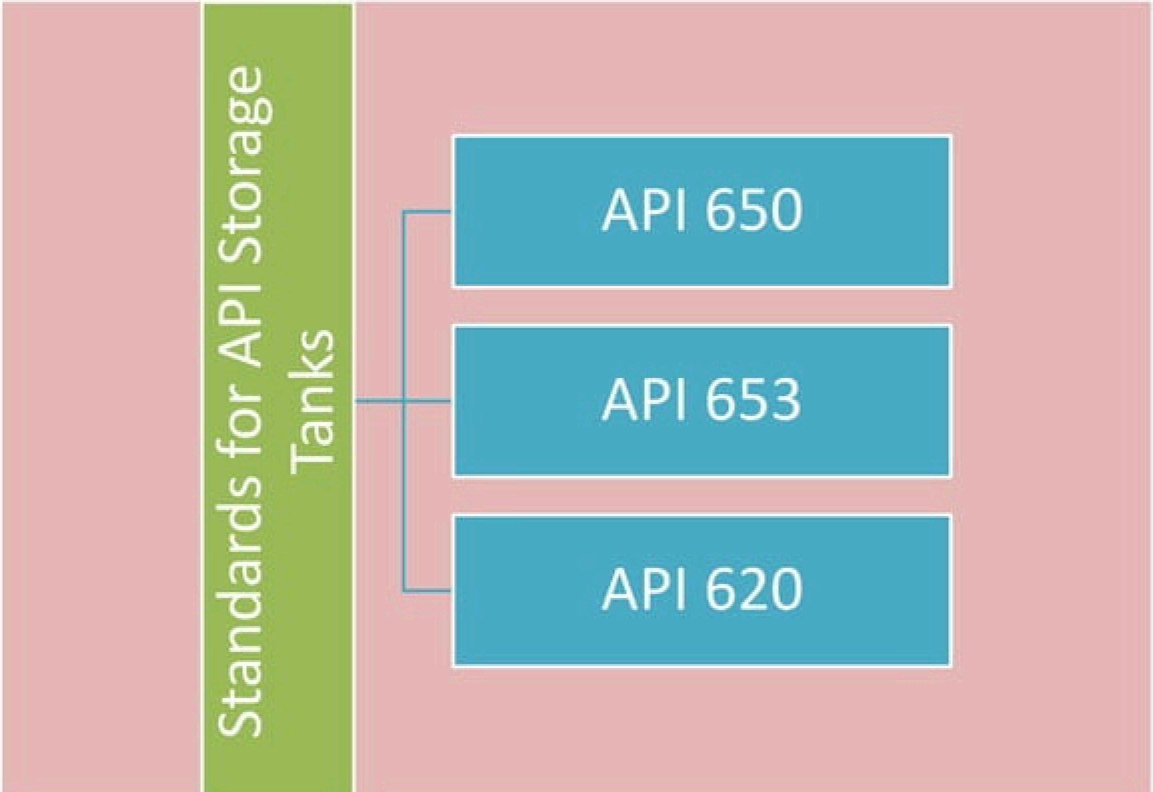
where the roof floats on the product in a fixed roof tank.

Fixed Roof with Internal Floating Roof Tank

This type of tank is used when the service of an existing fixed roof tank is changed and a floating roof tank should be used for the new service. The tank is prepared for the new service by adding the internal floating roof inside the existing tank.

This type of tank also may be required when a floating roof tank needs a fixed roof for environmental protection or product quality. In this case, a fixed roof is often added to an existing floating roof tank.

A fixed roof with internal floating roof tank has the same usage as a floating roof tank.


Standards for API Storage Tanks
API 650
API 653
API 620

API Standard 650
Welded Steel Tanks for Oil Storage

This standard provides the requirements for vertical, cylindrical, aboveground, carbon-steel storage tanks.

This standard applies to the following tanks:

- Tanks with internal pressures from atmospheric pressure to 17 kPa (ga) (2.5 psig)
- Tanks that are non refrigerated
- Tanks with design temperatures less than (200°F)
- Tanks that store petroleum, other liquid products, or water

This standard covers material, design, fabrication, erection, and testing.

API Standard 620
Welded, Low-Pressure Storage Tanks

This standard provides the requirements for aboveground tanks with a single vertical-axis-of-revolution.

The standard applies to the following tanks:

- Tanks with internal pressures greater than 3.4kPa (ga) (0.5 psig) but not greater than 103kPa (ga) (15 psig)
- Tanks with metal temperatures from -168°C to +120°C (-270°F and +250°F)
- Tanks that are large enough to require field Erection
- Tanks that store liquid or gaseous petroleum products, water, and other liquids

API 653

This standard covers requirements for inspection, repair, alteration and reconstruction of API 650 atmospheric storage tanks that have already been placed in service.

The standard includes the following sections:

- Suitability for Service
- Inspection
- Considerations for Reconstruction
- Tank Repair and Alteration
- Welding
- Examination and Testing

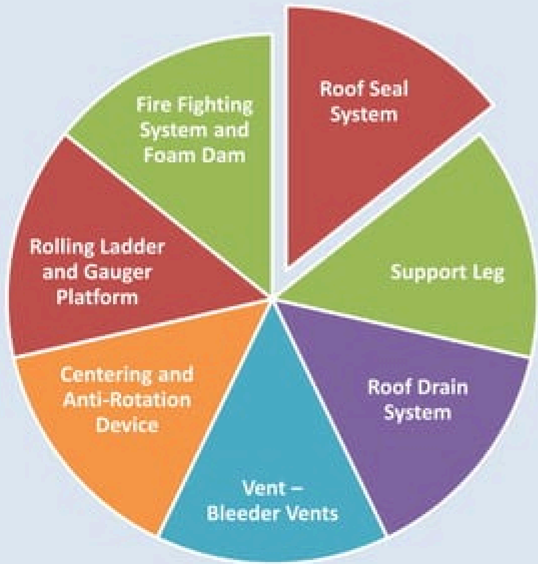
Why floating roof ?

floats directly on the product

there is no vapour space and thus eliminating any possibility of flammable atmosphere.

It reduces evaporation losses and hence reduction in air pollution.

Typical Fitting and Accessories For Floating Roof



Roof Seal System

roof seal is used to prevent the escape of vapour from the rim gap and to minimize the amount of rain water entering the product.

The sealing system has to be flexible enough to allow for any irregularities on the construction of the roof and shell when the roof moves up and down and for any radial or lateral movement of the roof due to wind and seismic.

types of seals

- primary seal
- secondary seal

The primary seal

its functions are :-

- minimize vapour loss .
- centralize the floating roof .
- Prevent entering snow & rain .

Primary seal could be :-

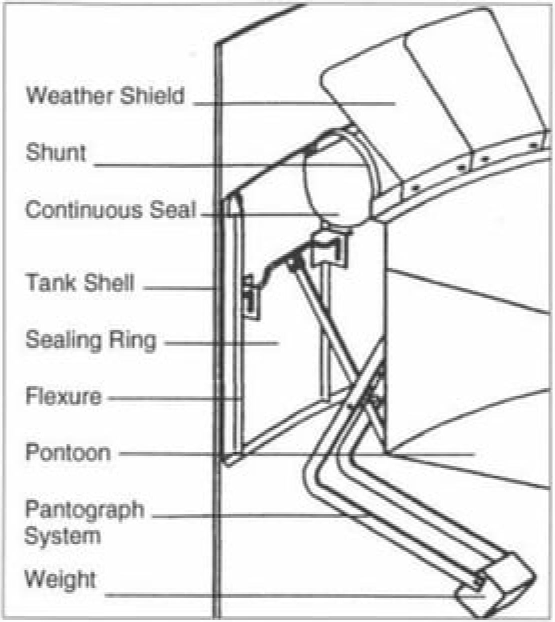
- metallic (Mechanical Shoe Seal)
- non metallic (Resilient Filled Seal) .

API 650 recommends The Mechanical Shoe Seal

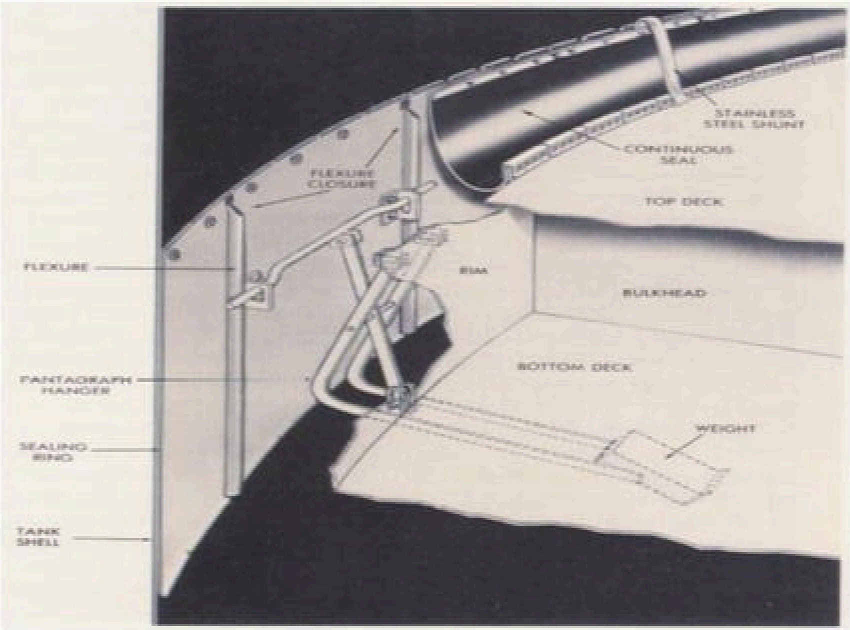
The Mechanical Shoe Seal

- Pantograph Hanger
- Scissor Hanger.

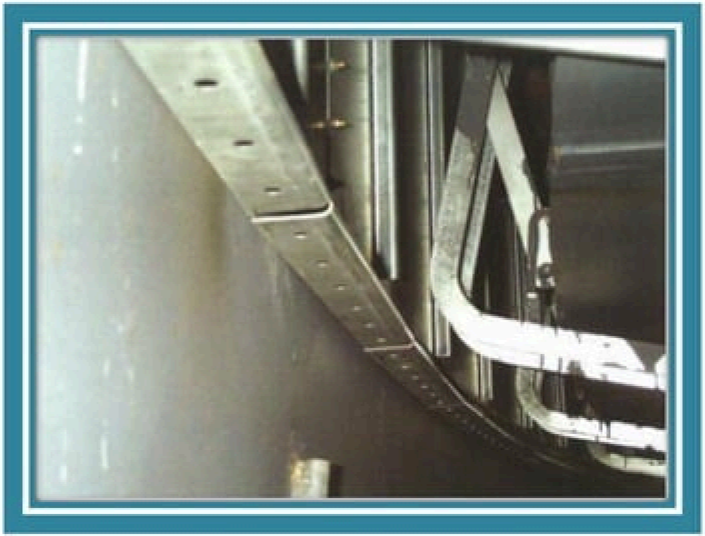
Pantograph Hanger



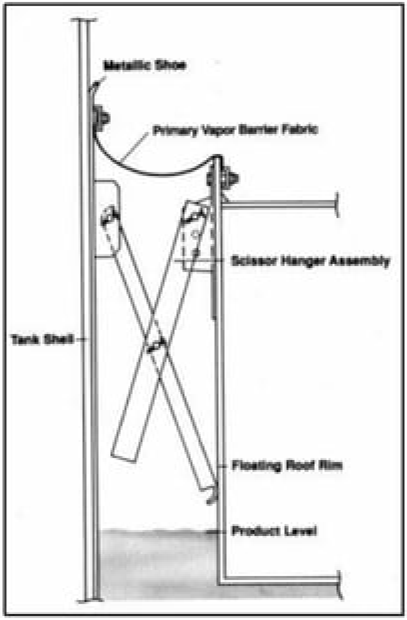
Roof Seal System



Pantograph Hanger



Scissor Hanger



Secondary seal

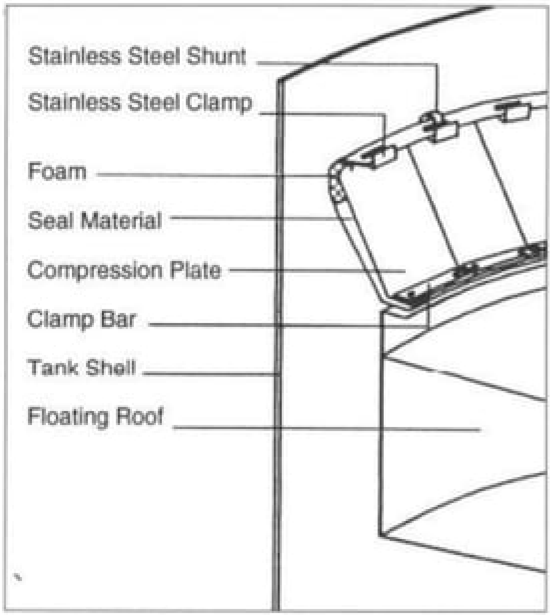
it is mounted on top of the primary seal

it reduced vapour loss which in turn :-

- cost saving.
- enhanced safety by protection against rim fires.
- Environmental protection with less odour and compliance with the air standards .

it significantly reduces the amount of rainwater entering the tank contents.

