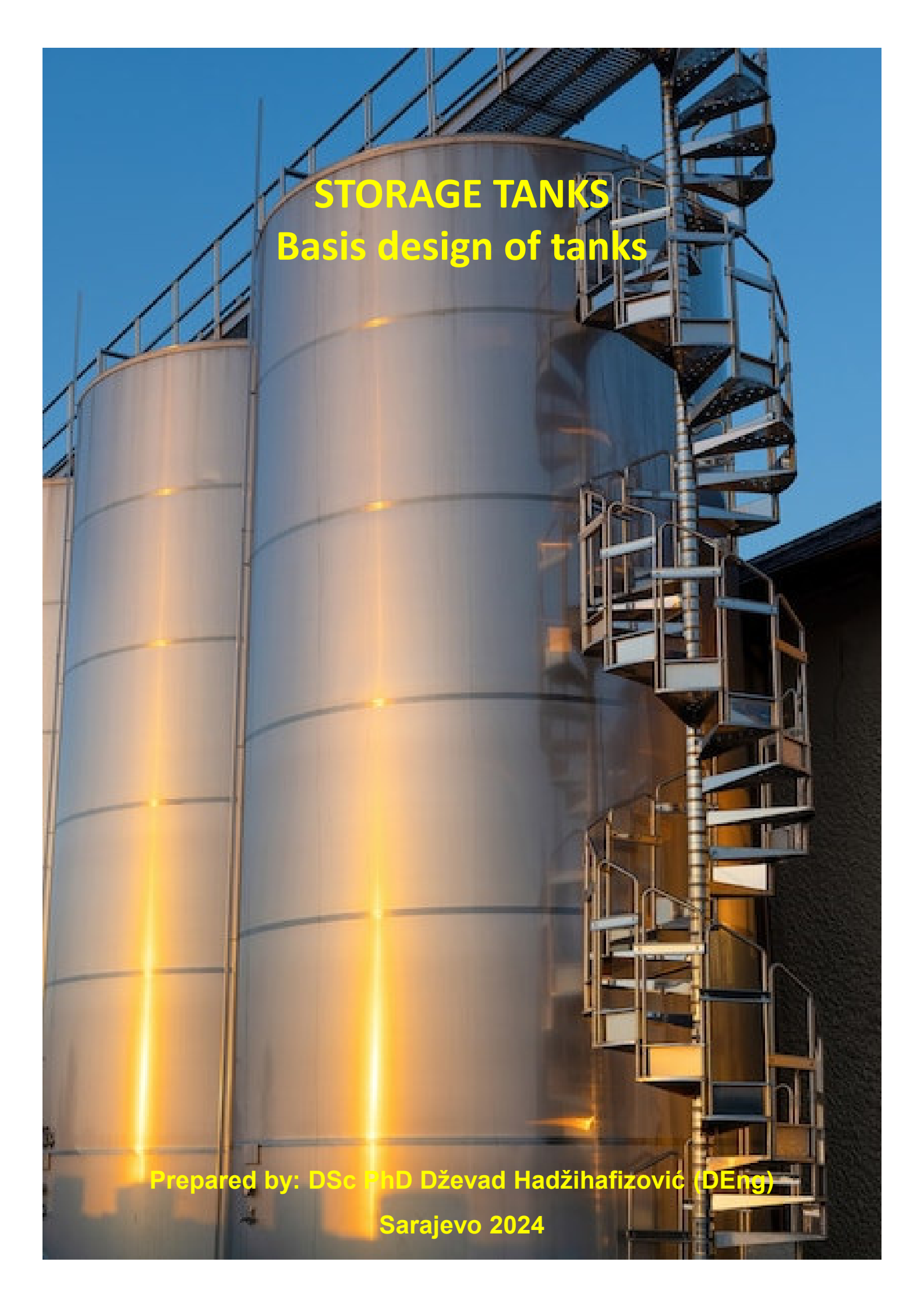


A photograph of a large, cylindrical industrial storage tank, likely made of stainless steel, with a spiral staircase winding around its exterior. The tank is illuminated by warm, golden light, possibly from the setting or rising sun, creating a strong vertical glow. The sky in the background is a clear, deep blue.

STORAGE TANKS

Basis design of tanks

Prepared by: DSc PhD Dževad Hadžihafizović (DEng)

Sarajevo 2024

STORAGE TANKS

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Unit 1

LIQUID STORAGE TANKS

LESSON 1

TYPE OF TANKS

1. Fixed Cone Roof Tanks

- a. self supporting cone roof (7 to 10m) $t = \frac{D}{400 \sin \theta}$
- b. supported cone roof
 - with rafters (up to 15m)
 - with rafters & column (15 to 25m)
 - with truss > (25m)

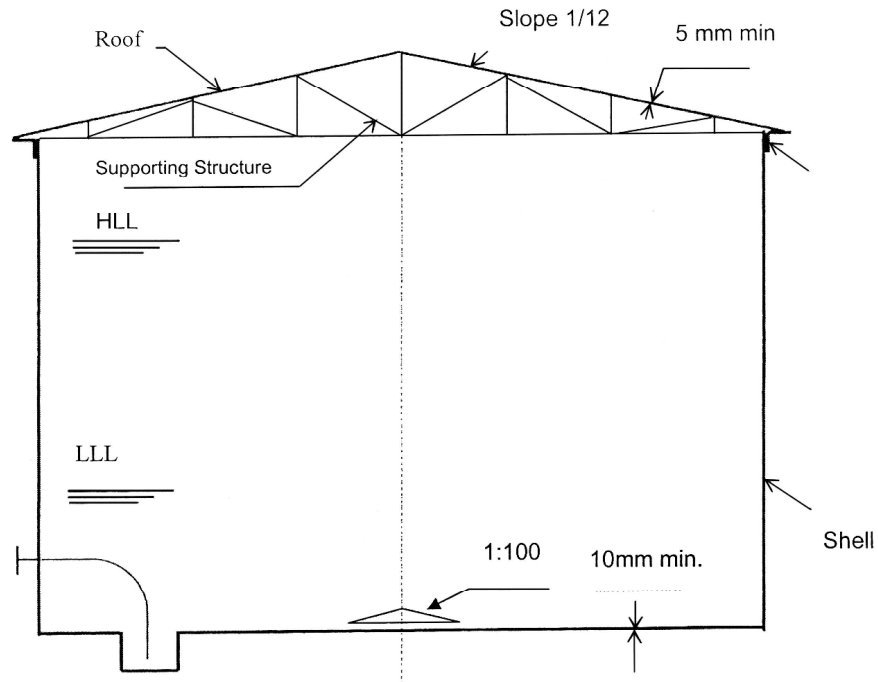
2. Floating Roof Tanks

- Pan type tank < **20m**
- Single pontoon < **50m**
- Double deck > **50m**
- Covered floating roof < **80m**
- Internal floating roof (< **30m**) (**Aluminum + Plastics**)

3. Low Pressure Tanks P = 0.5 to 15 psig

- Hemi spherical (Plain - noded)
- Noded Spheroidal
- Spheroidal

1. Fixed Cone Roof Tank



Working Capacity (Net Capacity)

Volume enclosed between HLL and ILL

Gross Capacity (geometric Capacity)

Volume enclosed by the full dimension of the tank

Dead Volume

Volume enclosed by the LLL

Design of Tank

Thickness Calculations:

1. Design:

$$t_d = \frac{2.6D(H-1)G}{S_d} + C.A$$

2. Hydro-test:

$$t_t = \frac{2.6D(H-1)}{S_t}$$

t = Required thickness (inch)

D = Tank inside diameter (ft)

H = Design liquid level (ft)

G = Specific gravity of product

S_d = allowable stress for design (psi)

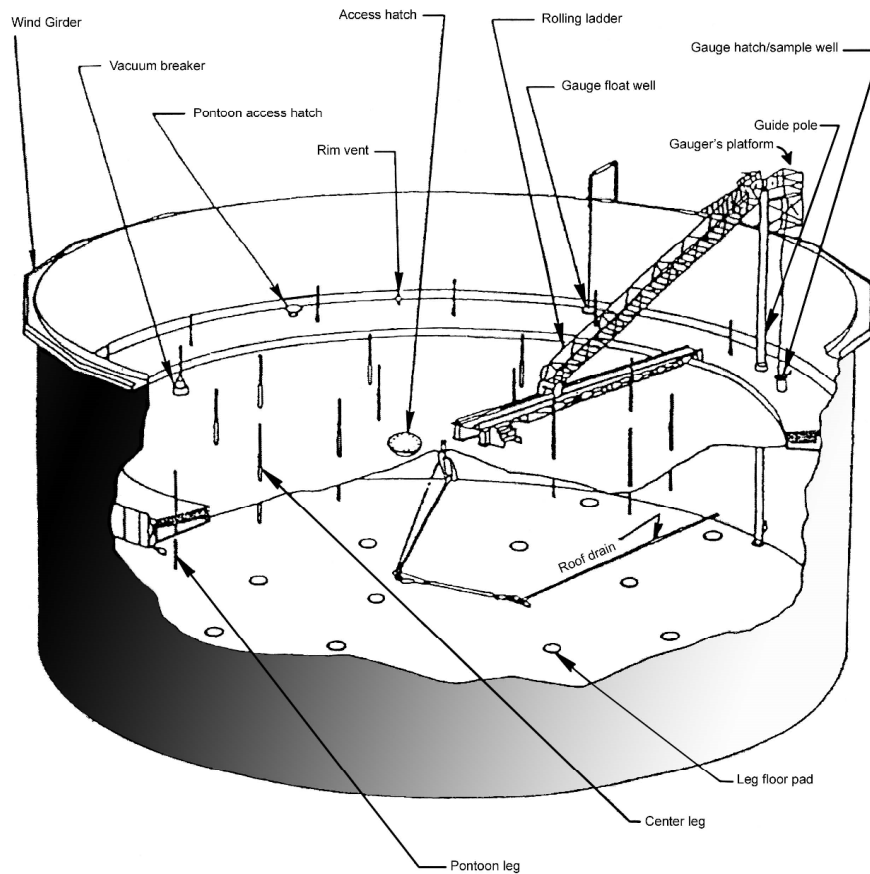
S_t = allowable stress for hydro-test (psi)

Shell Design

Nominal tank diameter (m)	Nominal plate thickness (mm)
D < 15	5
15 < D < 36	6
36 < D < 60	8
D > 60	10
Top Angles :	

Nominal tank diameter (m)	Nominal angle dimensions (mm)
D < 11	50 × 50 × 5
11 < D < 18	50 × 50 × 8
D > 18	75 × 75 × 10

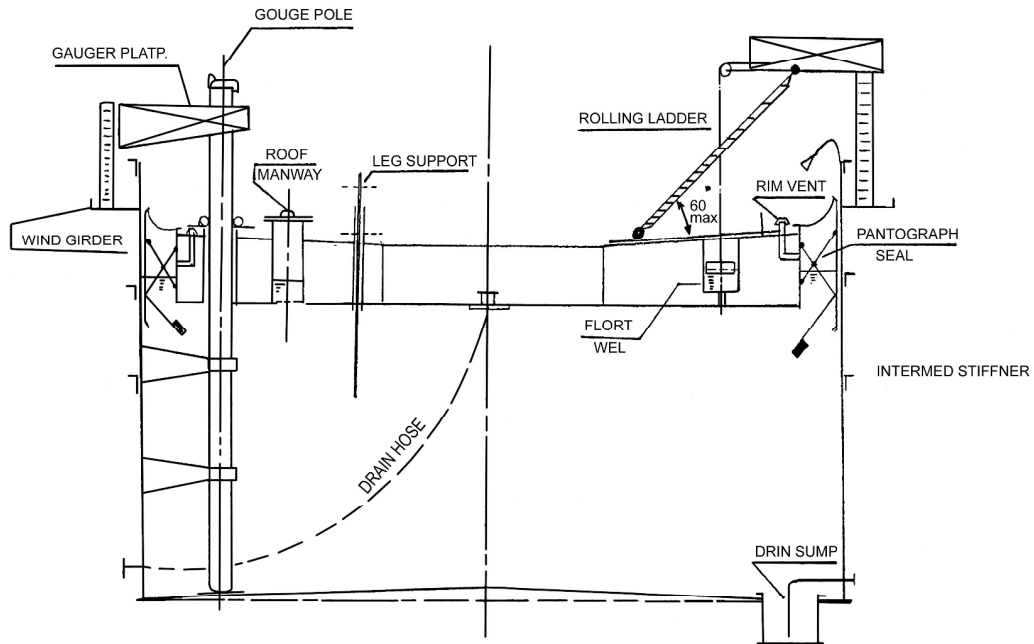
2. Floating Roof Tanks



The floating roof tanks are developed to store volatile liquids (ex: condensate) to minimize the loss of valuable vapors, as well as, to minimize the hazard of dangerous vapor formation underneath a fixed roof.

The floating roof - a " floating roof," as the name implies, actually floats on the surface of the oil, rather than being carried above the oil on structural steel supports. It rides up and down inside the tank shell as the oil level changes. However, when the normal roof and roof supports are removed, a wind girder is installed around the outside of the tank at or near the top. This stiffens the tank shell and holds it "in round" when the floating roof is low in the tank.

Floating Roof Components



SINGLE PONTON
FLOATING ROOF TANK

2.1 Floating Roof

A. Pan Floating Roof

It is the simplest form of floating roof, it is merely a large, flat pan slightly smaller in diameter than the inside of the tank shell. It is provided with a system of flexible "shoes" to close the space between the edge of the roof and the tank shell.

B. Pontoon Floating Roof

The floating roof is built from a series of "pontoons," or closed compartments, around its outer edge to increase floating stability and to simplify the structure

C. Double Deck Floating Roof

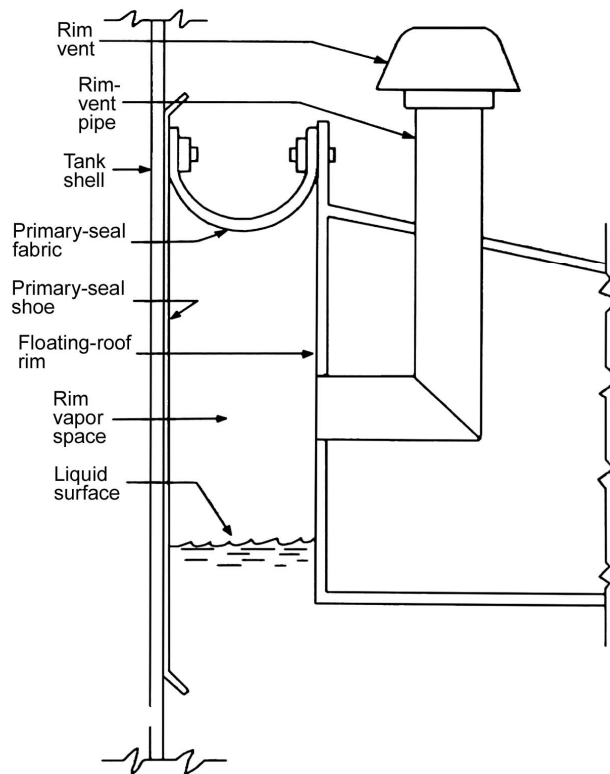
The "double-deck" type employs two separate decks of steel plate over the entire tank area. The space between the upper and lower plates is divided into compartments. With this type of roof the oil is never in contact with the underside of a plate whose top surface is directly exposed to the sun's rays.

2.2 RIM Seal

A Seal is loaded between the tank shell and float rim to minimize the evaporation losses and to eliminate the entrance of any rain water, Sand , etc...., to the stored liquid.

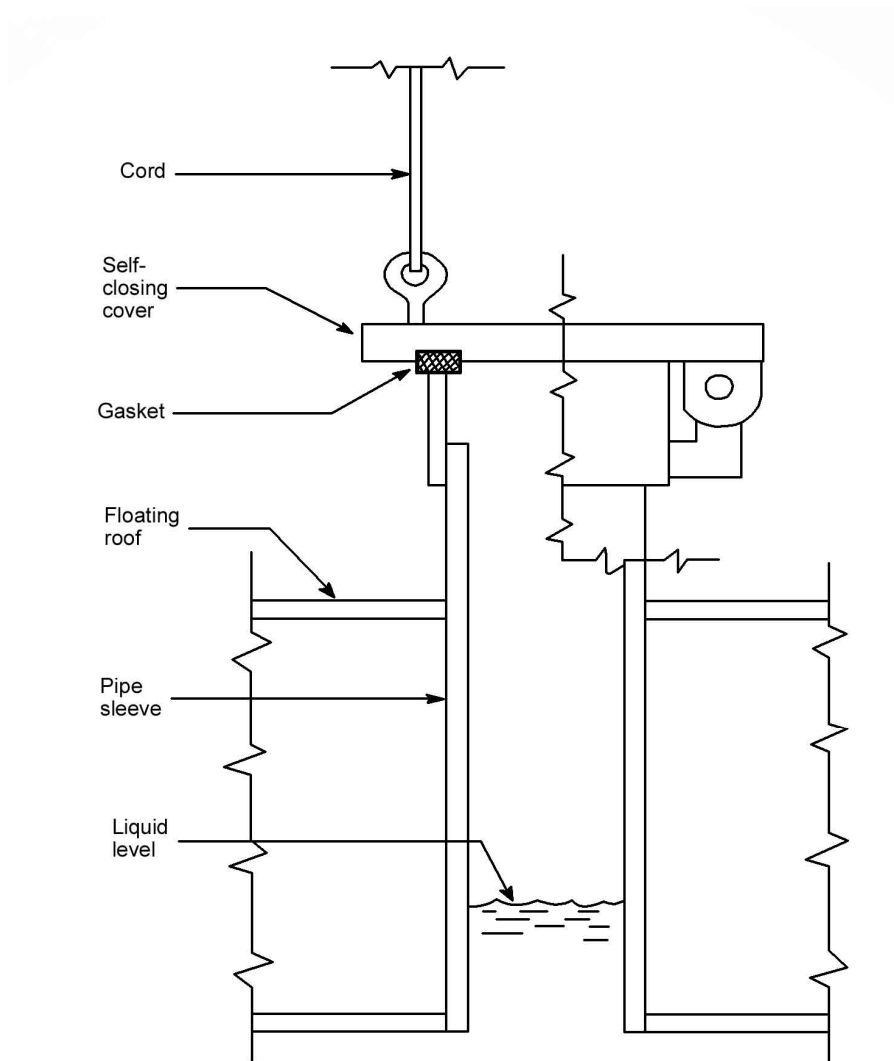
2.3 RIM Vent

The rim vent is connected to the rim vapor space by a pipe and releases any excess pressure or vacuum that is present. The rim vapor space is bounded by the floating roof rim, the primary seal shoe, the liquid surface, and the primary seal fabric. Rim vents usually consist of weighted pallets that rest on gasketed surfaces.



2.4 Gauge - Hatch / Sample Wells

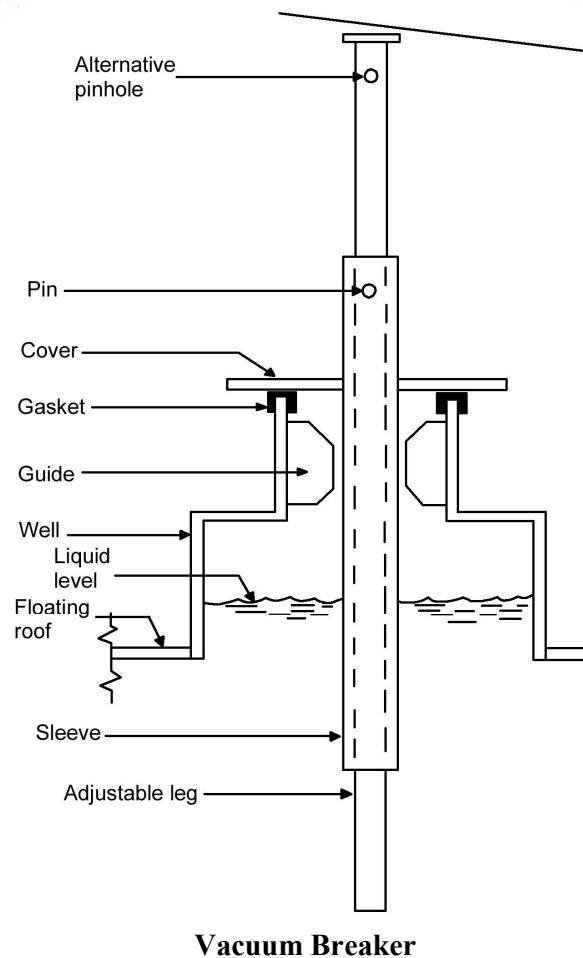
Gauge -hatch/ sample wells provide access for hand gauging the level of stock in the tank and for taking thief samples of the tank contents. A gauge- hatch /sample well consists of a pipe sleeve through the floating roof and a self-closing gasketed cover. Gauge hatch/sample wells are usually located under the gauger's platform, which is mounted on the top of the tank shell. The cover may have a cord attached so that it can be opened from the gauger's platform. A gasketed cover will reduce evaporative losses.



Gauge-Hatch/Sample Well

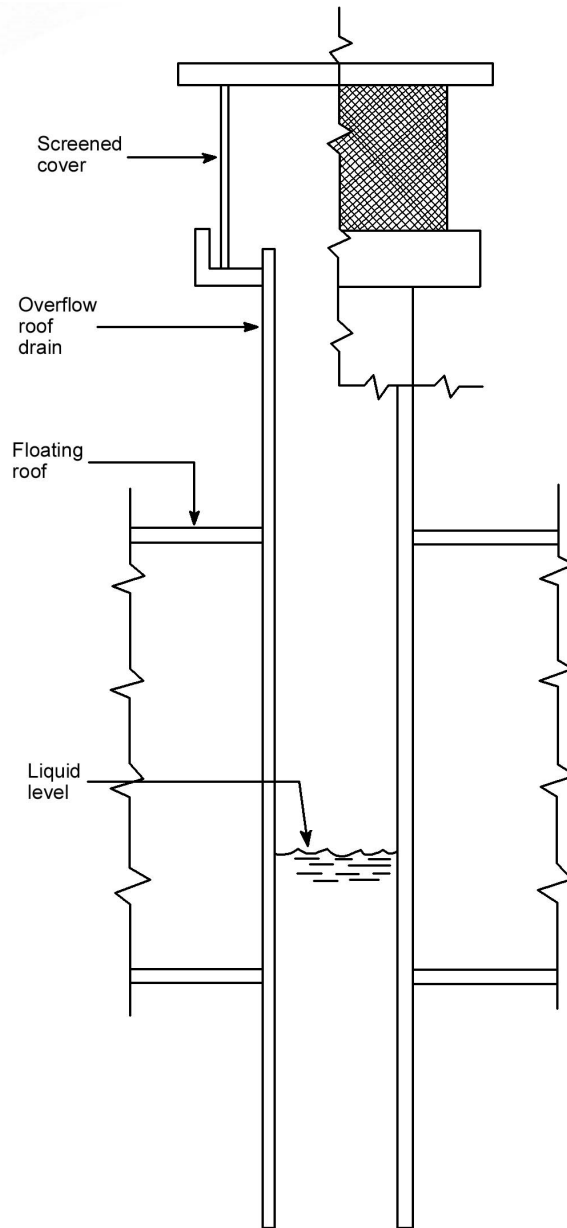
2.5 Vacuum Breakers

A vacuum breaker is used to equalize the pressure in the vapor space beneath the floating roof when the roof is either banded on its legs or floating off its legs. This is accomplished by opening a roof fitting, usually a well formed of pipe on which rests a cover. A guided leg is attached to the underside of the cover and comes in contact with the tank bottom just at the point when the roof floats freely on the stock. When the leg is in contact with the tank bottom, it mechanically opens the vacuum breaker by lifting the cover off the well. When the leg is not in contact with the bottom, the opening is closed by the cover resting on the well. Some vacuum breakers have adjustable legs to permit changing the roof level at which vacuum breaker is to allow the free exchange of air or vapor, the well does not extend appreciably below the bottom of the floating roof. A gasket can be used to reduce the evaporative loss when the cover is seated on the well.



2.6 Overflow Roof Drain

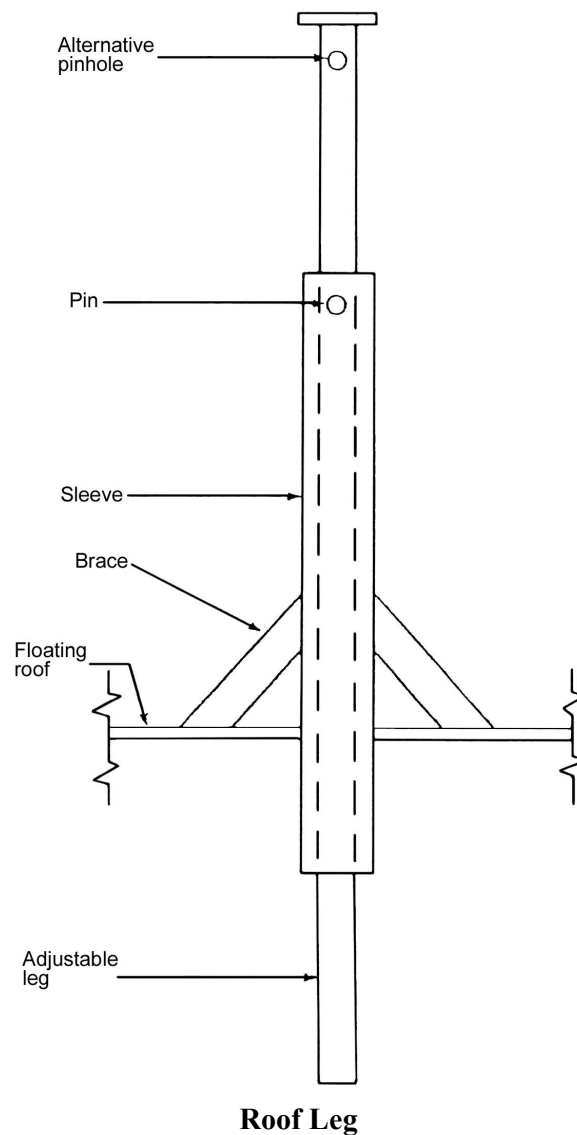
Overflow drains consist of a drain opening that is elevated above the top surface of the floating roof. Overflow drains limit the maximum amount of rain water that can accumulate on the floating roof and are thus used to provide emergency drainage of rainwater. They are normally used in conjunction with a closed drainage system to carry rainwater to the outside of the tank.