Secondary seal



Roof Seal Material

The basic requirement of the seal material is

- the chemical resistance.
- the material has to be flame retardant.
- the ultraviolet resistance in which the seal expose to direct sunlight.

Roof Seal Material

Material	Resistance Against		Flame Retardant?
	Hydrocarbons	UV light	
Vition ® (FPM)/ nylon (PA)	Very Good	Very Good	Yes
Teflon ® (PTFE)/ glass	Very Good	Very Good	Yes
Neoprene (CR)/ calcium silicate	Reasonable	Good	No
Polyurethane (EU)/ nylon (PA) or polyester (TPE-E)	Good	Good	No
PVC-nitrile (PVC-NBR)/ nylon (PA) or polyester (TPE-E) or glass	Good	Reasonable	No
Nitrile (NBR)/ Nylon (PA) or polyester (TPE-E)	Reasonable	Poor	No

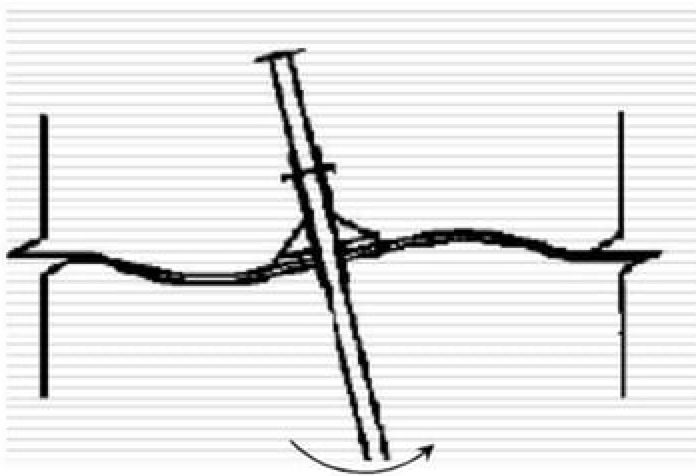
Support leg

Support leg is the supporting element for the floating roof when the tank is empty where the roof fall to its lowest position.

The roof needed to be supported at a certain height above the floor

not only that the roof will not foul with any internal accessories that installed at the lowest shell such as heating coil, mixing propeller, it also provide access room for maintenance personnel.

Support leg

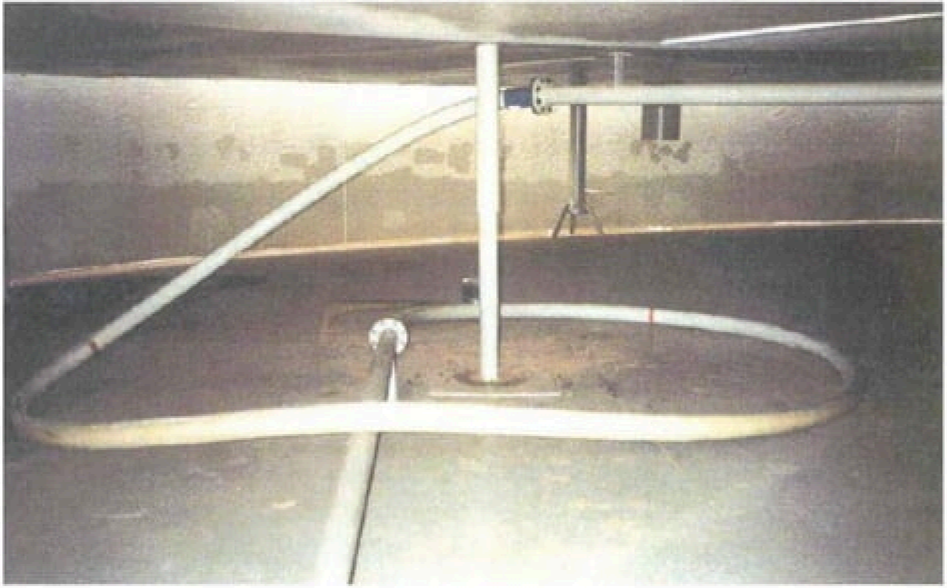


Applied Force

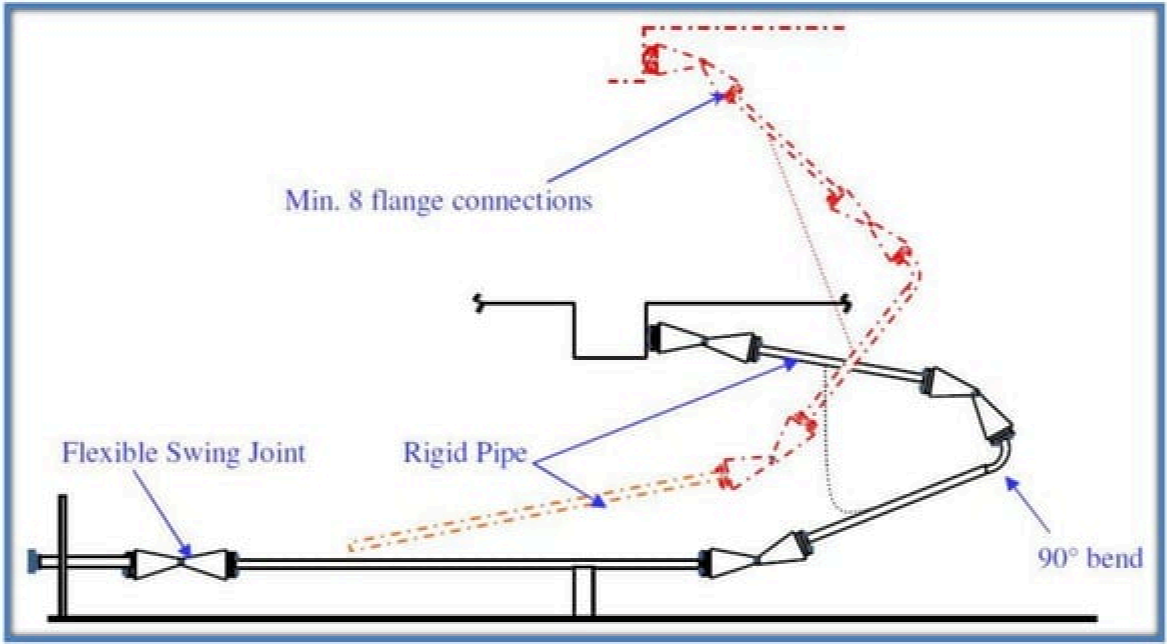
Roof Drain System

the roof drains shall be sized and positioned to accommodate the rainfall rate while preventing the roof from accumulate a water level greater then design, without allowing the roof to tilt excessively or interfere with its operation.

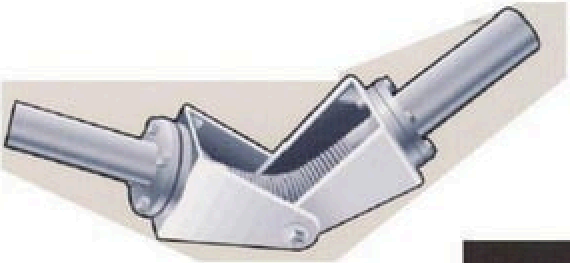
Roof Drain System

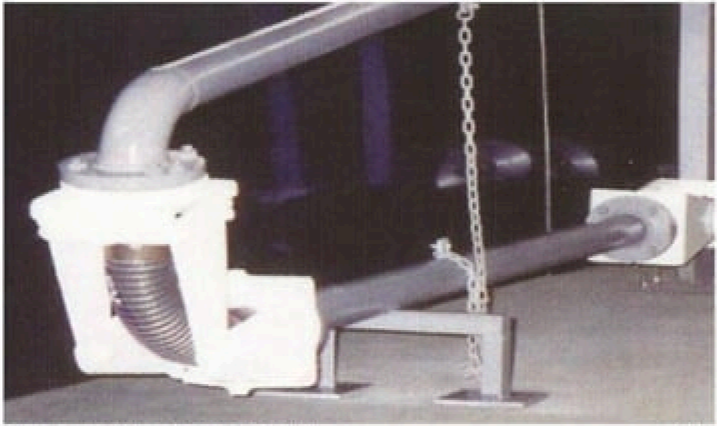


Articulated Piping System



Articulated Piping System





disadvantage

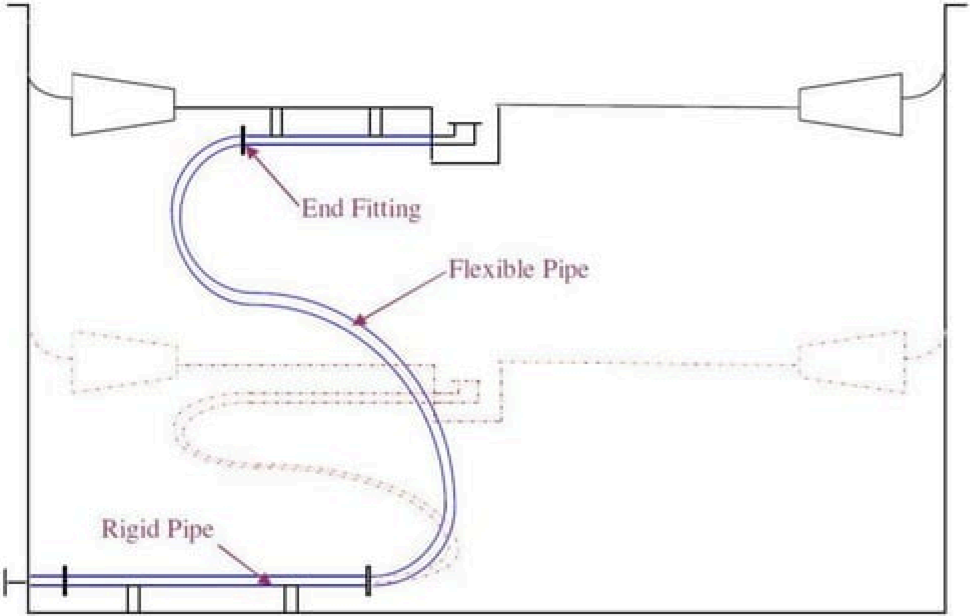
- heavy weight to the system
- stress the deck plate
- wearing of the roof seal.
- Complicated installation

Flexible Drain Pipe System

It consists of only single continuous pipe which expands and contracts with the rise and fall of the floating roof.

Full length of the pipe is flexible without any joint.

Flexible Drain Pipe System



features

- leakage is eliminated
- much lighter
- easy installation
- Expensive cost

Drain Pipe Design

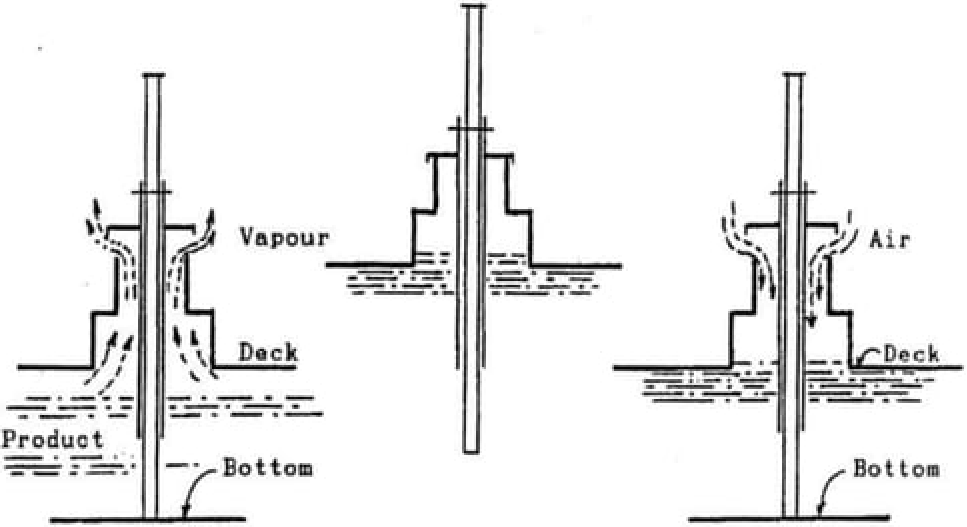
1. The Rain Fall, RH (m/hr) (given)
2. The Drainage (Q)= RH x deck area (m^3/hr)
3. A = Q / V , V = $\sqrt{\dfrac{2\, g\, \Delta z}{\sum \frac{f\, l}{d} + 1}}$
4. f = Flow Coefficient , d=pipe diameter
   l= Pipe Length , Δz =elevation
5. Select the Drain Pipe (Ex. 4" Schedule 80)

Vent – Bleeder Vents

Automatic bleeder vents shall be furnished for venting the air to or from the underside of the deck when filling and emptying the tank. This is to prevent overstress of the roof deck or seal membrane.

These vent only come to operate when the floating roof landed, and the tank is drained down or being filled.

Vent – Bleeder Vents

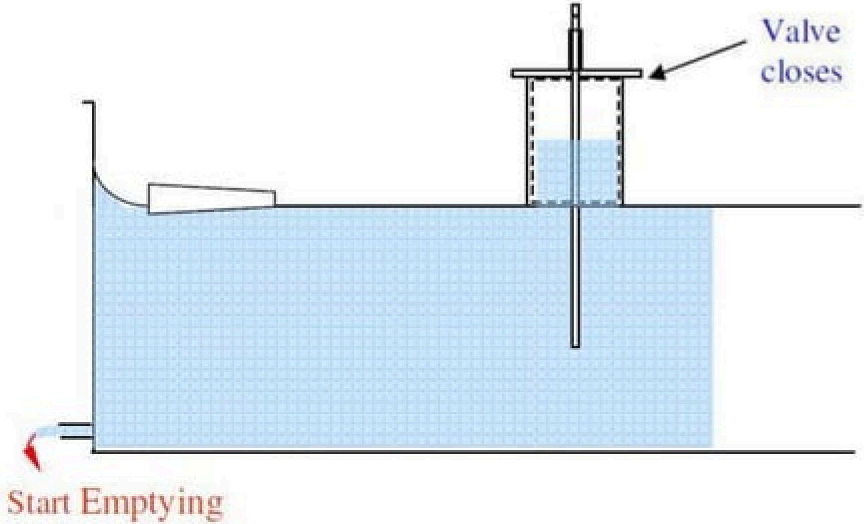


Roof on support legs
Tank filling

Roof floating

Roof on support legs
Tank emptying

Vent – Bleeder Vents



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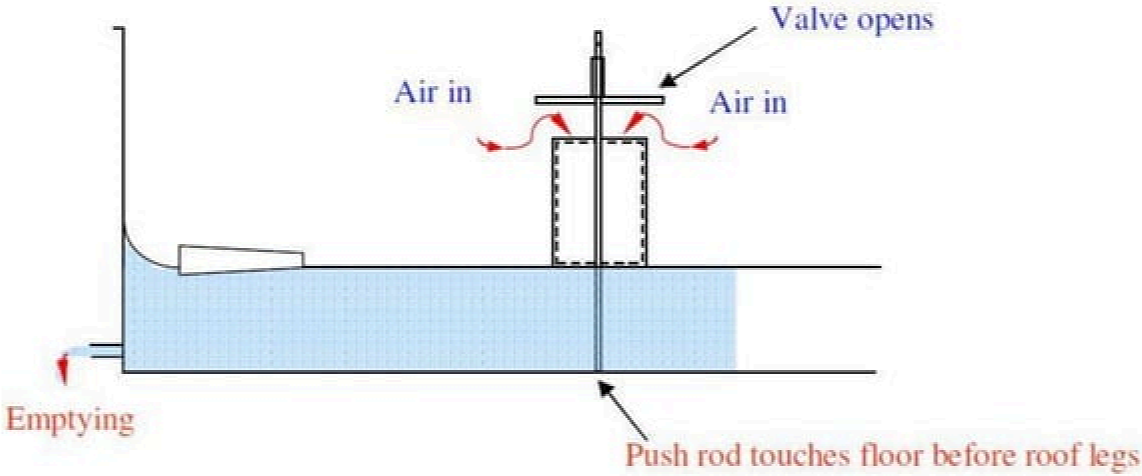

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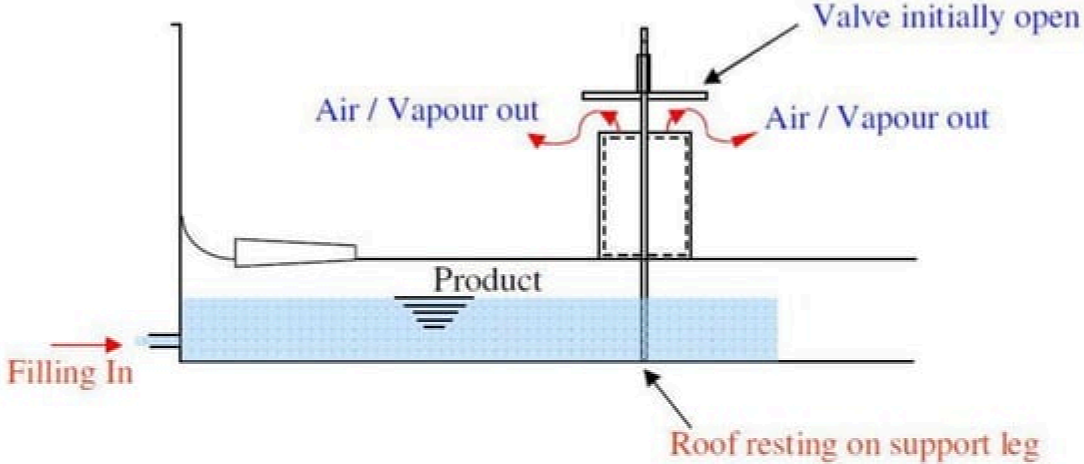

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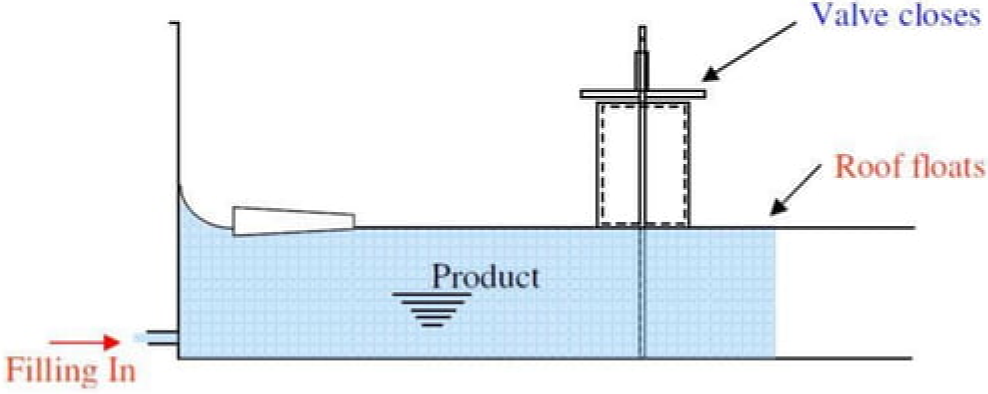


Bleeder Vent Design

The design data for the venting design is as follow:

Design Filling Rate, V_i

Design Emptying Rate, V_o

The vacuum venting (In-Breathing)

The venting capacity for maximum liquid emptying will be 15.86 m^3/h of free air for each 15.9 m^3/h of maximum empty rate.

Flow rate of free air for liquid movement,

$V_{v1} = V_o / 15.9 * 15.86$

The pressure venting (out-Breathing)

The venting capacity for maximum liquid Filling will be 17 m^3/h of free air for each 15.9 m^3/h of maximum Filling rate.

Flow rate of free air for liquid movement,

$V_{p1} = V_i / 15.9 * 17$

Cross sectional area of vent

$$A_{v\_rq} = \frac{Q}{k}\sqrt{\frac{\gamma}{2\,g\,\Delta p}}$$

Q= maximum flow rate

ΔP = Pressure different

γ= Specific weight of air

A_{v_rq}= Cross sectional area of vent

k= Discharge Coefficient, 0.62 for circular

Rolling Ladder

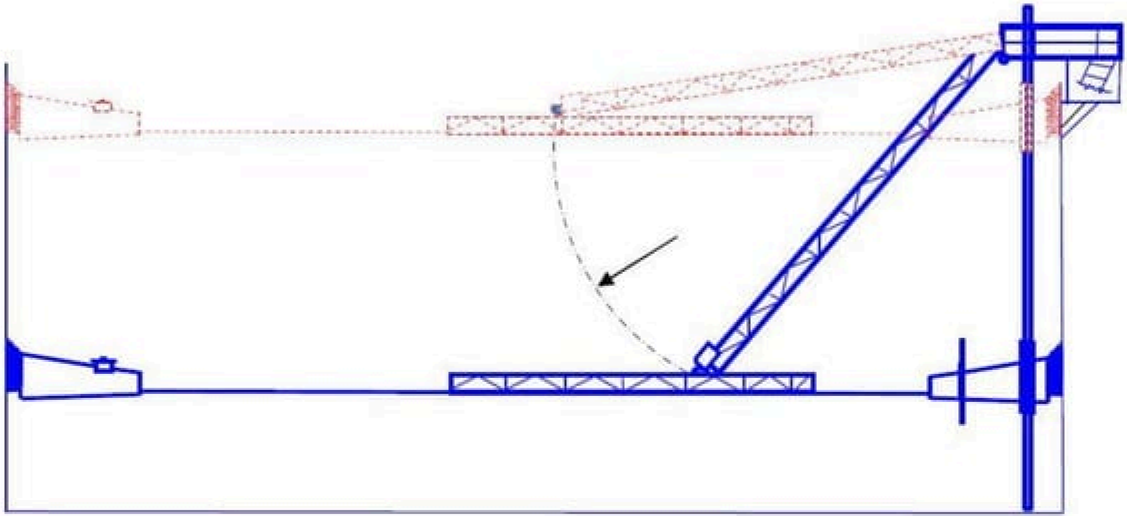
The rolling ladder installed on the floating roof tank to provide safe access onto the floating roof.

The ladder consists of self-levelling treads and it slides along the track as the roof move up and down.

The upper end of the ladder is attached to the gauger platform by hinged brackets

lower end is provided with wheels run on a steel track mounted on a runway structure support off the roof.