Overflow Roof Drain

2.7 Roof Legs

To prevent damage to fittings located beneath the floating roof and to allow clearance for tank cleaning or repair, roof legs are provided to hold the tank bottom when the tank is emptied. The larger the diameter of the tank, the greater the number of legs required. Roof legs generally consist of an adjustable pipe leg that passes through a slightly larger diameter vertical pipe sleeve. The sleeve is welded to the floating roof, extending both above and below it. Steel pins are passed through holes in the sleeve and leg to permit height adjustment the length of the sleeve above the roof. Evaporative loss occurs in the annulus between the leg and its sleeve.



2.8 Gauge-Float wells

Gauge floats are used to indicate the level of stock within the tank. They usually consist of a float contained within a well that passes through the floating roof, the float is connected to an indicator on the exterior of the tank by a cable or tape that passes through a guide system. The well is closed by a cover that contains a hole through which the cable or tape passes. Evaporative loss can be reduced by gasketing and/or bolting the cover to the well.

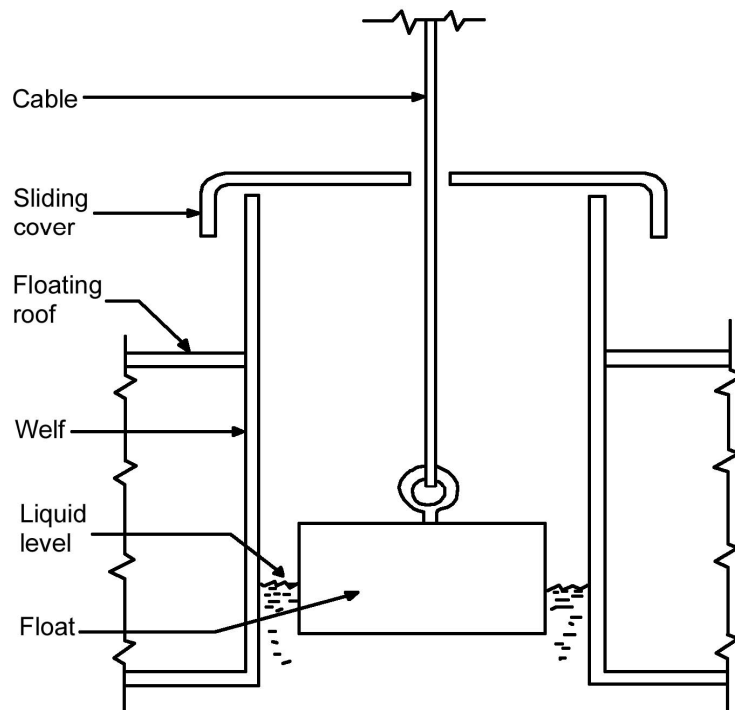
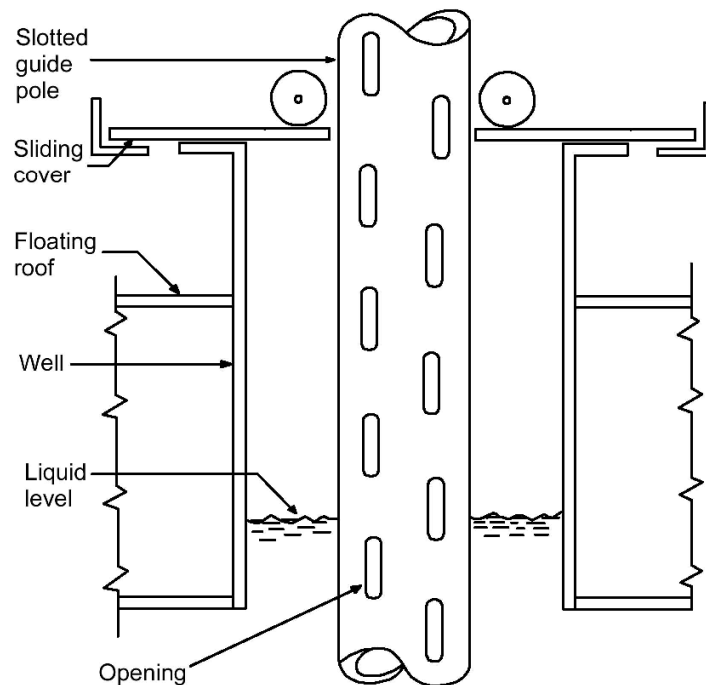


Figure – Gauge-Float Well

2.9 Guide Pole

One commonly used antirotation device is a guide pole that is fixed at the top and bottom of the tank. The guide pole passes through a well on the floating roof. Rollers attached to the top of the well ride on the outside surface of the guide pole to prevent rotation of the floating roof. The guide-pole well has a sliding cover to accommodate limited radial movement of the roof. The sliding cover can be equipped with a gasket between the guide pole and the cover to reduce evaporative loss. The guide-pole well can also be equipped with a gasket between the sliding cover and the top of the well to reduce evaporative loss. Openings at the top and bottom of the guide pole provide a means of hand gauging the tank level and of taking bottom samples.



Slotted Guide-Pole/Sample Well

In this figure the wall of the guide pole is constructed with a series of holes or slots that allow the product to mix freely in the guide pole and thus have the same composition and liquid level as the product in the tank. To reduce evaporative loss caused by these openings, a removable float is sometimes placed inside the guide pole.

2.10 Roof Drain Hose

A Special hose design supplied with or without Lead Cable Ballast for Roating Roof Tanks

Description

A hose designed to meet the special conditions required for total immersion in petroleum products for long periods.

Construction

The hose is constructed from specially compounded synthetic rubbers with synthetic fiber and steel reinforcement.

The hose is supplied with attached couplings to match the tank fittings.

The flexible hose construction allows a tight bend radius without risk of damage.

The ballast material is a high-strength steel cable onto which lead is extruded to give maximum ballasting effect with minimum loss of hose capacity.

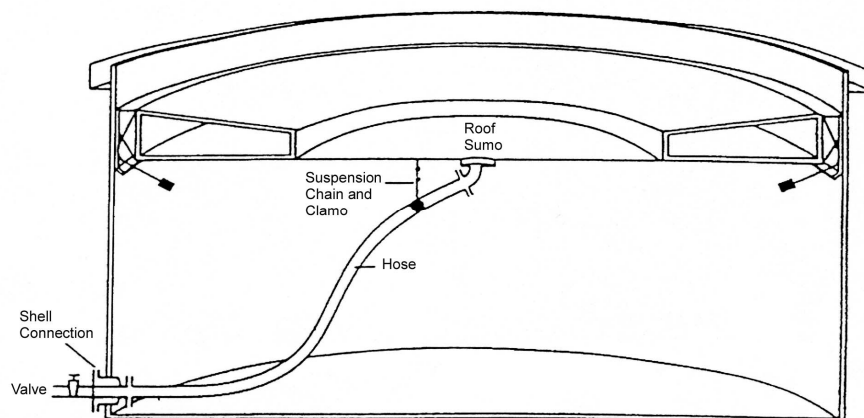
Aromatic Resistance

Standard hose - up to 70%

Fluoroelastomer - covered hose -up to 100%

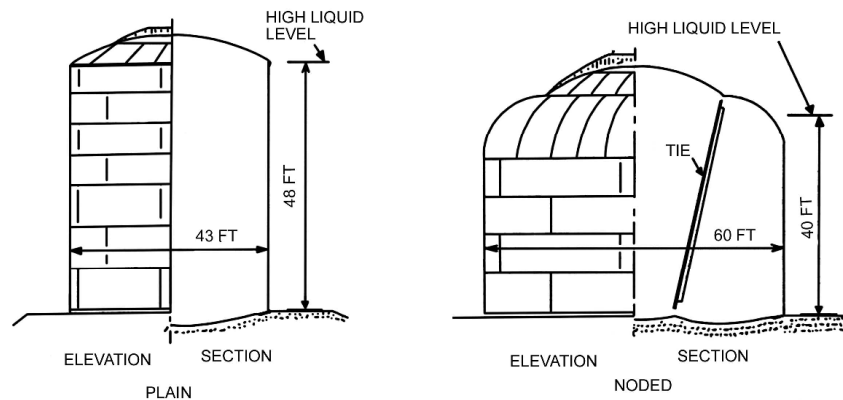
Sizes

75 mm, 100 mm and 150 mm are the standard diameters. Others can be produced to order. Lengths are made up to suit each individual tank size.



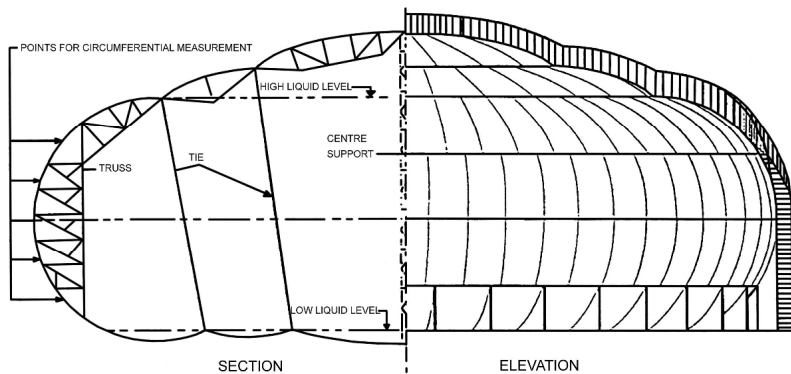
3. Low Pressure Tanks

1. Hemispherical

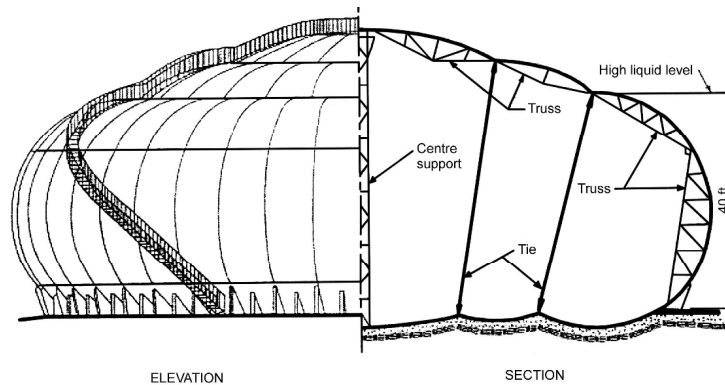


Drawings of Hemispheroids

2. Noded Spheroidal



Noded Spheroidal tank



Noded Spheroidal Tank

LESSON 2

BASIS DESIGN OF TANKS

1. JOINTS

1.1 Definitions

The definitions in 2.1.1.1 through 2.1.1.8 apply to tank joint designs (see 7.1 for definitions that apply to welders and welding procedures).

Double-welded butt joint: A joint between two abutting parts lying in approximately the same plane that is welded from both sides.

Single-welded butt joint with backing: A joint between two abutting parts lying in approximately the same plane that is welded from one side only with the use of a strip bar or another suitable backing material.

Double-welded lap joint: A joint between two overlapping members in which the overlapped edges of both members are welded with fillet welds.

Single-welded lap joint: A joint between two overlapping members in which the overlapped edge of one member is welded with a fillet weld.

Butt-weld: A weld placed in a groove between two abutting members. Grooves may be square, V-shaped (single or double), or U-shaped (single or double), or they may be either single or double beveled.

Fillet weld: A weld of approximately triangular cross section that joins two surfaces at approximately right angles, as in a lap joint, tee joint, or corner joint.

Full-fillet weld: A fillet weld whose size is equal to the thickness of the thinner joined member.

Tack weld: A weld made to hold the parts of a weldment in proper alignment until the final welds are made.

1.2 Welding

- The size of a groove weld shall be based on the joint penetration (that is, the depth of chamfering plus the root penetration when specified).
- The size of an equal-leg fillet weld shall be based on the leg length of the largest isosceles right triangle that can be inscribed within the cross section of the fillet weld. The size of an unequal-leg fillet weld shall be based on the leg lengths of the largest right triangle that can be inscribed within the cross section of the fillet weld.
- The minimum size of fillet weld shall be as follows:

- On plates 5 mm (3/16 in.) thick, the weld shall be a full-fillet weld, and on plates more than 5 mm (3/16 in.) thick, the weld thickness shall not be less than one-third the thickness of the thinner plate at the joint and shall be at least 5 mm (3/16 in.).
- Single-welded lap joints are permissible only on bottom plates and roof plates.
- Lap-welded joints, as tack-welded, shall be lapped at least five times the nominal thickness of the thinner plate joined; however, with double-welded lap joints, the lap need not exceed 50 mm (2 in.), and with single-welded lap joints, the lap need not exceed 25 mm (1 in.).

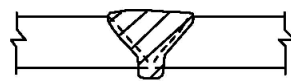
1.3 Welding Symbols

Welding symbols used on drawings shall be the symbols of the American Welding Society.