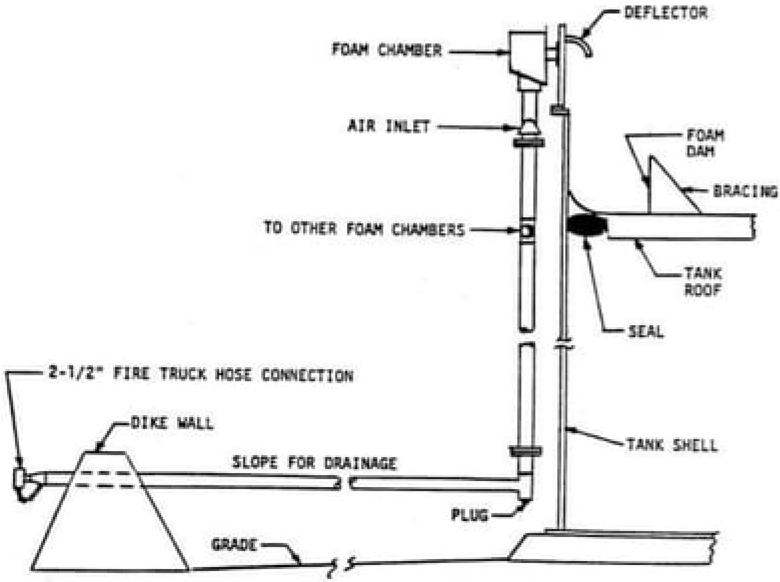
Rolling Ladder



Fire Fighting System

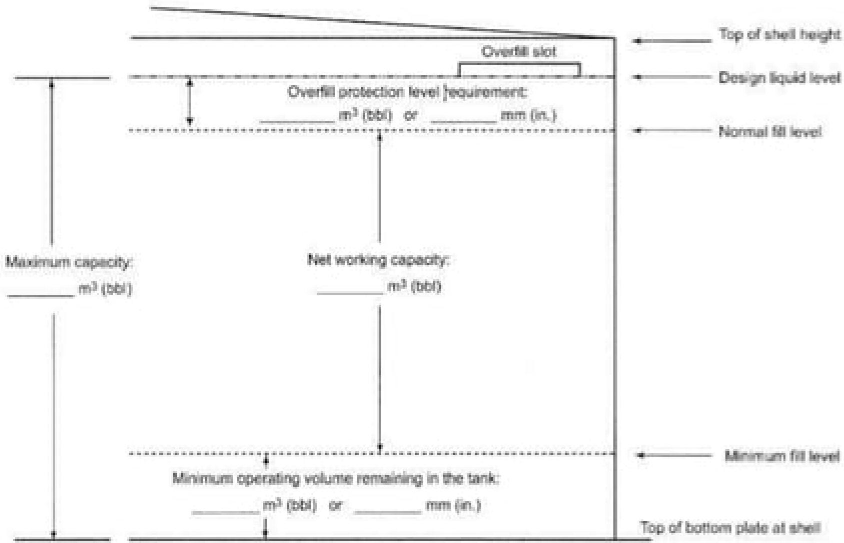
- Fire on the floating roof tanks are common and it usually happened in the rim space where the vapour escaped, this was called as rim fires. The main cause of the floating roof rim fires is lighting. Most lighting ignited rim fires result from induced charges on the roof and not direct strikes. Fire fighting system is to be designed and installed on the floating roof to fight over and extinguishes the rim fire.

Fire Fighting System



The tank design

Tank capacities



Field Erected Tanks

Table 2-10. Selection of Typical Sizes of API Field Constructed Tanks.

Diameter		Approx. Capacity		Height		Volume	
Ft	m	Gal/ft	m3/m	ft	m	gal	m^3
15	4.6	1320	16.4	18	5.5	23,700	90
20	6.1	2350	28.0	18	5.5	42,500	161
25	7.6	3670	45.6	18	5.5	66,000	250
25	7.6	3670	45.6	24	7.3	88,000	334
30	9.1	5290	65.6	24	7.3	127,000	481
35	10.7	7190	89.3	30	9.1	216,000	819
45	13.7	11900	148.0	36	11.0	429,000	1625
70	21.3	28800	358.0	36	11.0	1040,000	3940
100	30.5	58700	728.0	36	11.0	2110,000	8000
120	36.6	84500	1050.0	48	14.6	4060,000	15400
180	54.9	190000	2380.0	48	14.6	9150,000	34700

SOURCE: "Welded Steel Tanks for Oil Storage," American Petroleum Institute, Washington, D.C. 1973 as cited by Baasel, 1974.

Material Selection

- Corrosion Assessment
- Mechanical stresse

CO_2 Corrosion

Carbon dioxide dissolves in water and dissociates to form weak carbonic acid which causes corrosion on carbon steels . Higher temperatures and pressure increase the corrosion rate .

Corrosion resistant alloys (CRA) are used to avoid corrosion at high CO2 contents, but it would be more economical to use carbon steel with a corrosion allowance and/or chemical inhibitor treatment.

The presence of CO2 infers that carbon steel will have finite life due to the wall thinning, a corrosion allowance is practical to accommodate up to 6mm.

Mercury

Mercury (Hg) is a trace component of all fossil fuels.

It is therefore present in liquid hydrocarbon and natural gas deposits.

may transfer into air, water and soil.

Materials unsuitable for hydrocarbon streams in presence of mercury which will result in crack are:

Aluminum and Aluminum Alloys

Titanium and Titanium Alloys

Copper and Copper Alloys

Zinc and Zinc Alloys

Material Selection Guide

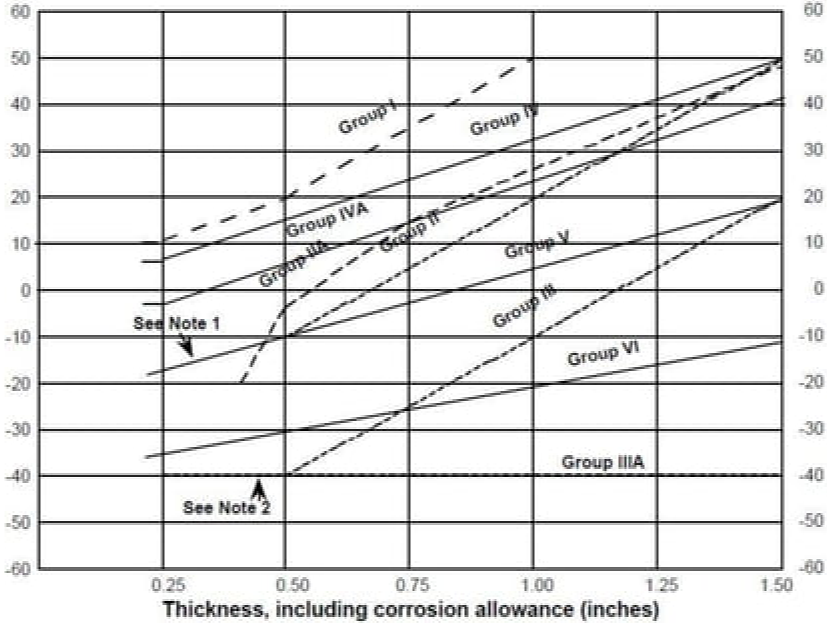
Design Temperature, °F		Material	Plate	Pipe	Forgings	Fittings	Bolting
Cryogenic	−425 to −321	Stainless steel	SA-240-304, 304L, 347, 316, 316L	SA-312-304, 304L, 347, 316, 316L	SA-182-304, 304L, 347, 316, 316L	SA-403-304, 304L, 347, 316, 316L	SA-320-B8 with SA-194-8
	−320 to −151	9 nickel	SA-353	SA-333-8	SA-522-1	SA-420-WPL8	
Low temperature	−150 to −76	3½ nickel	SA-203-D	SA-333-3	SA-350-LF63	SA-420-WPL3	SA-320-L7 with SA-194-4
	−75 to −51	2½ nickel	SA-203-A				
	−50 to −21	Carbon steel	SA-516-55, 60 to SA-20	SA-333-6	SA-350-LF2	SA-420-WPL6	
	−20 to 4		SA-516-All	SA-333-1 or 6			SA-193-B7 with SA-194-2H
	5 to 32		SA-285-C	SA-53-B SA-106-B	SA-105 SA-181-60,70	SA-234-WPB	
Intermediate	33 to 60 61 to 775		SA-516-All SA-515-All SA-455-II				
Elevated Temperature	776 to 875	C-½Mo	SA-204-B	SA-335-P1	SA-182-F1	SA-234-WP1	
	876 to 1000	1Cr-½Mo	SA-387-12-1	SA-335-P12	SA-182-F12	SA-234-WP12	
		1Cr-½Mo	SA-387-11-2	SA-335-P11	SA-182-F11	SA-234-WP11	
	1001 to 1100	2¼Cr-1Mo	SA-387-22-1	SA-335-P22	SA-182-F22	SA-234-WP22	with SA-193-B5 SA-194-3
	1101 to 1500	Stainless steel	SA-240-347H	SA-312-347H	SA-182-347H	SA-403-347H	SA-193-B8 with SA-194-8
		Incoloy	SB-424	SB-423	SB-425	SB-366	
	Above 1500	Inconel	SB-443	SB-444	SB-446	SB-366	

API Standard 650 material groups.

Group I As Rolled, Semikilled		Group II As Rolled, Killed or Semikilled		Group III As Rolled, Killed Fine-Grain Practice		Group IIIA Normalized, Killed Fine-Grain Practice	
Material	Notes	Material	Notes	Material	Notes	Material	Notes
A 283 C	2	A 131 B	7	A 573-58		A 131 CS	
A 285 C	2	A 36	2, 6	A 516-55		A 573-58	10
A 131 A	2	A 442-55		A 516-60		A 516-55	10
A 36	2, 3	A 442-60		G40.21M-260W	9	A 516-60	10
Fe 42 B	4	G40.21M-260W		Fe 42 D	4, 9	G40.21M-260W	9, 10
Grade 37	3, 5	Fe 42 C	4	Grade 41	5, 9	Fe 42 D	4, 9, 10
Grade 41	6	Grade 41	5, 8			Grade 41	5, 9, 10

Group IV As Rolled, Killed Fine-Grain Practice		Group IVA As Rolled, Killed Fine-Grain Practice		Group V Normalized, Killed Fine-Grain Practice		Group VI Normalized or Quenched and Tempered, Killed Fine-Grain Practice Reduced Carbon	
Material	Notes	Material	Notes	Material	Notes	Material	Notes
A 573-65		A 662 C		A 573-70	10	A 131 EH 36	
A 573-70		A 573-70	11	A 516-65	10	A 633 C	
A 516-65		G40.21M-300W	9, 11	A 516-70	10	A 633 D	
A 516-70		G40.21M-350W	9, 11	G40.21M-300W	9, 10	A 537 I	
A 662 B				G40.21M-350W	9, 10	A 537 II	
G40.21M-300W	9					A 678 A	
G40.21M-350W	9					A 678 B	
Fe 44 B, C, D	4, 9					A 737 B	
Fe 52 C, D	9						
Grade 44	5, 9						

The minimum design metal temperature



Tank Shell Design Methods

- one-Foot Method
- Variable-Design-Point Method
- Elastic Analysis

one-Foot Method

- The 1-foot method calculates the thickness required at design points 0.3 m (1 ft) above the bottom of each shell course.
- For design shell thickness

$$t_d = \frac{4.9D(H-0.3)G}{S_d} + C.A$$

- t_d = Design shell thickness, in mm
- H = Design liquid level, in m
- G = Design specific gravity of the liquid to be stored
- $C.A$ = Corrosion allowance, in mm
- S_d = Allowable stress for the design condition, in Mpa
- D = nominal tank diametr, m

NOTE

This method is shall not be used for tanks larger than 60 m in diameter.

Variable-Design-Point Method

Very complex method where we use point with certain equation.

This method normally provides a reduction in shell-course thickness and total material weight .

This method may only be used when

1-foot method is not specified & $\frac{L}{H} = \frac{1000}{6}$

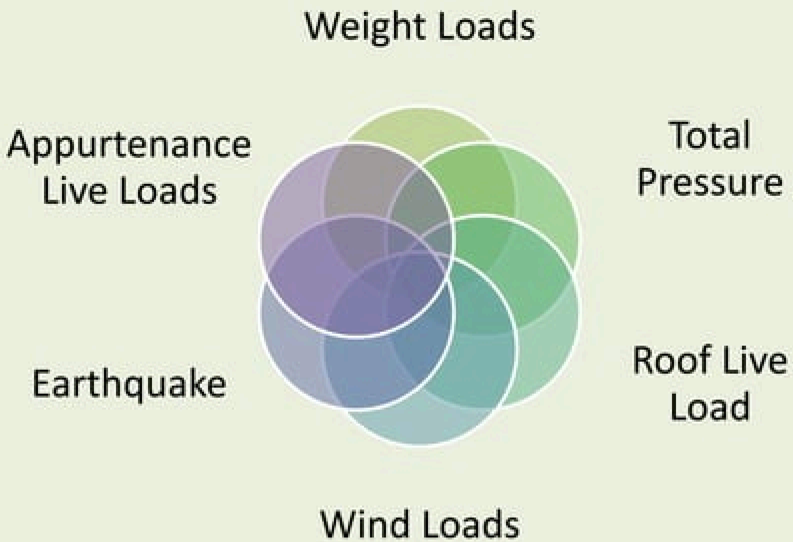
L = $(500\ D\ t)^{0.5}$ in mm

t = bottom-course shell thickness, in mm,

Elastic Analysis method

For tanks where L / H is greater than 1000/6, the selection of shell thickness shall be based on an elastic analysis that shows the calculated circumferential shell stress to be below the allowable stress.

CIVIL/MECHANICAL LOADS



1-Weight Loads

When designing a tank and its foundation, the design engineer must consider the weight loads which are the weight of the tank and the maximum weight of its contents.

Since most petroleum products are lighter than water, the heaviest weight load occurs during hydrostatic testing, which is done using water.

1-Weight Loads

- weight of bottom
- weight of the shell
- weight of the roof
- weight of any appurtenances
- weight of insulation
- water weight

2-Total Pressure

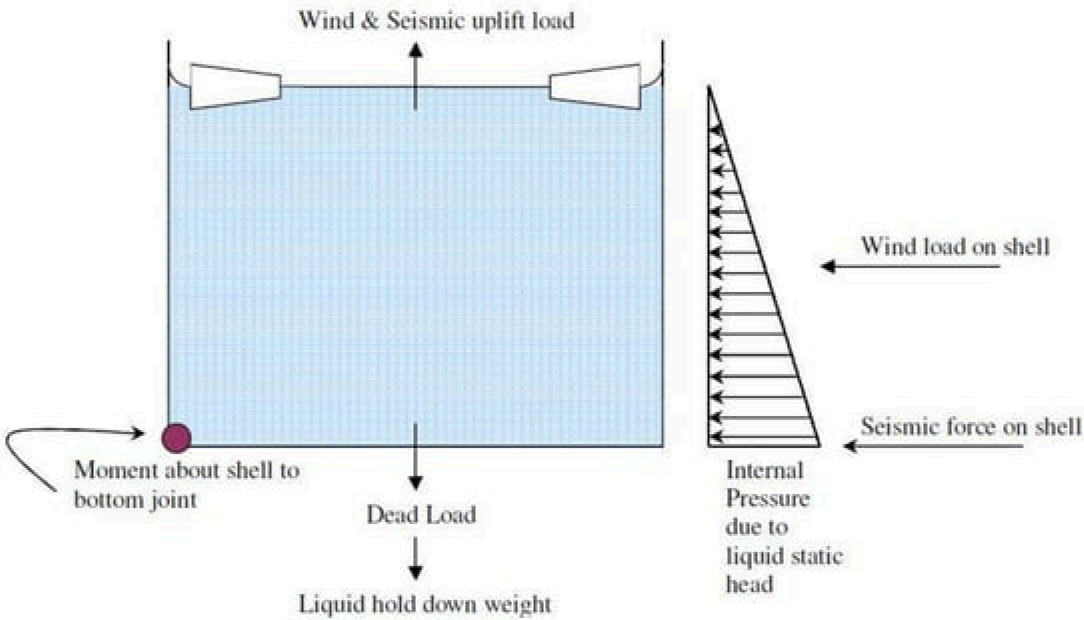
- Hydrostatic pressure
- Vapor pressure
- wind pressure (will be covered later)

3-Roof Live Load

the weights of items on the roof that are not a part of the permanent structure.

- Personnel
- Equipment
- Rainwater&dust

Loading Diagram on a Tank Shell



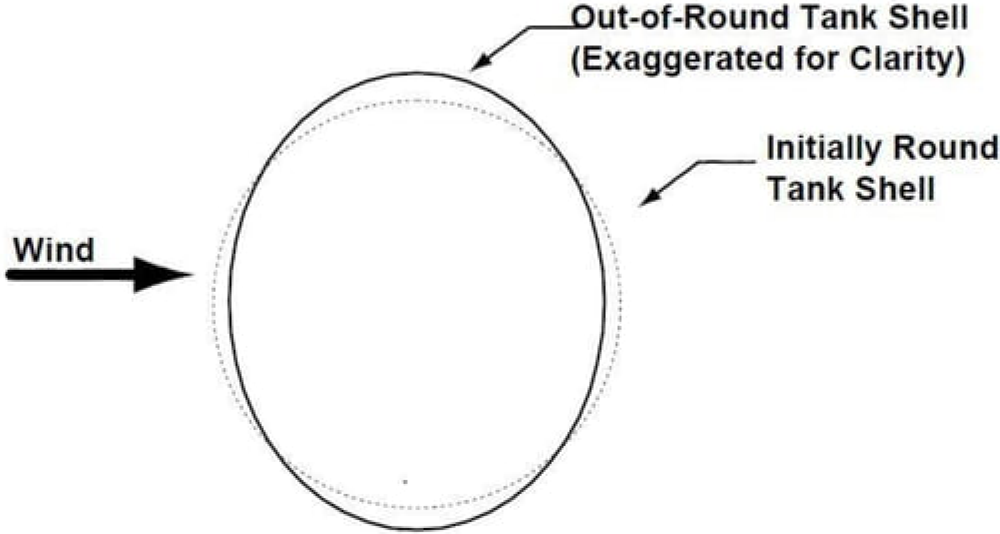
Top Stiffener/ Wind Girder

An open-top tank is essentially a vertical cylinder that is open at the top and closed at the bottom.

this cylinder can be forced out-of-round by wind pressure that acts against it, unless adequate stiffness against deformation is provided by the shell alone or by other means.

If excessive, shell out-of-roundness could prevent free vertical travel of the floating roof, or could cause the formation of cracks in shell welds.

Top Stiffener/ Wind Girder



Top Stiffener/ Wind Girder

top wind girder are to be provided in an open-top tank to maintain the roundness when the tank is subjected to wind load.

The stiffener rings shall be located at

or near the top course and outside of the tank shell.

The top wind girder must be sized to

have a large enough section modulus to provide adequate shell stiffening.

Top Wind Girder selection

- calculating the minimum required section modulus
- API-650 contains an equation
- Selecting a large enough wind girder section
- API-650 also contains a table

Minimum required section modulus

$$Z = \frac{D\,H_2}{17}\left(\frac{V}{190}\right)^2$$

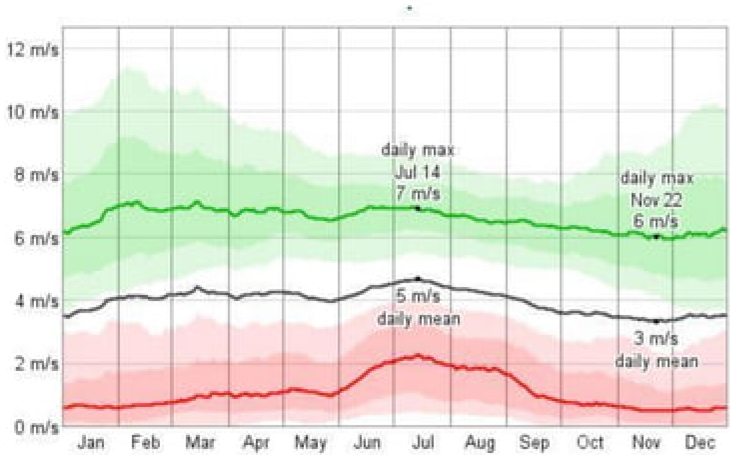
Z = Minimum required section modulus, cm^3

D = Nominal tank diameter, m

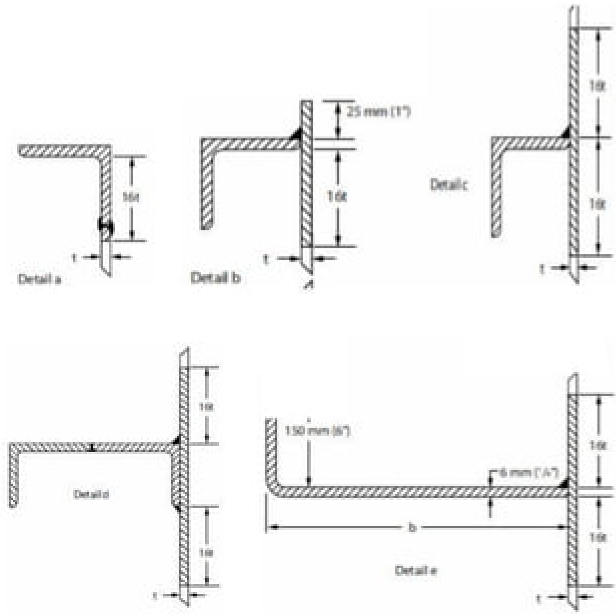
H_2 = Height of the tank shell, in m, including any freeboard provided above the maximum filling height

V = design wind speed (3-sec gust), km/h

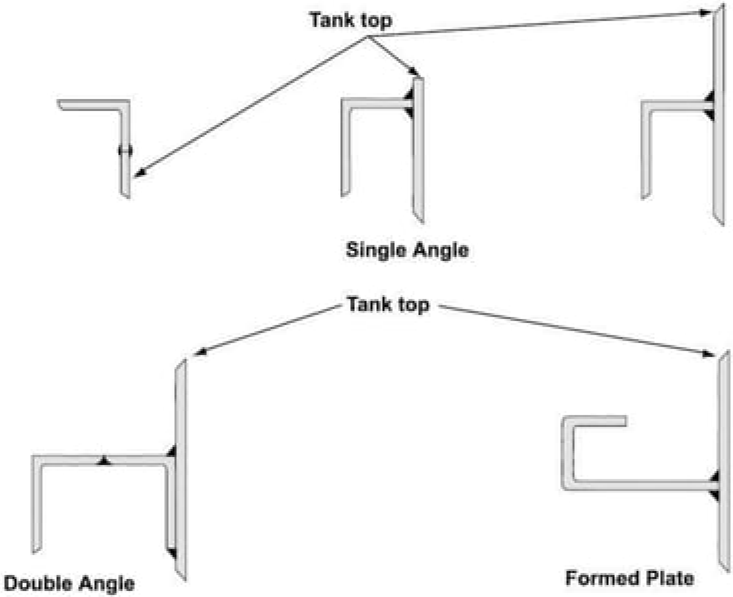
Wind speed


12 m/s
10 m/s
8 m/s
6 m/s
4 m/s
2 m/s
0 m/s
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
daily max
Jul 14
7 m/s
daily max
Nov 22
6 m/s
5 m/s
daily mean
3 m/s
daily mean

Top Stiffener/ Wind Girder



Top Stiffener/ Wind Girder



Section Moduli of Stiffening-Ring

Table 5-20a—(SI) Section Moduli (cm^3) of Stiffening-Ring Sections on Tank Shells

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Member Size	As-Built Shell Thickness (mm)				
mm	5	6	8	10	11
Top Angle: Figure 5-24, Detail a					
65 × 65 × 6	6.58	6.77	—	—	—
65 × 65 × 8	8.46	8.63	—	—	—
75 × 75 × 10	13.82	13.97	—	—	—
Curb Angle: Figure 5-24, Detail b					
65 × 65 × 6	27.03	28.16	—	—	—
65 × 65 × 8	33.05	34.67	—	—	—
75 × 75 × 6	35.98	37.49	—	—	—
75 × 75 × 10	47.24	53.84	—	—	—
100 × 100 × 7	63.80	74.68	—	—	—
100 × 100 × 10	71.09	87.69	—	—	—

Intermediate Wind Girder

At some situations just a top wind girder alone will not provide enough shell stiffness for a given combination of tank height, tank diameter, and tank shell course thicknesses.

Put in simple terms, the distance between the top wind girder and the tank bottom is too large.

In these situations, to resist wind induced shell deformation, installation of an intermediate wind girder at a location between the top wind girder and the tank bottom reduces the unstiffened length of the shell, and is required in order to prevent shell deformation in these cases.

Intermediate Wind Girder

The shell of the storage tank is susceptible to buckling under influence of wind and internal vacuum, especially when in a near empty or empty condition.

It is essential to analysis the shell to ensure that it is stable under these conditions. Intermediate stiffener or wind girder will be provided if necessary.