1.4 Typical Joints

1.4.1 Vertical Shell Joints

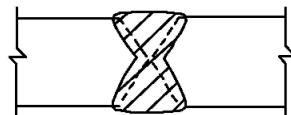
- Vertical shell joints shall be butt joints with complete penetration and complete fusion attained by double welding or other means that will obtain the same quality of deposited weld metal on the inside and outside weld surfaces to meet the requirements of API 650
- Vertical joints in adjacent shell courses shall not be aligned but shall be offset from each other a minimum distance of $5t$, where t is the plate thickness of the thicker course at the point of offset.



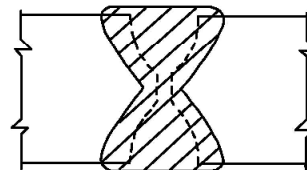
Single-V butt joint



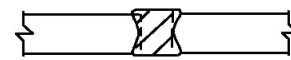
Single-U butt joint



Double-V butt joint



Double-U butt joint

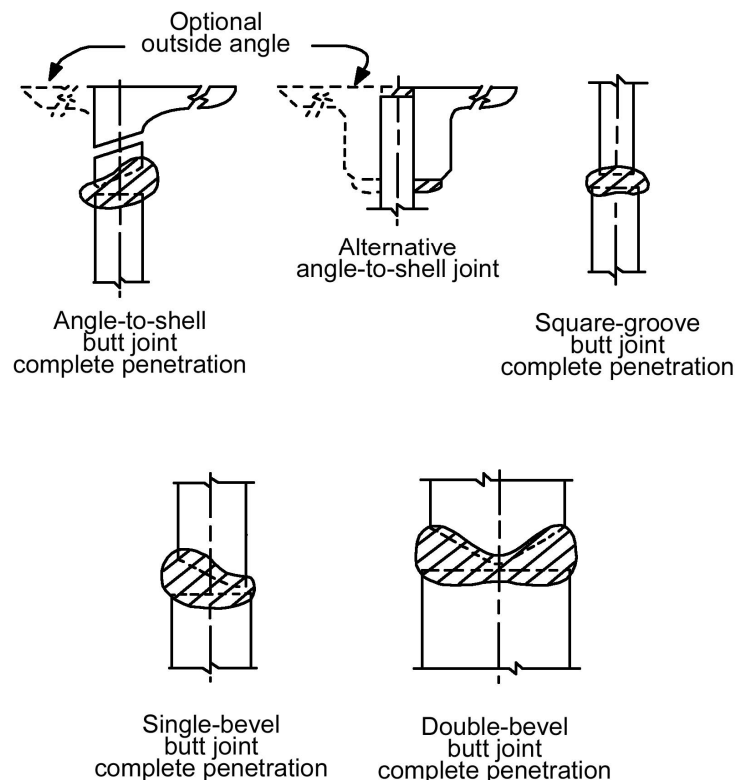


Square-groove butt joint

Typical Vertical Shell Joints

1.4.2 Horizontal Shell Joints

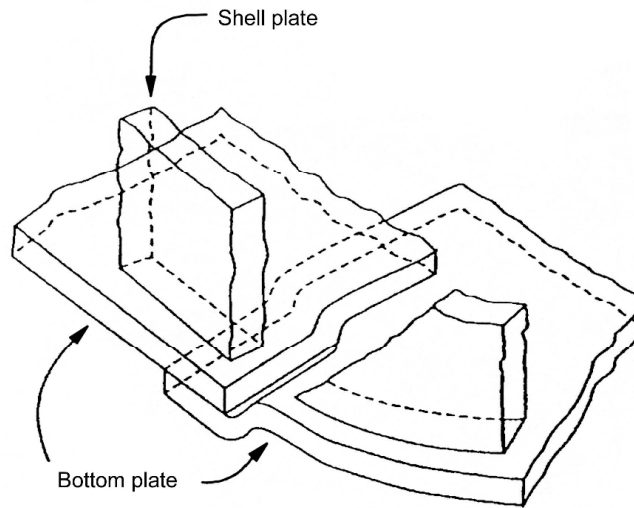
- a. Horizontal shell joints shall have complete penetration and complete fusion; however, as an alternative, top angles may be attached to the shell by a double-welded lap joint.
- b. Unless otherwise specified, abutting shell plates at horizontal joints shall have a common vertical centerline.



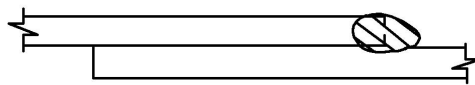
Typical Horizontal Shell joints

1.4.3 Lap-Welded Bottom Joints

Lap-welded bottom plates shall be reasonably rectangular and square edged. Three-plate laps in tank bottoms shall be at least 300 mm (12 in.)-from each other, from the tank from butt-welded annular-plate joints, and from joints between annular plates and the bottom. Lapping of two bottom plates on the butt-welded annular plates does not constitute a three-plate lap weld. When annular plates are used or are required, they shall be butt-welded and shall have a radial width that provides at least 600 mm (24 in.) between the inside of the shell and any lap-welded joint in the remainder of the bottom. Bottom plates need to be welded on the top side only, with a continuous full-fillet weld on all seams. Unless annular bottom plates are used, the bottom plates under the bottom shell ring shall have the outer ends of the joints fitted and lap-welded to form a smooth bearing for the shell plates.



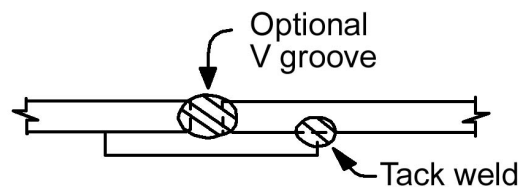
**Method for Preparing Lap-Welded Bottom Plates
Under Tank Shell**



**Single-welded
Full-fillet lap joint**

1.4.4 Butt-Welded Bottom Joints

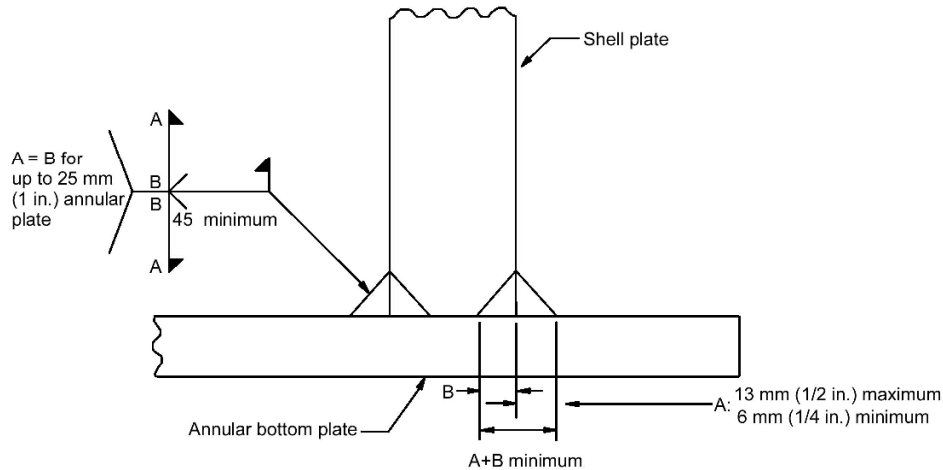
Butt-welded bottom plates shall have their parallel edges prepared for butt welding with either square or V grooves. If square grooves are employed, the root openings shall not be less than 6 mm ($1/4$ in.). The butt-welds shall be made by tack welding a backing strip at least 3 mm ($1/8$ in.) thick to the underside of the plate. A metal spacer shall be used to maintain the root opening between the adjoining plate edges unless the manufacturer submits another method of butt-welding the bottom for the purchaser's approval. Three plate joints in the tank bottom shall be at least 300 mm (12 in.) from each other and from the tank shell.



**Single-welded butt joint
With backing strip**

1.4.5 Bottom Annular-Plate Joints

Bottom annular-plate radial joints shall be butt-welded in accordance with 3.1.5.5 and shall have complete penetration and complete fusion. The backup bar shall be compatible for welding the annular plates together.

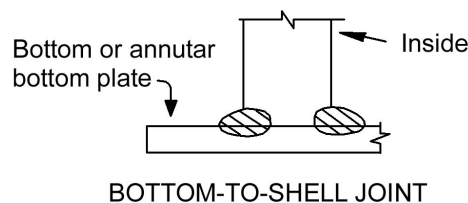


1. A = Fillet weld size limited to 13mm (Vain.) maximum.
2. A + B = Thinner than shell or annular bottom plate thickness.
3. Groove weld B may exceed fillet size A only when the annular plate is thicker than 25mm(1 inch).

Detail of Double Fillet -Groove Weld for Annular Bottom Plates with a Nominal Thickness Greater than 13mm (½ in)

1.4.6 Shell-to-Bottom Fillet Welds

- a. For bottom and annular plates with a nominal thickness 125 mm (1/2 in.), and less, the attachment between the bottom edge of (he lowest course shell plate and the bottom plate shall be a continuous fillet weld laid on each side of the shell plate. The size of each weld shall not be more than 12.5 mm (1/2 in.) and shall not be less than the nominal thickness of the thinner of the two plates joined (that is. the shell plate or the bottom plate immediately under the shell) or less than the following values:



Nominal Thickness of Shell Plate		Minimum Size of Fillet Weld	
(mm)	(in.)	(mm)	(in.)
5	0.1875	5	3/16
> 5 to 20	>0.1875to0.75	6	1/4
> 20 to 32	> 0.75 to 1.25	8	5/16
> 32 to 45	> 1.25 to 1.75	10	3/8

- b. For annular plates with a nominal thickness greater than 125 mm (5 in.), the attachment welds shall be sized so that either the legs of the fillet welds or the groove depth plus the leg of the fillet for a combined weld is of a size equal to the annular-plate thickness, but shall not exceed the shell plate thickness.
- c. Shell-to-bottom fillet welds for shell material in Groups IV, IVA, V, or VI shall be made with a minimum of two passes.

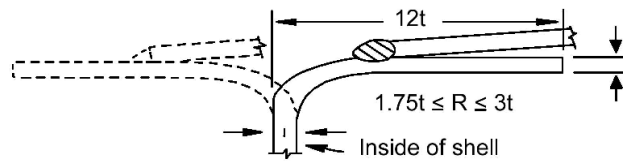
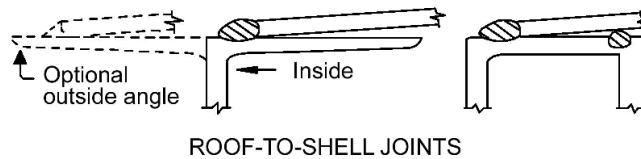
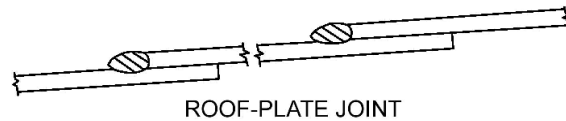
1.4.7 Wind Girder Joints

- a. Full-penetration butt-welds shall be used for joining ring sections.
- b. Continuous welds shall be used for all horizontal top-side joints and for all vertical joints. Horizontal bottom-side joints shall be seal-welded if specified by the purchaser. Seal-welding should be considered to minimize the potential for entrapped moisture, which may cause corrosion.

1.4.8 Roof and Top-Angle Joints

- a. Roof plates shall, as a minimum, be welded on the top side with a continuous full-fillet weld on all seams. Butt-welds are also permitted.
- b. Roof plates shall be attached to the top angle of a tank with a continuous fillet weld on the top side only.
- c. The top-angle sections for self-supporting roofs shall be joined by butt-welds having complete penetration and fusion.
- d. At the option of the manufacturer, for self-supporting roofs of the cone, dome, or umbrella type, the edges of the roof plates may be flanged horizontally to rest flat against the top angle to improve welding conditions.
- e. Except as specified for open-top tanks, for self-supporting roofs, and for tanks with the flanged roof-to-shell detail, tank shells shall be supplied with top angles of not less than the following sizes: for tanks with a diameter less than or equal to 11 m (35 ft), 51 x 51 x 48 mm (2x2x3/16 in.); for tanks with a diameter greater than 11 m (35 ft) but less than or equal to 18 m (60 ft), 51 x 51 x 6.4 mm (2 x 2 x 1/4 in.); and for tanks with a diameter greater than 18m (60 ft), 76 x 76 x 95 mm (3 x 3 x 3/8 m.). At the purchaser's option, the outstanding leg of the top angle may extend inside or outside the tank shell.

- f. For tanks with a diameter less than or equal to 9 m (30 ft) and a supported cone roof, the top edge of the shell may be flanged in lieu of installing a top angle. The bend radius and the width of the flanged edge shall conform to the details of figures. This construction may be used for any tank with a self-supporting roof if the total cross-sectional area of the junction fulfills the stated area requirements for the construction of the top angle. No additional member, such as an angle or a bar, shall be added to the flanged roof-to-shell detail.



**ALTERNATIVE ROOF-TO-SHELL JOINT
(SEE NOTE 2)**

2. Design Considerations

2.1 Design Factors

The purchaser shall state the design metal temperature (based on ambient temperatures), the design specific gravity, the corrosion allowance (if any), and the design wind velocity.

2.2 External loads

The purchaser shall state the magnitude and direction of external loads or restraint, if any, for which the shell or shell connections must be designed. The design for such loadings shall be a matter of agreement between the purchaser and the manufacturer.