The maximum height of unstiffened shell	$$H_1 = 9.47\, t \sqrt{\left(\frac{t}{D}\right)^3 \left(\frac{190}{V}\right)^3}$$
	H1 = Vertical distance, in m, between the intermediate wind girder and top wind girder
	t = Thickness of the top shell course, mm
	D = Nonimal tank diameter, m
	V = design wind speed (3-sec gust), km/h

The height of the transformed shell (H_2)	$$W_{tr} = W\sqrt{\left(\frac{t_{uniform}}{t_{actual}}\right)^5}$$
	W_{tr} = Transposed width of each shell course, mm
	W = Actual width of each shell course, mm
	$t_{uniform}$= Thickness of the top shell course, mm
	t_{actual} = Thickness of the shell course for which the transpose width is being calculated, mm

The sum of the transposed width of the courses will be the height of the transformed shell

$$(H_2 = \sum W_{tr}).$$

If the height of transformed shell is greater than the maximum height of un-stiffened shell, intermediate wind girder is required.

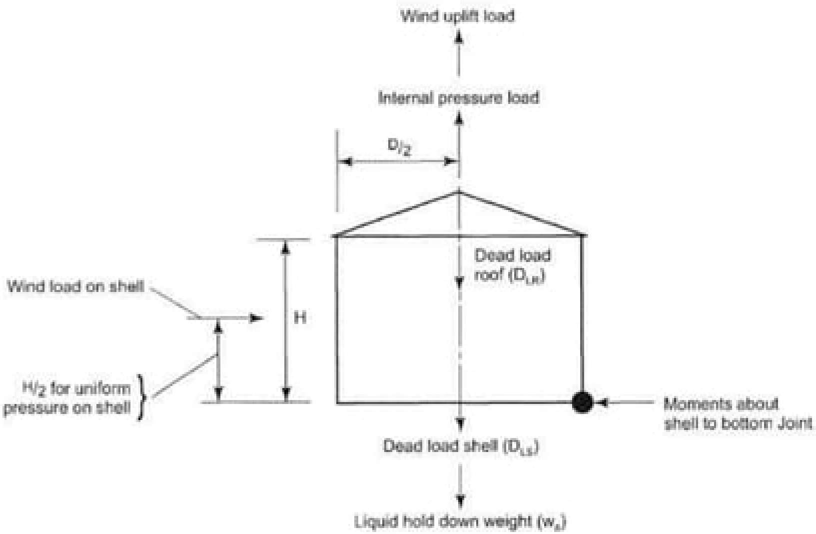
location of the intermediate wind girder

The ideal location of the intermediate wind girder is such that the portions of the tank shell between the intermediate wind girder and the top wind girder, and between the intermediate wind girder and the bottom of the tank, have approximately the same stiffnesses.

It would be incorrect, however, to locate the intermediate wind girder at the mid-height between the top wind girder and the tank bottom.

As the tank shell thickness decreases in going from the bottom to the top course. Because the lower courses are thicker than the upper courses, the lower portion of the tank shell is inherently stiffer than the upper portion of the tank shell. Therefore, if the intermediate wind girder was located at the mid-height of the shell, the upper portion of the tank shell would not be stiffened enough.

Overturning Stability against Wind Load



The overturning stability of the tank shall be analyzed against the wind pressure, to determine the stability of the tank with and without anchorage.

The wind pressure used in the analysis is given by API 650

W_s = 0.86 kPa $(V/190)^2$

wind pressure on the vertical projected areas of cylindrical surface area

W_r = 1.44 kPa $(V/190)^2$

Uplift pressure on horizontal projected area of conical surface .

the tank will be structurally stable without anchorage when the below uplift criteria are meet :-

$$0.6\ M_w + M_{pi} < M_{DL} / 1.5$$

$$M_w + 0.4\ M_{pi} < (M_{DL} + M_f) / 2$$

M_{pi} = moment about the shell-to-bottom from design internal pressure (*Pi*)

M_w = Overturning moment about the shell-to-bottom joint from horizontal plus vertical

F_r and F_s is the wind load acting on the roof and shell respectively and L_r and L_s is the height from tank bottom to the roof center and shell center respectively.

$$M_{pi} = \left(\frac{\pi}{4} D^2 P_i\right) * \frac{1}{2} D$$

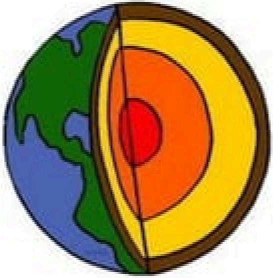
$$M_w = F_r L_r + F_s L_s$$

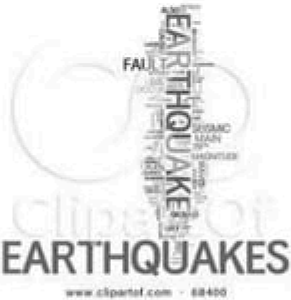
M_{DL} = Moment about the shell-to-bottom joint from the weight of the shell and roof supported by the shell

$$M_{DL} = \frac{D}{2} * W_{DL}$$

M_f = Moment about the shell-to-bottom joint from liquid weight

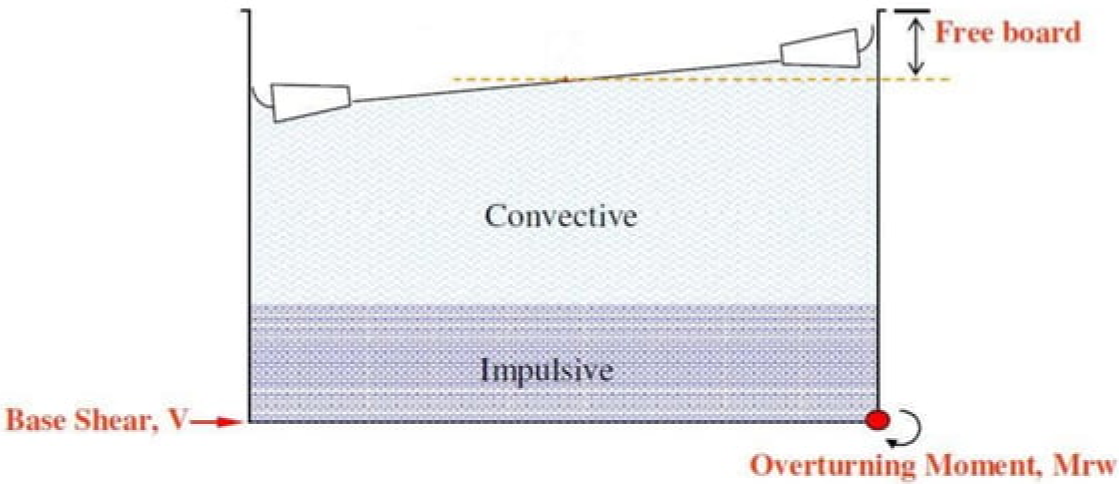
Seismic design





seismic design

- Overturning Stability
- Maximum base shear
- Freeboard required


Free board
Convective
Impulsive
Base Shear, V
Overturning Moment, Mrw

seismic load

The vibration of liquid filled tanks subject to seismic loading depends on the inertia of the liquid and on the interaction effects between the liquid and the tank shell.

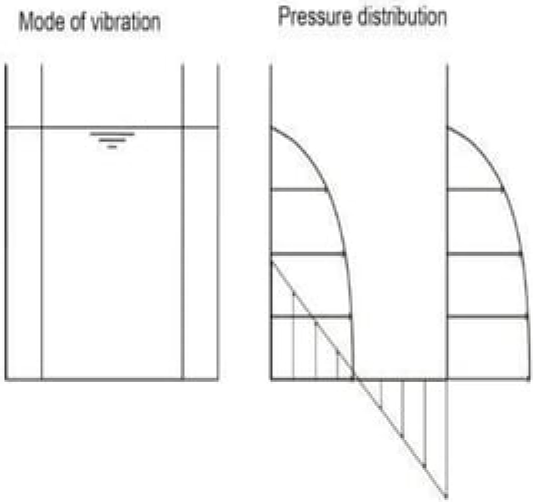
Response modes

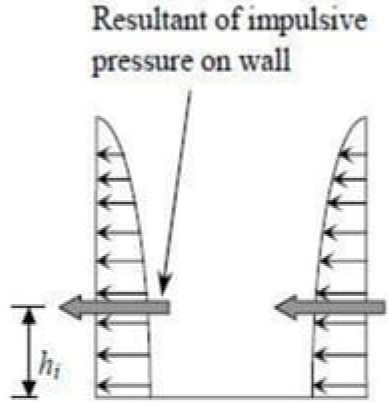
- impulsive
- convective

The impulsive component

- The part of the liquid in the lower part of the tank which moves with the tank & foundation as though it were a solid. It experiences the same accelerations as the earthquake.

impulsive pressure



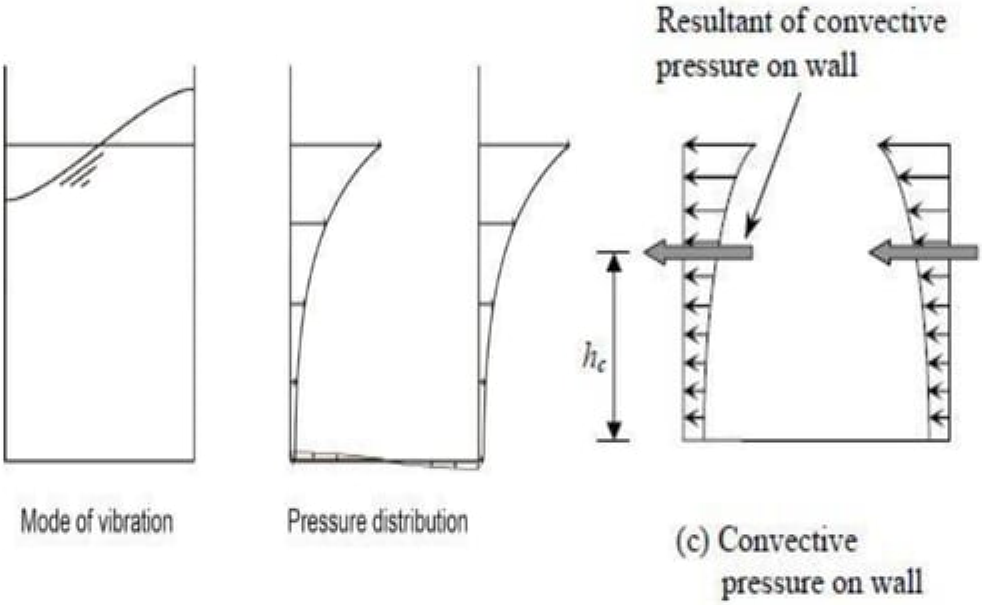


(a) Impulsive pressure on wall

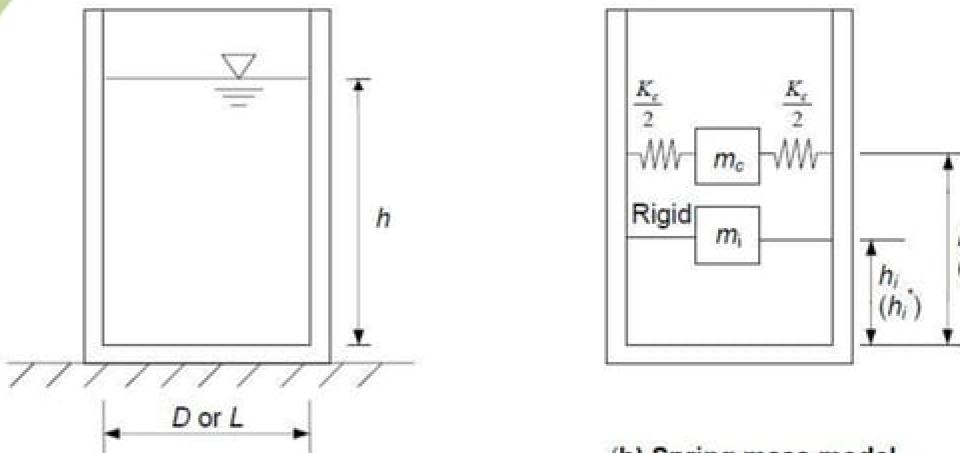
The convective component

- the part of the liquid in the upper part of the tank which is free to form waves or to slosh. It has a much longer natural frequency time than the impulsive portion.