2.3 Protective Measures

The purchaser should give special consideration to foundations, corrosion allowance, hardness testing, and any other protective measures deemed necessary.

2.4 External Pressure

This standard does not contain provisions for the design of tanks subject to partial internal vacuum, however, tanks that meet the minimum requirements of this standard may be subjected to a partial vacuum of 0.25 kPa (1 in. of water) of water pressure.

3. Special Considerations

3.1 Foundation

The selection of the tank site and the design and construction of the foundation shall be given careful consideration, as outlined in Appendix B, to ensure adequate tank support. The adequacy of the foundation is the responsibility of the purchaser.

3.2 Corrosion Allowances

When necessary, the purchaser, after giving consideration to the total effect of the liquid stored, the vapor above the liquid, and the atmospheric environment, shall specify the corrosion allowance to be provided for each shell course, for the bottom, for the roof, for nozzles and manholes, and for structural members.

3.3 Service Conditions

When the service conditions might include the presence of hydrogen sulfide or other conditions that could promote hydrogen-induced cracking, notably near the bottom of the shell at the shell-to-bottom connections, care should be taken to ensure that the materials of the tank and details of construction are adequate to resist hydrogen-induced cracking.

The purchaser should consider limits on the sulfur content of the base and weld metals as well as appropriate quality control procedures in plate and tank fabrication. The hardness of the welds, including the heat-affected zones, in contact with these conditions should be considered. The weld metal and adjacent heat-affected zone often contain a zone of hardness well in excess of Rockwell C 22 and can be expected to be more susceptible to cracking than unwelded metal is. Any hardness criteria should be a matter of agreement between the purchaser and the manufacturer and should be based on an evaluation of the expected hydrogen sulfide concentration of the product, the possibility of moisture being present on the inside metal surface, and the strength and hardness characteristics of the base metal and weld metal.

3.4 Weld Hardness

When specified by the purchaser, the hardness of the weld metal for shell materials in Group IV, IVA, V, or VI shall be evaluated by one or both of the following methods:

- a. The welding-procedure qualification tests for all welding shall include hardness tests of the weld metal and heat-affected zone of the test plate. The methods of testing and the acceptance standards shall be agreed upon by the purchaser and the manufacturer.
- b. All welds deposited by an automatic process shall be hardness tested on the product-side surface. Unless otherwise specified, one test shall be conducted for each vertical weld, and one test shall be conducted for each 30 m (100 ft) of circumferential weld. The methods of testing and the acceptance standards shall be agreed upon by the purchaser and the manufacturer.

4. Bottomplates

- 4.1 All bottom plates shall have a minimum nominal thickness of 6 mm [70 kPa] exclusive of any corrosion allowance specified by the purchaser for the bottom plates. Unless otherwise agreed to by the purchaser, all rectangular and sketch plates (bottom plates on which the shell rests that have one end rectangular) shall have a minimum nominal width of 1800mm.
- 4.2 Bottom plates of sufficient size shall be ordered so that, when trimmed, at least a 25 mm width will project beyond the outside edge of the weld attaching the bottom to the shell plate.

5 Annular Bottom Plates

- 5.1** When the bottom shell course is designed using the allowable stress for materials in Group IV, IVA, V, or VI, butt-welded annular bottom plates shall be used. When the bottom shell course is of a material in Group IV, IVA, V, or VT and the maximum product stress for the first shell course is less than or equal to 160 MPa or the maximum hydrostatic test stress for the first shell course is less than or equal to 172 MPa (24,900 Vsfr^{m.2}), lap-welded bottom plates may be used in lieu of butt-welded annular bottom plates.
- 5.2** Annular bottom plates shall have a radial width that provides at least 600 mm (24 in.) between the inside of the shell and any lap-welded joint in the remainder of the bottom and at least a 50 mm (2 in.) projection outside the shell. A greater radial width of annular plate is required when calculated as follows:

In SI Units:

$$\frac{215t_b}{(HG)^{0.5}}$$

Where

- t_b = thickness of the annular plate, in mm,
 H = maximum design liquid level, in m,
 G = design specific gravity of the liquid to be stored

- 5.3** The thickness of the annular bottom plates shall not be less than the thicknesses listed in Table plus any specified corrosion allowance.

Table 2-1 Annular Bottom- Plate Thicknesses

SI Units				
Nominal Plate Course Thickness ^a of First Shell Course (mm)	Hydrostatic Test Stress ^b in First Shell (MP _a)			
	<190	<210	< 230	<250
$t < 19$	6	6	7	9
$19 < t < 25$	6	7	10	11
$25 < t < 32$	6	9	12	14
$32 < t < 38$	8	11	14	17
$38 < t < 45$	9	13	16	19

- (a) Nominal plate thickness refers to the tank shell as constructed.
- (b) Hydrostatic test stresses are calculated from $[4.9 D (H-0.3)]/t$
- (c) Hydrostatic test stresses are calculated from $[2.6 D (H-1)] t$

Note: The thicknesses specified in the table, as well as the width, are based on the foundation providing uniform support under the full width of the annular plate. Unless the foundation is properly compacted, particularly at the inside of a concrete ring wall, settlement will produce additional stresses in the annular plate.

- 5.4** The ring of annular plates shall have a circular outside circumference but may have a regular polygonal shape inside the tank shell, with the number of sides equal to the number of annular plates.
- 5.5** In lieu of annular plates, the entire bottom may be butt-welded provided that the requirements for annular plate thickness, welding, materials, and inspection are met for the annular distance specified.

6 Shell Design

6.1 General

6.1.1 The required shell thickness shall be the greater of the design shell thickness, including any corrosion allowance, or the hydrostatic test shell thickness, but the shell thickness shall not be less than the following:

Nominal Tank Diameter		Nominal Plate Thickness	
(m)	(ft)	(mm)	(in.)
>5	<50	5	3/16
5 to >36	50 to <120	6	1/4
36 to 60	120 to 200	8	5/16
>60	>200	10	3/8

6.1.2 The shell plates shall have a minimum nominal width of 1800 mm (72 in.). Plates that are to be butt-welded shall be properly squared.

6.1.3 The design shell thickness shall be computed on the basis that the tank is filled to a level H with a liquid that has a specific gravity specified by the purchaser.

6.1.4 The hydrostatic test shell thickness shall be computed on the basis that the tank is filled to a level H with water.

6.1.5 The calculated stress for each shell course shall not be greater than the stress permitted for the particular material used for the course. No shell course shall be thinner than the course above it.

6.1.6 The tank shell shall be checked for stability against buckling from the design wind velocity, as specified by the purchaser, if required for stability, intermediate girders, increased shell-plate thicknesses, or both shall be used. If the design wind velocity is not specified, the maximum allowable wind velocity shall be calculated, and the result shall be reported to the purchaser at the time of the bid.

6.1.7 The manufacturer shall furnish to the purchaser a drawing that lists the following for each course:

- The required shell thicknesses for both the design condition (including corrosion allowance) and the hydrostatic test condition.
- The nominal thickness used.
- The material specification.
- The allowable stresses.

6.1.8 Isolated radial loads on the tank shell, such as those caused by heavy loads on platforms and elevated walkways between tanks, shall be distributed by rolled structural sections, plate ribs, or built-up members.

6.2 Allowable Stress

6.2.1 The maximum allowable product design stress, S_d shall be as shown in Table 3-2. The net plate thicknesses—the actual thicknesses less any corrosion allowance—shall be used in the calculation. The design stress-basis, S_d , shall be either two-thirds the yield strength or two-fifths the tensile strength, whichever is less.

6.2.2 The maximum allowable hydrostatic test stress, S_i , shall be as shown in Table 3-2. The gross plate thicknesses, including any corrosion allowance, shall be used in the calculation. The hydrostatic test basis shall be either three-fourths the yield strength or three-sevenths the tensile strength, whichever is less.

Table 3-2—Permissible Plato Materials and Allowable Stresses

Pale Specification	Grade	Minimum Yield Strength MP_a(psi)	Minimum Tensile Strength MP_a(psi)	Product Design Stress S_d MP_a (psi)	Hydrostatic Test Stress S_t MP_a(psi)
ASTM Specifications					
A283M	C	205(30,000)	380(55,000)	137 (20,000)	154 (22,500)
A 285M	C	205 (30,000)	380 (55,000)	137 (20,000)	154 (22,500)
A 131M	A.B.CS	235 (34,000)	400 (58,000)	157 (22,700)	171 (24,900)
A 36M	—	250 (36,000)	400 (58,000)	160 (23,000)	171 (24,900)
A 131M	EH 36	360 (51,500)	490 ^a (71,000 ^a)	196 (28,400)	210 (30,400)
A 573M	400	220 (32,000)	400 (58,000)	147 (21,300)	165 (24,000)
A 573M	450	240 (35000)	450 (65,000)	160 (23,300)	180 (26,300)
A 573M	485	290 (42,000)	485 ^a (70,000 ^a)	193 (28,000)	208 (30,000)
A 516M	380	205 (30000)	380 (55,000)	137 (20,000)	154 (22,500)
A 516M	415	220 (32000)	415 (60,000)	147 (21,300)	165 (24,000)
A 516M	450	240 (35000)	450 (65,000)	160 (23,300)	180 (26,300)
A 516M	485	260 (38000)	485 (70,000)	173 (25,300)	195 (28,500)
A 662M	B	275 (40000)	450 (65,000)	180 (26,000)	193 (27,500)
A 662M	C	295 (43,000)	485 ^a (70,000 ^a)	194 (28,000)	208 (30,000)
A 537M	1	345 (50,300)	485 ^a (70,000 ^a)	194 (28,000)	208 (30,000)
A 537M	2	415 (60,000)	550 ^a (80,000 ^a)	220 (32,000)	236 (34,300)
A 633M	C,D	345 (50000)	485 ^a (70,000 ^a)	194 (28,000)	208 (30,000)
A 678M	A	345 (50000)	485 ^a (70,000 ^a)	194 (28,000)	208 (30,000)
A 678M	B	415 (60000)	550 ^a (80,000 ^a)	220 (32,000)	236 (34,300)
A 737M	B	345 (50000)	485 ^a (70,000 ^a)	194 (28,000)	208 (30,000)
CSA Specifications					
G40.21M	260W	260 (37,700)	410 (59,500)	164 (23,800)	176 (25,500)
G40.21M	300W	300 (43,300)	450 (65300)	180 (26,100)	193 (28,000)
G40.21M	350WT	350 (50,300)	480 ^a (69,600 ^a)	192 (27,900)	206 (29,300)
G40.21M	350W	350 (50,800)	450 (65,300)	180 (26,100)	193 (28,000)

National Standards					
	37	205 (30,000)	365 (52,600)	137(20000)	154(22,500)
	41	235 (34,000)	400 (58,300)	157(22,700)	171(25000)
	44	250 (36,000)	430 (62,600)	167 (24000)	184(26300)
ISO 630					
E275	C,D	265 (38,400)	61,900 (61,300)	170 (24,700)	182 (26,500)
E355	C,D	345 (50,000)	71,000 ^a (71,000 ^a)	196 (28,400)	210 (30,400)

- ^aBy agreement between the purchaser and the manufacturer, the (ensile strength of these materials may be increased to 515 MPa (75,000psi) minimum and 620 MPa (90,000psi) maximum (and to 585 MPa (85,000psi) minimum and 690 MPa (100,000psi) maximum for ASTM A 537M, Class 2, and A 678M, Grade B). When this is done, the allowable stresses shall be determined as stated in 3.62.1 and 3.6.22.

2.6.3 Calculation of Thickness by the 1 -Foot Method

2.6.3.1 The 1-foot method calculates the thicknesses required at design points 03 m (1 ft) above the bottom of each shell course. This method shall not be used for tanks larger than 60 m in diameter.

2.6-3.2 The required minimum thickness of shell plates shall be the greater of the values computed by the following formulas:

In SI units:

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

$$t_d = \frac{4.9D(H - 0.3)}{S_t}$$

Where

- t_d = design shell thickness, in mm,
- t_t = hydrostatic test shell thickness, in nun,
- D = nominal tank diameter, in m
- H = design liquid level, in m,
= height from the bottom of the course under consideration to the top of the shell including the top angle, if any; to the bottom of any overflow that limits the tank filling height; or to any other level specified by the purchaser, restricted by an internal floating roof, or controlled to allow for seismic wave action,
- G = design specific gravity of the liquid to be stored, as specified by the purchaser, CA = corrosion allowance, in mm, as specified by the purchaser
- S_d = allowable stress for the design condition, in MPa
- S_t = allowable stress for the hydrostatic test condition, in MPA

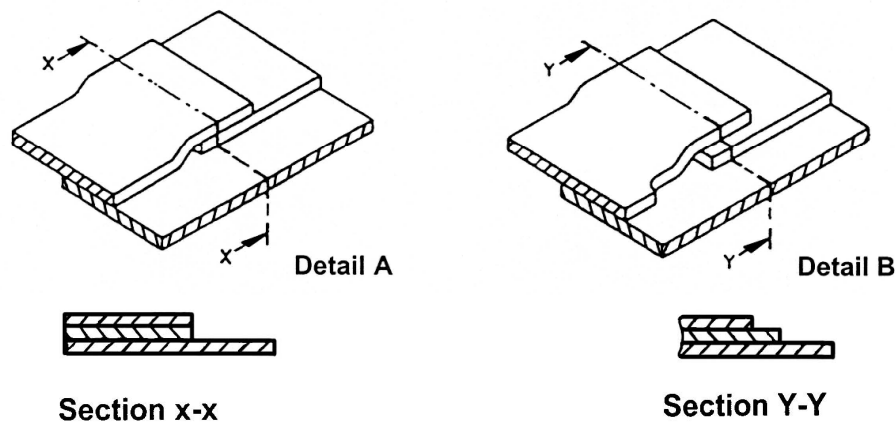
LESSON 3

TANK MANUFACTURING

1. All joints in rectangular and sketch plates shall be lapped. They shall be welded on the top side only with a full fillet weld, and with a minimum lap of five times the thickness of the plate.