Convective pressure

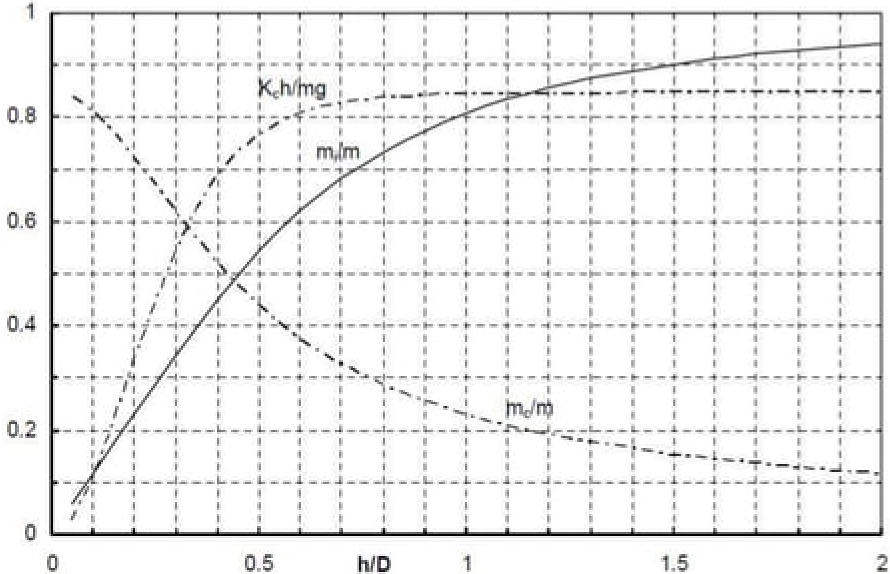


Spring mass model

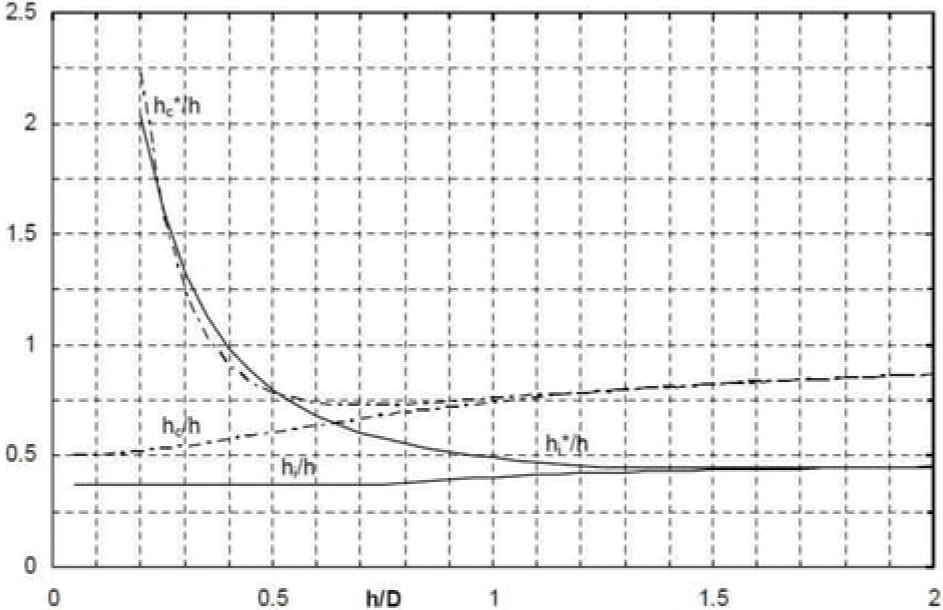


(a) Tank

(b) Spring mass model



(a) Impulsive and convective mass and convective spring stiffness


2.5
2
1.5
1
0.5
0
0
0.5
h/D
1
1.5
2
h_c^*/h
h_c/h
h_i/h
h_i^*/h

NOTE

Sometimes, vertical columns and shaft are present inside the tank. These elements cause obstruction to sloshing motion of liquid. In the presence of such obstructions, impulsive and convective pressure distributions are likely to change. At present, no study is available to quantify effect of such obstructions on impulsive and convective pressures. However, it is reasonable to expect that due to presence of such obstructions, impulsive pressure will increase and connective pressure will decrease.

Seismic overturning stability

The seismic overturning moment at the base of the tank shall be the SRSS summation of the impulsive and convective components.

$$M = \sqrt{[A_i(W_i.X_i + W_s.X_s + W_r.X_r)]^2 + [A_c.W_c.X_c]^2}$$

- A_i= Impulsive response coefficient
- A_c = Convective response coefficient
- W_i = Effective impulsive liquid weight
- W_s = Total weight of the tank shell
- W_r = Total weight of fixed tank roof
- W_c = Effective convective liquid weight
- X_i Height from the bottom of the tank shell to impulsive force
- X_s=Height from the bottom of the tank shell to the shell's center
- X_r = Height from the bottom of the tank shell to the roof
- X_c = Height from the bottom of the tank shell to the convective force

A_i = Impulsive response coefficient

$$A_i = \frac{S_{DS}\,.\,I}{R_{wi}}$$

S_{DS} = Design spectral response acceleration at 0.2 sec & 5% damped

I = importance factor

R_{wi} = Response Modification Factor

IMPORTANCE FACTOR

Occupancy category	I
I or II	1
III	1.25
IV	1.5

Response Modification Factors

Anchorage System	R_{wi}	R_{wc}
Self-anchored	3.5	2
Mechanically - anchored	4	2

Factors used for force reduction

$$W_i = \frac{\tanh\left(0.866\,\frac{D}{H}\right)}{0.866}\,.W_p \text{(total liquid weight)}$$

$$W_c = 0.23\,\frac{D}{H} W_p \tanh\left(\frac{0.367\,H}{D}\right)$$

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

$$X_i = 0\,.375\,H$$

Base Shear Force

Base shear is defined as the SRSS combination of the impulsive and convective components

$$V = \sqrt{V_i^{\,2} + V_c^{\,2}}$$

$$V_i = A_i\left(W_s + W_r + W_f + W_i\right)$$

$$V_c = A_c\, W_c$$

W_i = Effective impulsive portion of liquid weight, N

W_s = Total weight of the tank shell, N

W_r = Total weight of fixed tank roof including framing, knuckles, any permanent attachments and 10% of the roof design snow load, N

W_f = Total weight of the tank bottom, N

W_c = Effective convective (sloshing) portion of liquid weight, N

Anchorage requirement

The anchorage requirement is checked by the Anchorage Ratio, J, it will determine whether the tank can be self-anchored or mechanically anchored.

$$J = \frac{M_{rw}}{D^2[w_t(1-0.4A_v)+w_a-0.4\,w_{int}]}$$

Anchorage requirement

Anchorage Ratio	Criteria
$J \leq 0.785$	No calculated uplifted The tank is self-anchored.
$0.785 < J \leq 1.54$	Tank is uplifting, check shell compression requirements. Tank is self anchored.
$J > 1.54$	Tank is not stable

w_t = Weight of tank shell & portion of roof supported by shell

$w_t = \frac{w_s}{\pi D} + w_{rs}$ (Roof load acting on shell)

W_{int} = Uplift due to product pressure

w_a = Resisting force of annulus = 7.9 $t_a \sqrt{f_y G_e H}$

f_y = Min. specified yield strength of bottom annulus

G_e = Effective specific gravity including vertical seismic effect

G_e = G.(1 - 0.4 A_v) A_v (Vertical earthquake acceleration coefficient)(given or $\frac{F_v}{W_{eff}}$)

Response parameter

Table E-2—Value of F_v as a Function of Site Class

Site Class	Mapped Maximum Considered Earthquake Spectral Response Accelerations at 1 Sec Periods				
	$S_1 \le 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \ge 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	a	a	a	a	a

Shell Compression

The maximum shell longitudinal compression stress at the bottom of the shell

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

The shell compression stress has to be less than the allowable stress F_c

$$F_c = \frac{83\ t_s}{2.5D} + 7.5\sqrt{G\ H}$$

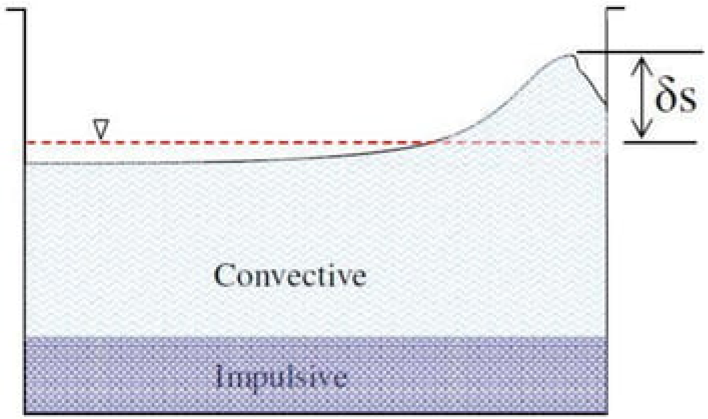
Anchorage Design

the design uplift load on the anchor bolts due to the seismic is determined

$$w_{AB}=\left(\frac{1.273\, M_{rw}}{D^2}-w_t(1-0.4A_v)\right)+\ w_{int}$$

$\frac{w_{AB}}{N.A_b} < 0.8\, S_y$ (Bolt allowable tensile strength)

Freeboard



$$\delta_s = 0.5\, D\, A_f$$

$$A_f = 2.5 \,.\, F_a . S_o \;\; \frac{4\,.\,T_S}{{T_c}^2}$$

$$T_S = \frac{S_{D1}}{S_{Ds}}$$

$$T_c = 1.8\, \frac{0.578}{\sqrt{\tanh\left(\frac{3.68H}{D}\right)}} \sqrt{D} \text{ [Convective (Sloshing) Period]}$$

Response parameter

Table E-1—Value of F_a as a Function of Site Class

Site Class	Mapped Maximum Considered Earthquake Spectral Response Accelerations at Short Periods				
	$S_s \le 0.25$	$S_s = 0.50$	$S_s = 0.75$	$S_s = 1.0$	$S_s \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	a	a	a	a	a

Mapped MCE spectral response acceleration

S_S

5% damped

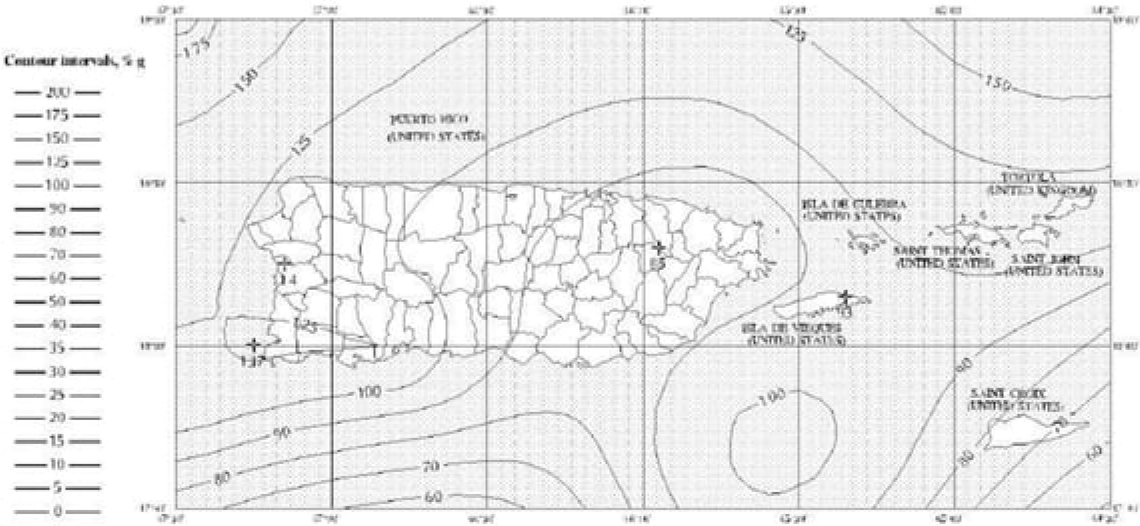
period of 0.2sec

S_1

5% damped

period of 1.0 sec

Mapped MCE spectral response acceleration



0.2 SEC SPECTRAL RESPONSE ACCELERATION (5% OF CRITICAL DAMPING)

Foundation

In the early phases of tank foundation engineering, several types of information should be considered and evaluated:

- Site conditions like pore water pressures and dewatering quantities.
- Condition and settlement of similar equipment in nearby areas.

Soil investigations

Although many tanks have been built without the soils reports, the advantages of having these reports available are substantial.

Foundation design usually begins with specifications provided in the soils report. The soils report addresses subsurface conditions, soil bearing capacity, and potential settlement.

These are determined from soil borings, load tests and laboratory testing.

In addition, one of the most important bits of information available to the tank foundation designer is the experience with similar structures available from a soils engineer familiar with the area.

Important Elements to Consider in Foundation Design

The final elevation of the tank bottom is important because the tank shell may sit in moist conditions

This results in accelerated corrosion or pitting and a reduced tank bottom life.

Tanks should be designed to be at least 8 to 12 in above the surrounding grade level

Use of a material which contains mineral salts or is contaminated with organic matter that can decompose, induce microbial corrosion, or turn acidic can accelerate underside corrosion.

The solution is to use appropriate backfill. When a granular material such as sand is used, it should be cleaned and washed to minimize the presence of salts and minerals.

Another consideration for setting tank foundations is the possibility of buoyancy of the tank due to submergence in water.

Since typical tanks require less than 1 ft of submergence to float off of the foundation. the most likely cause of this is the rainfall. the probability of this happening while the tanks are empty .

Foundation profile

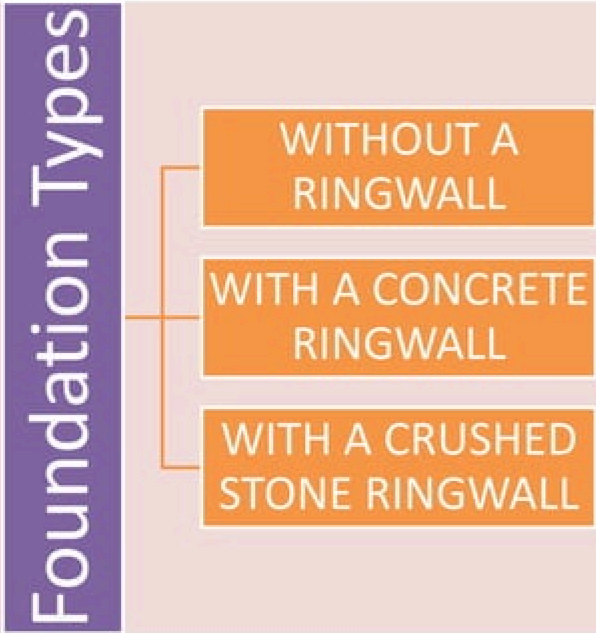
Cone up	This is the most common profile.
	A typical slope of 1 to 2 in per 10 ft of horizontal run is used.
	This pattern prevents and minimizes intrusion of rainwater from the outside periphery of the tank bottom.

Cone down, The bottom slopes toward the center of the tank, and an internal sump is usually included here for water bottom removal. The rate of slope is the same as for a cone-up tank.

Planar sloped bottom, the bottom is constructed as a plane but it is tilted to one side. it is easier to construct. However, it is slightly more complex for the shell construction to accommodate this pattern.

Plane flat bottom, For small tanks it is not worthwhile to provide a sloped bottom for services where water removal is not required. It is also not necessary to use sloped bottom tanks.

Foundation


Foundation Types
WITHOUT A RINGWALL
WITH A CONCRETE RINGWALL
WITH A CRUSHED STONE RINGWALL

foundation should accomplish the following:

- Provide a stable plane for the support of the tank.
- Limit overall settlement of the tank grade to values compatible with the allowances used in the design of the connecting piping.
- Provide adequate drainage.
- Not settle excessively at the perimeter due to the weight of the shell wall.

FOUNDATIONS WITHOUT A RINGWALL

FOUNDATIONS WITH A CONCRETE RINGWALL

Large tanks and tanks with heavy or tall shells and/or self-supported roofs impose a substantial load on the foundation under the shell.

When there is some doubt whether a foundation will be able to carry the shell load directly, a concrete ring wall foundation should be used.

Advantages

It provides better distribution of the concentrated load of the shell to produce a more nearly uniform soil loading under the tank.

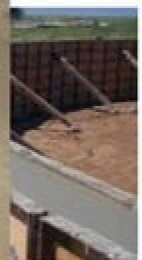
It provides a level, solid starting plane for construction of the shell.

it is capable of preserving its contour during construction.

It retains the fill under the tank bottom and prevents loss of material as a result of erosion.

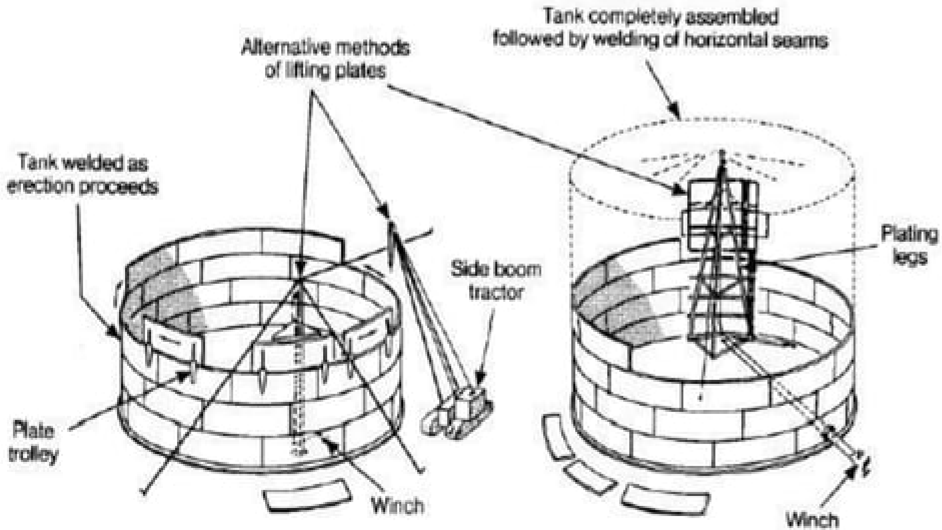
It minimizes moisture under the tank.

FOUNDATIONS WITH A CONCRETE RINGWALL



TANK CONSTRUCTION

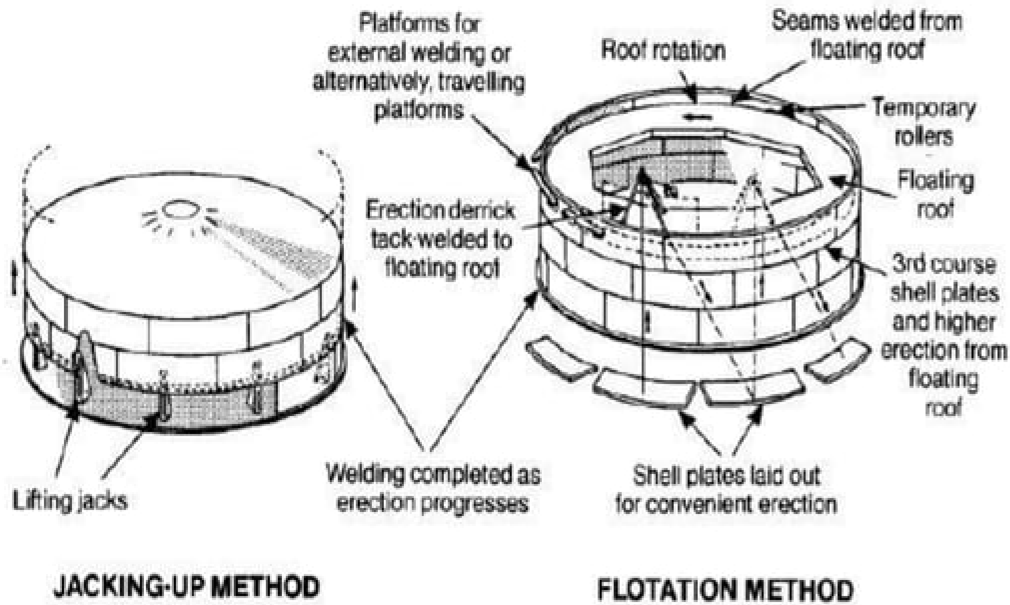
Just as most of the construction task, welded vertical tanks can be erected satisfactorily in several ways, erector contractors normally have a particular method, which they have adopted as the result of experience.



PROGRESSIVE ASSEMBLY AND WELDING

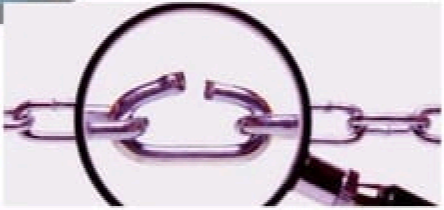
COMPLETE ASSEMBLY FOLLOWED BY WELDING OF HORIZONTAL SEAMS


NAEC


Platforms for external welding or alternatively, travelling platforms
Roof rotation
Seams welded from floating roof
Temporary rollers
Floating roof
Erection derrick tack-welded to floating roof
3rd course shell plates and higher erection from floating roof
Lifting jacks
Welding completed as erection progresses
Shell plates laid out for convenient erection
JACKING-UP METHOD
FLOTATION METHOD

101.00

Tank Testing



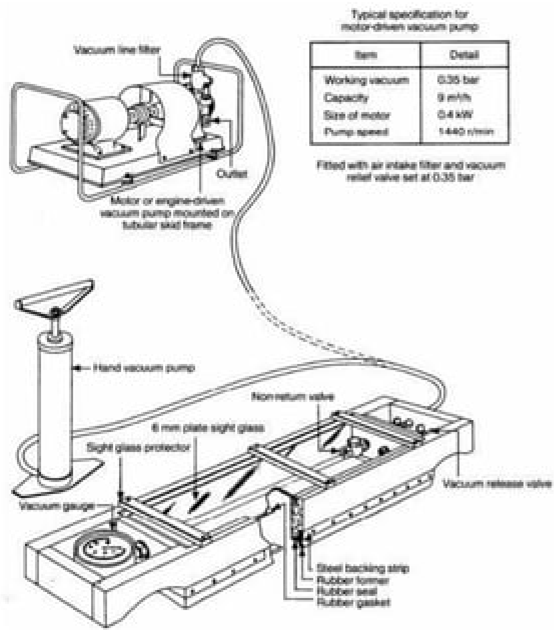
Tank Bottom Testing

After welding of the bottom plates has been completed, all welds will be tested to ensure that the tank bottom is free from leaks.

This can be done by using a vacuum box, which enables any leaks in the seams to be positively located by visual examination.

The test is preferably be made as soon as possible after welding of the bottom but before any surface coating is applied. The bottom plates has to be tested before water is put into the tank for hydrostatic testing.

vacuum box


Typical specification for
motor-driven vacuum pump
Item
Detail
Working vacuum
0.35 bar
Capacity
$9\ m^3/h$
Size of motor
0.4 kW
Pump speed
1440 r/min
Fitted with air intake filter and vacuum relief valve set at 0.35 bar
Vacuum line filter
Outlet
Motor or engine-driven vacuum pump mounted on tubular skid frame
Hand vacuum pump
Non-return valve
6 mm plate sight glass
Sight glass protector
Vacuum gauge
Vacuum release valve
Steel backing strip
Rubber former
Rubber seal
Rubber gasket

Tank Shell Testing

The tank shells should be water tested/ hydro tested after completion of the wind girder.

The tank will be filled up with water to its design level.

The water test not only to ensure no leakage of the tank, it also tested the foundation for its capability of taking the filled tank load. Settlement will also be measured during the water testing.

Hydro/ Water Test

- Water is always an issue on construction site to fill up and test the huge tank.
- Some contractor who has limited knowledge on the tank and material properties, for cost saving purpose, they would use sea water as water medium to perform the water test.
- However sea water contains very high chlorine and it would cause corrosion to the tank.
- The materials selected were not designed for the sea water.
- After the water test, never dewatering from the Manway or the clean out door, the tank venting were not designed for emptying in such big opening.

Floating Roof Testing

The floating roof has to be liquid-tight in order for it to function safely and effectively, for all the weld seams and joints has to be liquid-tight, they will be inspected and tested in a more careful way.

- Centre Deck

The weld seams of the centre deck plates should be controlled on liquid-tightness by the vacuum box method.

- Roof Drain

The roof drain pipe systems for the floating roof will be tested with water to a pressure of 3.5 bar, and during the flotation test, the roof drains should be kept open and observed for leakage of tank contents into the drain lines.

References

Design, Construction and Operation of the Floating Roof Tank Submitted by **Kuan Siew Yeng**

API 650: Welded Steel Tanks for Oil Storage

Aboveground Storage Tanks

Philip E. Myers