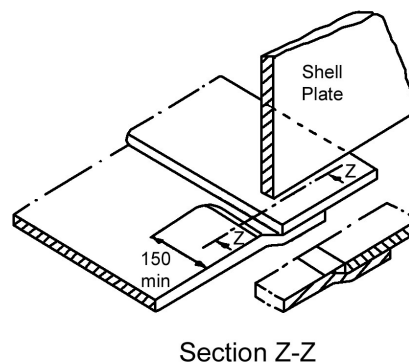
The rectangular plates and the sketch plates shall be lapped over the annular ring of segmental plates where these are used. They shall be welded on the top side only with a full fillet weld and the minimum lap shall be 60 mm.

At the ends of cross joints in rectangular plates and sketch plates where three thicknesses occur, the upper plate shall be hammered down and welded as indicated in detail A or B of the figure as a corrective measure if the upper plate overlaps with the lower plate.



Cross joints in Bottom Plates where three Thicknesses Occur

2. For tanks of 12.5 m diameter and under, the ends of the joints in the sketch plates under the bottom course of shell plates shall be welded for a minimum distance of 150 mm as shown in figure

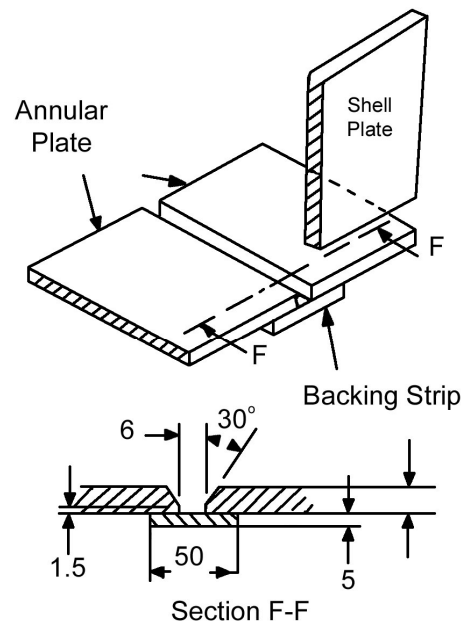


All dimensions are in millimeters

Figure -Typical joints in Sketch Plates Under Shell
Plates Tanks up to and Including 12.5m diameter

3. For tanks exceeding 12.5 m diameter, the radial seams connecting the ends of the annular segmental plates shall be full penetration butt-welded, a backing strip weld of the form shown in figure 5 is acceptable.

Annular Plate



All dimensions are in millimeters

Figure - Typical Annular Plate joint Under
Shell Plates : Tanks Over 12.5m Diameter

4. The attachment between the bottom edge of the lowest course of shell plates and the bottom sketch plate or annular plate shall be fillet-welded continuously on both sides of the shell plate.

The leg length of each fillet weld shall be equal to the thickness of the sketch plate or annular plate, except that they shall not exceed the appropriate value given in table when the shell plate thickness is less than the bottom plate thickness.

Table . Leg length of fillet weld	
Shell plate thickness mm	Leg length of fillet weld mm
5	6
6 and over	8

5. Shell Plates

5.1 Design Stresses

The maximum allowable design stress in any plate shall be 260 N/mm² or two-thirds of the material specified minimum yield strength (in N/mm²) at room temperature for all tank courses, whichever is the lower. Where the operating temperature is over 150 °C. consideration shall be given to the effect of that temperature on the yield strength.

5.2 In calculating the thickness of plate required, the joint efficiency factor has been taken as 1.0. No relaxation shall be permitted to the requirements of this standard with regard to the approval of procedures and welders and the site inspection of shell joints.

5.3 In no case shall the specified thickness of shell plates be less than is given in table
The maximum thickness of shell plates shall be 40 mm.

Table. minimum Specified Shell Thickness	
Nominal Tank Diameter D(m)	Specified Shell Thickness T (mm)
D < 15	5
15 < D < 30	6
30 < D < 60	8
60 < D < 75	10
75 < D < 100	12
100 < D	14

6. Plates Layout

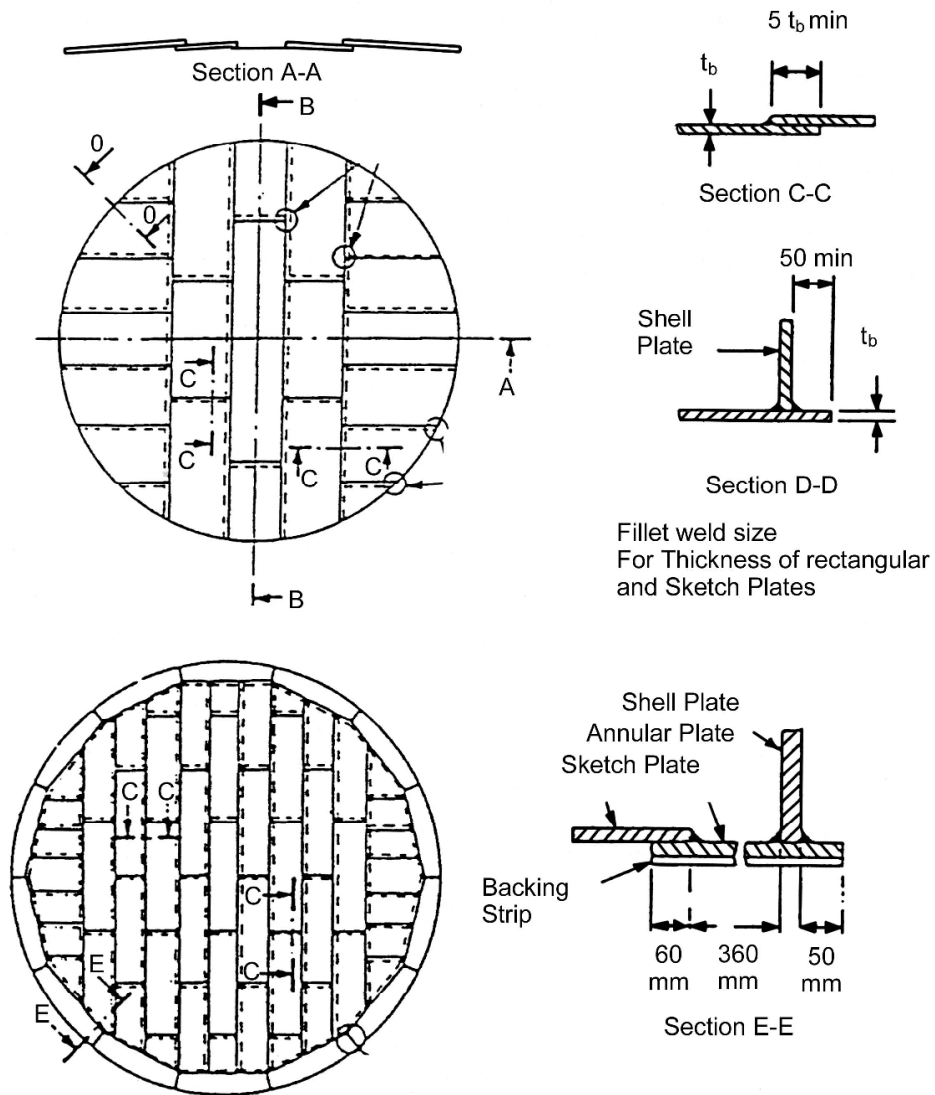
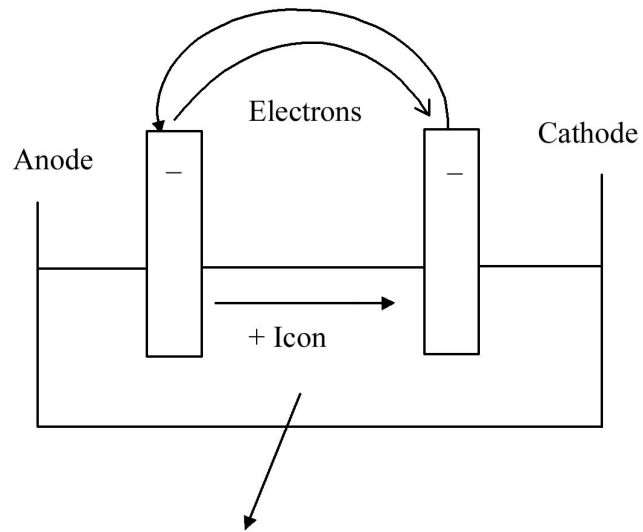


Figure -Typical Bottom Layouts for Tanks

1. Sacrificial Anode (Calarnic cell)

Cathodic Protection



Electrolite (Resistivity)

2. Impressed Current

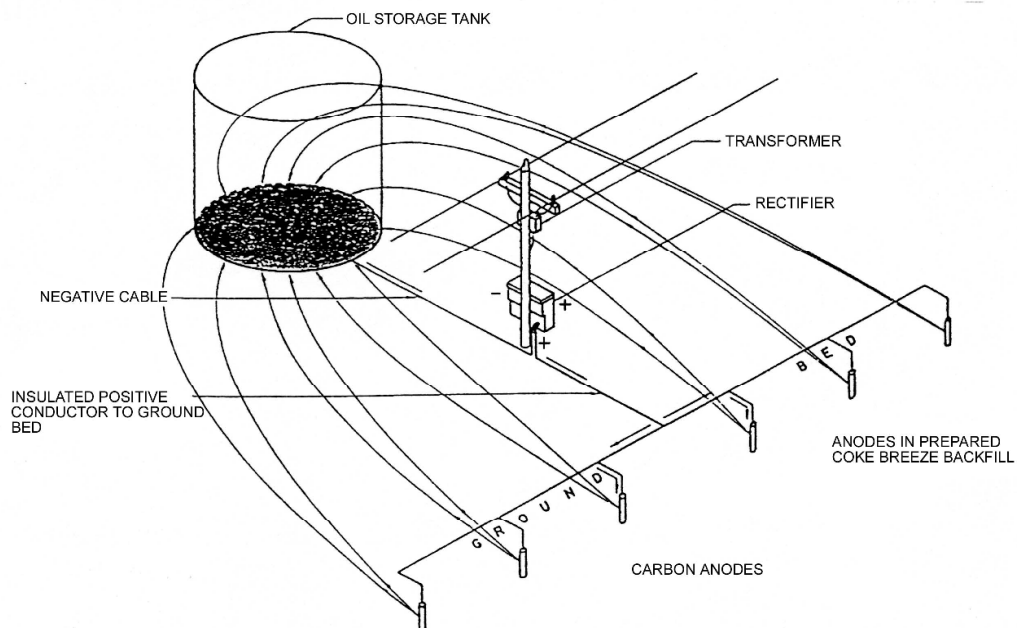


Figure- Typical Rectifier and ground Bed Installation

LESSON 4

INSPECTION, REPAIR AND MAINTENANCE OF TANKS

1. Auxiliary Equipment:

- Liquid level glass
- Pressure relieving devices
- Pressure vacuum venting
- Gage hatch
- Roof drain
- Mixing devices
- Service steel structure
- Electric grounding
- Manholes / cleanout door
- Cathodic protection equipments

2. Corrosion:

2.1 External Factors :

Corrosive Atmospheric Condition:

Sulfurous or acidic atmosphere (Protective Coating - paint - cathodic protection)

- **Leaks: Cracks and Pits:**

(Repair by welding patches or replacement)

- **Soil Corrosion: (Under Ground Water):**

(Sand injection, concrete pumping, bottom (Replacement)

- **Electrolytic Corrosion: (Galvanic Cell):**

Inside shell, under bottom, soil corrosion, clay electrolytic Properties Repair by cathodic protection

- **Tank Leak Under Bottom:**

- **Improper Sealed Foundation:**

2.2 Internal Factors:

- **Tank Content**

Acidic salts, chlorides, hydrogen sulfide, water (lining with mgh resistance materils)

- **Roof Internal Corrosion:**

(Hydrogen Sulfide Vapors .Water Vapor .Oxygen)

- **Electrolytic Corrosion: (Galvanic Cell)**

(Cathodic Protection)

- **Hydrogen Blistering: (Stress Corrosion Cracking)**

- **Caustic Embitterment: (cracks .Flows)**

2.3 Lining Against Corrosion:

Corrosion Resistant Materials Are:

Lead, Alloy Steel .Aluminum, Rubber, Fiberglass, Paint, Zink enriched Coating.
Plastics Concrete (Gunned Or Poured)

Examples:

Internally:

- | | |
|------------------------|--------------------------------------|
| 1 - Zink Silicate | : 50 Micron Primer |
| 2- Cross Linked Epoxy | : 250 Micron |
| 3- Fiber Glass | : Potable Water .Salty water, Water. |
| 4- Polyvenyle Ethylene | : 250 Micron |
| 5- Rubber lining | |

Externally :

- | | |
|---------------------|------------------------|
| 1. Zink Silicate | : 50 Micron (Primer) |
| 2. High Built Epoxy | : 100 Micron |

Bottom of Tank :

- | | |
|-------------------|----------|
| 1 . Zink Silicate | : Primer |
| 2. Bitomine | |

3. Leaks (Cracks and Mechanical Deterioration)

3.1 Effects:

- **Economic Losses**
- **Pollution of Ground Water**
- **Hazards**

3.2 Reasons:

- **Flange Leaks**
- **Weld Cracks**
- **Tank Plate Cracks**
- **Faulty Welding**
- **Earthquake**
- **Unrelieved Stress Concentrated Welding**
- **Insufficient Reinforcement**
- **Stresses Caused By Settlement of Earth**
- **Vibration (Mixers)**
- **Poor Design or Repair**

3.3. Leaks / Cracks Occurrence:

- **Bottom / Shell Joint**
- **Nozzle to Shell Connections**
- **Welded Brackets**
- **Welded Seams**
- **Bottom Welded Joints**

4. Crack Repair

- 4.1.** Sand Blasting .grinding / gauging .filling by welds.
- 4.2.** Temporary blockers: air harenig adhesive fillers application to steel plates.
- 4.3.** Drilling of pits tapping .fixing of tapered plug.
- 4.4.** Roof Leaks: Soft patches of rubber, asbestos .neoprene .glass cloth with asphalt.
- 4.5.** Permanent Repair: Welding of steel plate patches to cracked area and dye penetrant test application.
- 4.6.** Corrosive Soil/bottom settlement repaired by pumping sand, concrete injection, bottom replacement.

5. Inspection

5.1 Factors Affecting Frequency of Inspection

- **Nature of Material Stored.**
- **Results of Visual Examination.**
- **Corrosion rates.**
- **Conditions of previous inspection.**
- **Location of Tank (Isolated or in High Risk Areas).**
- **Potential Risk of Air or water Pollution.**

5.2 Intervals For Inspection.

- **Mild Corrosive Service : Every Five Years.**
- **Fflgh Corrosive Service : Each Year.**
- **More Viscous Lubricating Oil : Every 10 Years.**
- **External Visual Inspection :**

More Frequent. (Leakage, settlement, pipe corrosion, performance of mechanical equipments as vents .rolling ladder .gauging devicesEtc)

UNIT 2

LIQUEFIED GAS STORAGE

1. Types of Liquefied Gases

Storage of gases at their atmospheric pressure boiling point has provided industry with economical and safe means of storing large quantities of liquefied gases. Low temperature storage tanks covers sub-ambient temperatures down to -GOT (-51 °C), while cryogenic storage tanks covers the storage of liquids at temperatures as low as -452°F (-268°C).

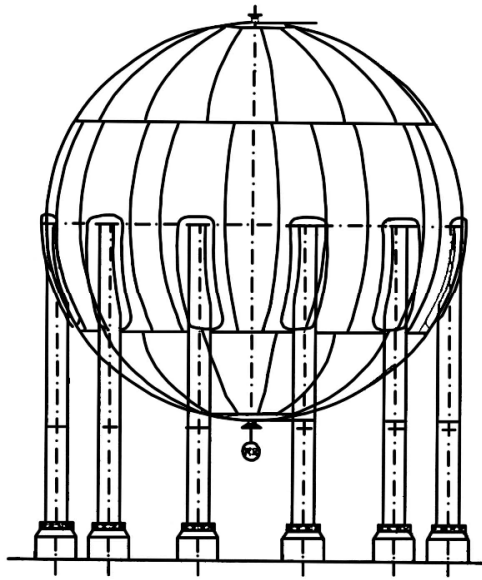
Storage at essentially atmospheric pressure is termed "fully refrigerated." Products stored in these tanks are contained at temperatures near their atmospheric boiling point.

Types Of Liquefied Gases Table

Gas	Storage Temperature (°F)	Storage Temperature (°C)
Butane	31	-0
Butadiene	24	-4
Ammonia	-28	-33
Chlorine	-30	-34
Propane	-43	-42
Propylene	-53	-47
Carbon	-60	-51
Dioxide	-154	-103
Ethylene	-259	-162
Methane	-297	-183
Oxygen	-302	-186
Argon	-320	-196
Nitrogen	-423	-253
Hydrogen	-452	-268
Helium		

Spherical pressurized Storage Tanks

Above 1 barg, spheres are used at the gas/liquid equilibrium pressure. Spheres as large as 7500 m³ at 17 barg. have been built for LPG. Determining the allowable maximum capacity of a sphere is dependent on the strength of materials and the maximum allowable thickness for the given design pressure. High strength materials are available to provide larger capacity high pressure spheres.



Flat Bottom Tanks

Flat bottom tanks are designed for pressures near atmospheric. Tank walls are cylindrical, roofs are spherical, and bottoms are normally flat.

Flat bottom tanks are used for storage where internal design pressure will not exceed approximately 15 psig for smaller capacity tanks, and 2.5 psig for larger tanks. The tank rests upon load bearing insulation that transmits the weight of the contents to the foundation and ground beneath the tank. The bottom serves as a liquid and vapor pressure boundary membrane and is not normally subject to significant stresses, thus permitting the bottom to be constructed of relatively thin material.

Anchorage for flat bottom tanks must hold the shell down against uplift forces from wind, earthquake and internal pressure acting under the roof. Anchorage must also permit the vessel to move radially in response temperature changes. A system of anchor bolts or straps attached to the tank shell and embedded in a mass of concrete is sufficient anchorage since the weight of the concrete equals the total weight of the acting uplift forces. The shell-to-roof connection, under unusually high internal pressure conditions, could be expected to fail before the anchorage system. In some cases, however, the shell-to-roof connection is provided with additional strength to meet other design requirements. In these cases the purchaser may wish to increase the anchorage requirements. Flat bottom tanks are normally used for storage where internal design pressures will not exceed approximately 5 psig (0.35 kg/cm²) for smaller capacity tanks, or approximately 2.5 psig (0.175 kg/cm²) for larger capacities.

A low-pressure flat bottom tank provides storage at minimum cost. Other storage shapes may be dictated by service requirements such as increased pressure required for transfer of contents either in or out of the storage tank, critical foundation conditions and quantity of product to be stored.

Materials

A suitable structure for low temperature service incorporates design, fabrication, construction and welding procedures which avoid notches, sharp bends and highly stressed weldments.

Integrity of storage is obtained by the correct combination of:

- **Selection of proper material**
- **A suitable tank design**
- **Use of proven welding and inspection procedures**
- **Testing prior to placing structure in service**

Material selected must have proven notch toughness and other necessary physical properties for the intended service conditions. Along with other recognized tests such as Charpy V-notch impact, nil-ductility and tensile/compression testing, fracture mechanic testing has been an efficient tool in the evaluation and selection of proper materials for construction.

The following table lists materials used as primary components in low temperature storage tanks.

**Materials For Low-Temperature Tanks (Down Through -60f)
Allowable Stress (PSI)**

Material Designations Number	Pressure Storage (ASME) psi (kg/cm²)	Fiat Bottom Storage Tank psi (kg/cm²)
A 51 6-55	13,700 (963)	16,500 (1160)
A 51 6-60	15,000 (1055)	18,000 (1265)
A 51 6-65	16,250 (1140)	19,500 (1370)
A 51 6-70	17,500 (1230)	21,000 (1475)
A 537 Grade 1	17,500 (1.230)	21,000 (1475)
A 537 Grade 2	20,000 (1405)	24,000 (1690)
A 737 Grade B	17,500 (1230)	21,000 (1475)

Cryogenic Tanks

Selection of the proper materials of construction for cryogenic service is one of the most important considerations. Of primary concern is how the material will perform at cryogenic temperatures.

Fracture mechanics involving such properties as notch toughness, ductility, critical flaw sizes, specific heat, coefficients of thermal expansion and thermal conductivity at cryogenic temperatures, as well as the usual strength and elastic properties of the material, must be studied.

The cryogenic industry have long recognized the need to study the subject of fracture mechanics as it applies to material of construction for cryogenic service.

Most metals increase in strength with a decrease in temperature. Some, however, such as carbon steel, suffer an almost complete loss of ductility at low temperatures, making them useless for cryogenic vessel construction. Copper, nickel, aluminum and most alloys of these metals exhibit no ductile to brittle transitions and, therefore, are suitable for - cryogenic service. Stainless steel of the 18 per cent chrome, 8 per cent nickel classification also exhibits excellent ductility.

Certain minimum requirements have been established by the ASME Code, API Standard 620 and regulatory bodies in the construction of vessels for ultra-low temperatures.

**Materials For Cryogenic Tanks (Through -450°F)
Allowable Stress (PSI)**

Material	Designation Number	Pressure Storage (ASME)	Flat-Bottom Storage Tanks CB&I Design Methods
Stainless	A240 Type 304	18,750	22,500
Aluminum	AA5052	6,250	7,100
	AA5086	8,700	10,500
	.AA5083	10,000	13,300
5% Nickel	A 645	23,700	31,700
5% Nickel	-		31,700
9% Nickel	A553 Class 1 A353	23,750	31,700

Types of Tanks

1. Single Steel Wall Tanks

The vessel wall in the SW insulation system is insulated with rigid polyurethane insulation foamed-in-place between the steel shell and an aluminum jacket. This design results in a monolithic insulation without cracks or voids fully bonded in a "sandwich" construction between the tank shell and the outer jacket. The outer jacket serves as both the moisture vapor barrier and weather protection for the system.

Products normally stored in tanks using the FIP insulation are those held at -60°F (-51 °C) and warmer (foamed-in-place insulation). The FIP single wall insulation system provides the following advantages compared to other single wall insulation systems using conventional block or layered systems:

- Insulation is bonded to both the aluminum vapor barrier and the steel tank shell. The many joints and voids associated with block systems are eliminated except in the area of the anchorage system where movement is required. This composite system minimizes spaces for channeled "breathing" of outside air.
- Integrally bonded system provides a composite structure with good resistance to severe weather.
- The aluminum weather protective sheeting provides an excellent vapor barrier for single wall insulation. The possibility of moisture migration into the insulation is minimized by the use of wide sheets with flexible sealant between the lapped seams. Available thicknesses of two to six inches (50 to 150 mm) reduce heat leak and thus reduce size, first costs and operating costs for holding refrigeration.
- Integrally bonded system is resistant to fire exposure. Fire retardant foam is used, and air is excluded from the bonded system thus preventing ignition prior to penetration of the outer jacket.

2. Double Steel Wall Tanks

DW tank provides the best possible low temperature insulation. The system provides superior performance especially in the following potential problem areas:

- Wind and storms do not damage DW insulation systems. The outer steel tank is normally designed to withstand 100 miles (161 km) per hour winds and has withstood winds of hurricane force without damage.
- Vapor barrier integrity is assured by steel plates with welded seams. The annular insulation space is maintained under a slight positive purge pressure by use of a suitable dry gas.
- Repairs and work on the outer tank may be performed in the same way that work is done on conventional product storage tanks.

- Fire resistance of the DW system is excellent since the steel plate vapor barrier maintains almost full strength up to 650°F (343°C) and is still relatively strong during temperature excursions up to 1500°F (816°C). The perlite insulation used in DW systems is not structurally affected or damaged by temperatures up to 2000°F (1,093° C).
- "Insulation "K" Value" of the DW insulation remains constant once the loose-fill perlite in the sidewalls has been installed. The loose-fill perlite in the sidewalls and on the suspended insulation deck is fully protected from weather and humidity by a welded steel plate.

Products normally stored in tanks with DW type insulation are those stored at -28°F (-33°C) and colder. Storage temperatures of -50°F (-46°C) and below often require DW insulation in order to satisfy the owner's requirements for low heat leak, economical holding refrigeration, and low operating and maintenance costs.

Sidewall insulation is provided by perlite expanded and installed. Perlite is an inorganic, nonflammable, lightweight insulation produced from special volcanic rocks. The volcanic rock or ore is finely ground and then expanded in furnaces operating at about 2100°F. The perlites normally expand in a field operated furnace and are placed in the insulation space while still hot. This method minimizes moisture in the insulation. It also minimizes breakdown of the perlite particles, since they are handled only once after expansion. The welded steel plate outer shell provides both containment and vapor protection for the perlite insulation.

The insulation closure is a lap welded steel plate between the inner tank roof and the outer shell. The outer shell is entirely butt welded together and fillet welded to the outer steel bottom. The outer lap welded tank bottom furnishes a positive bottom seal for the shell insulation and a positive vapor barrier for the load-bearing bottom insulation.

A resilient blanket is wrapped around the inner tank shell to prevent pressure build up due to the perlite settlement that occurs if the perlite is not laterally supported when the vessel walls expand and contract. If this lateral support is not provided, the perlite will settle into the void left when the vessel walls contract and will be compressed due to excessive pressure when the walls expand. The outer vessel wall moves with changes in ambient temperature and the inner vessel moves with cooldown and warmup of the inner vessel. Also, filling and emptying the tank causes expansion and contraction of the inner tank wall due to elastic shell movements from hydraulically imposed stresses. Without the resilient blanket, this action can cause compaction of perlite that may damage the inner wall and attached fittings.

3. Full Containment Tank

- (a) The full containment tank was designed and constructed so that both the self supporting primary container (9% Ni steel Plate) and the secondary container (concrete wall) are capable of independently containing the refrigerated liquid stored and for one of them its vapour. It is a basic design concept for the full containment tank.
- (b) Concrete outer shells have been utilized as additional resistance to tank damage and as containment in the unlikely event of tank leakage. This type of tank is the most costly, and has most often been used for the storage of LNG. These types of tanks can be built with several variations:
 - **Earth or pile supported foundations**
 - **Concrete outer shell and roof (as shown below)**
 - **Concrete outer shell with steel roof**
 - **Separate concrete wall for secondary containment**
 - **In-ground or mounded secondary containment**

Tank Shells and Insulation

Refrigerated storage tanks and their insulation systems must be designed to work together to assure optimum performance. Low temperature insulation is required for both spherical and flat bottom cylindrical refrigerated storage tanks.

There are three principal types of shell and insulation systems for refrigerated gases: single steel wall (SW), double steel wall (DW), and concrete outer shell with double steel wall interior. Common to both the SW and DW insulation systems is the suspended deck roof insulation system and load bearing bottom insulation systems. The following portions of this section describe DW, SW, suspended deck roof, and load bearing bottom insulation systems, and the concrete outer shell tanks in more detail.

Suspended Deck Roof Insulation

Common to both the SW and DW insulation systems is the suspended deck roof insulation system. This system has been widely accepted because it provides permanent, inexpensive roof insulation. Externally applied insulation on curved roof surfaces is difficult to properly apply and has resulted in significant maintenance problems. These difficulties are completely eliminated by using the suspended insulation system.

The system consists of a lap-welded metal deck suspended from the tank roof framing. Perlite, mineral wool, glass fiber or other suitable insulation is distributed uniformly over the suspended deck. Open pipe vents are installed through the deck to equalize pressure above and below the deck. Super heated vapors remain stratified in the upper space between the deck and the outer roof, while colder nearly saturated product vapors are stratified below the suspended deck. The welded steel pressure containing tank roof provides positive, permanent weather protection for the suspended insulation. The insulating value of the suspended insulation will not change with age since there is no degradation or weathering of the insulation.

Load Bearing Insulation

All flat bottom cylindrical low temperature storage tanks require bottom insulation which limits heat flux into the stored product and transmits the liquid load into the foundation. The details of the bottom, or load bearing insulation, are similar for both SW and DW insulation systems.

Two load bearing insulation systems are normally used. These are foamed glass and EPS Concrete, a lightweight concrete using expanded polystyrene beads as aggregate. For applications within the United States, foamed glass has most often been used. Outside the United States where packing and freight costs for shipping foamed glass is a significant cost factor, EPS Concrete is an economically attractive alternative. Unlike other lightweight concrete aggregates such as perlite and vermiculite, the polystyrene beads in EPS Concrete are closed cell and do not absorb water. EPS Concrete also maximizes the use of local materials and labor in the area where the tank is built. Alternative insulations are available, but they must each be reviewed for application on an individual basis.

Diking and Secondary Containment

Common sense and experience with flammable fluids have led to the normal requirement for diking LPG, LNG and anhydrous ammonia facilities. Sometimes the provision for impoundment of spilled liquid is referred to as "secondary containment" but usually it is called "diking."

Every potential site is unique, and it is necessary to consider individual features and conditions when selecting an impoundment concept. The method chosen depends upon the topography, the surrounding property, the proximity and type of adjacent buildings and their uses, exposure to the public at work or at home, and applicable local requirements.

A typical arrangement uses an earthen dike to provide for the total volume of liquid equivalent to a tank full of product. In many cases, natural ground formations can help provide impoundment, but topography is seldom adequate for total containment. Earthen dikes are used to supplement natural barriers.

The use of concrete in the construction of secondary containment structures is becoming more prevalent within the industry. Concrete secondary containment structures can be installed as free-standing dikes or integral with the tank construction.

Another type of secondary containment is a separate structural steel dike constructed of material adequate for the loadings and temperatures it would be subjected to in the event of a spill. Such a dike for LPG must be protected from an exposure fire which could damage and reduce its effectiveness. Fire protection for the dike can be provided by various means such as insulation or water deluge.

UNIT 3

LNG STORAGE TANKS

I. Selection of Tank System:

The selection of a particular tank system depends on location, environmental considerations, operational conditions, safety and economic efficiency.

Taking these factors into account, the contractor has to set the following criteria when considering the type of to be proposed:

- Safety of personnel, operational safety of tanks and associated equipment
- Reliability, ease of operation and maintenance, and efficiency
- No detrimental effects to the environment in case of an accident

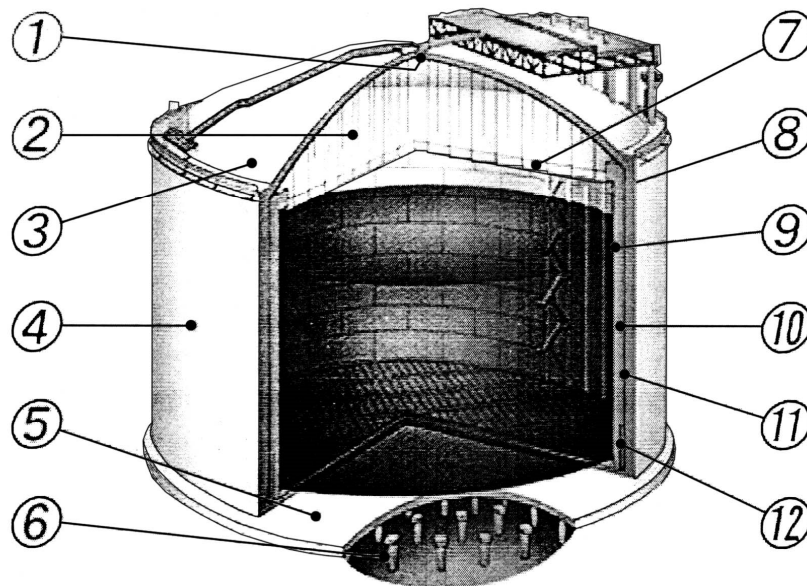
II. Full Containment Tank System:

A Full containment tank system consists of an inner steel tank able to contain the LNG without other support. In case of damage of the outer wall by defined external impact the inner steel tank can retain the LNG.

The outer tank withstands defined loadings from outside and as a minimum contains most of the LNG in case of a leakage of the inner steel tank.

The outer concrete wall is capable of withstanding higher external emergency loadings than an outer steel tank (increase of safety).

The concrete roof increases the safety again. It is less susceptible to damage from external forces and has better fire resistance properties.



1. Roof Liner

A steel roof liner is installed on the inside face of the RC roof to keep the natural gas vapor inside.

2. Suspension Rod

Stainless steel suspension rods hang the suspended deck from the roof structure.

3. RC Roof

A concrete roof has the advantage of protection from heat, from adjacent fires, and from the impact of flying objects.

4. PC Side Wall

PC concrete wall is a LNG-tight design and monolithic connections are made between wall and roof, wall and bottom.

5. RC Bottom Slab

RC concrete bottom slab with piles is the foundation of the tank.

6. RC Piles

Piles support the tank structure.

7. Roof Insulation

Perlite powder or glass wool is used for roof insulation to maintain the inside temperature.

8. Suspended Deck

Aluminum alloy suspended deck supports the roof insulation.

9. Inner Shell

9%Ni steel inner tank is an open top structure and holds LNG in it.

10. Side Insulation

Between the inner shell and outer side wall is filled with perlite powder to make side insulation.

11. Side Liner

A steel side liner is installed on the inside face of the PC side wall to keep natural gas vapor inside.

12. Secondary Barrier

In the very rare case of inner tank leakage, LNG will accumulate inside of the 9%Ni steel secondary barrier.

Storage tank shall be designed to meet the above mentioned characteristic with the following elements:

1. Horizontally and vertically pre-stressed outer concrete wall
2. Pre-stressed concrete roof ring beam
3. Reinforced concrete roof (dome)
4. Carbon steel vapor barrier on the inside surface of the dome, wall and base slab
5. Corner and bottom protection system in the insulation
6. A 9% nickel steel self supporting inner tank
7. A suspended aluminum inner deck, supported by hangers from the dome
8. An insulation system between inner and outer container which maintain certain accepted boil off rate
9. Steel platforms, staircase, stairs and caged ladder
10. All tank internal piping, including pump column, LNG stand pipe, spray ring, level instrument & LTD system stilling well and N2 purge system
11. All nozzles and manholes
12. A traveling hoist, an elevator
13. Process, N2, and instrument air piping
14. Cold insulation system for process piping
15. Fire fighting system including:
 - Water spray system
 - Dry-chemical extinguishing system
16. Fire proofing system
17. Safety valve system
18. All electrical work.
19. All instrument work.
20. All painting and coating work.

III. Design Feature:

From the point of safety a double wall LNG-storage-tank with a 9% nickel steel inner wall, pre-stressed concrete outer wall, vapor barrier on inner surface of outer wall, concrete roof and bottom with corner and bottom protection system is an effective and on a long-term basis also economic solution.

The design of LNG-storage tanks is governed by the very low (cryogenic) temperature of about -162 °C of the stored medium LNG. The inner steel tank has to withstand the liquid pressure under these cryogenic conditions during normal operating conditions during the whole life time.

A special steel alloy with 9% nickel is required to achieve sufficient toughness to arrest a fast running crack even at -170°C.

Under service conditions the outer concrete containment has:

- to retain thermal insulation.
- to act as gas-tight barrier between the ambient air and the gaseous methane within the insulation and in the roof space.
- to act as foundation slab for the inner steel tank.

More important for the design of the outer concrete tank are the emergency conditions:

- Liquid spill
- Earthquake
- Missile impact
- Heat radiation
- In tank fire

In the case of liquid spill when the inner steel tank is damaged and leaks, the outer containment has to retain the cryogenic medium. In addition to the liquid pressure an overpressure, resulting from the immediate evaporation of LNG on coming into contact with the concrete wall having the temperature of the environment, has to be retained by the outer wall.

These loadings require a pre-stressing of the wall in a horizontal direction. In a vertical direction the pre-stressing will be needed to control the overpressure resulting from the evaporating LNG during operation.

Without a LNG-tight insulation-liner the temperature drop-off in the concrete wall causes a centric shortening on the wall. This is restrained by the bottom slab and to a minor extent by the dome. Keeping integrity and tightness of the outer tank at the intersection between wall and bottom slab requires a 9% nickel steel corner protection and bottom liner will be provided as a structural measure in order to restrict temperature gradients, restrained stresses and crack formation to a controllable magnitude at this load case.

Tank Sizing:

The tank size shall be decided based on the following factors:

- Results from seismic analysis of earthquake loads,
- Hydraulic requirements,

According to the seismic analysis to earthquake loading, if the expected intensity of this loading is high, a tank with a larger diameter is selected in order to distribute the loads to a larger area. A larger diameter results in a smaller height with its economical advantages.

Inner Container

Regarding shell plate and bottom annular plate, the thickness calculation of these plates may be done based on API 620 or BS7777. The results shall be verified with a seismic design calculation using the QBE and SSE acceleration response.

Vapor Barrier System

A carbon steel 5mm thick vapor barrier is installed at inside surface of the concrete wall and bottom plate.

Carbon steel vapor barrier is selected since the steel is obviously more effective than a nonmetallic vapor barrier for moisture impermeability and easier to control during construction. The steel vapor barrier is also an economic solution.

Bottom Protection

A secondary minimum 5 mm thick 9% nickel bottom is installed on the insulation system. The secondary bottom is extended into the annular space and connected to the 9% nickel wall liner plates. L shape is inserted in the connection part to the vertical shield plates to secure their connection tightness.

Roof Liner

A carbon steel 5 mm thick roof liner is installed at the inside surface of the concrete roof. The liner functions as an integral part of the concrete roof using shear anchors for load transfer. The roof is used as framework for the concrete placing.

Suspended Deck

The suspended deck has open vents to ensure equilibrium of gas pressure on both side of the suspended deck.

At the edge of the suspended deck, near the inner tank shell, a partition, is installed to allow storage of more than 2.5% of total annular space volume of perlite powder and to prevent the perlite from flowing over and on the suspended deck.

The corrugated aluminum deck is 1.2mm in thickness.

The suspended deck is designed for a live load of 0.5kN/m².

Pump Well

When pumps well are installed in a tank, the pump well shall be supported from the concrete tank roof and guide from the inner tank at lowest part of it.

Safety Valves

- Pressure relief valves (set pressure 265 mbarG) shall be provided and connected to flare for each tank.
- In addition to the above, pressure relief valves (set pressure 290 mbarG) shall provided for emergency use. These valves release the gas directly to the atmosphere for each tank.
- Vacuum relief valves (set pressure -5 mbarG) are provided.

Since outer tank will be made of concrete, operation range of this tank is more widely, safety and economical compared with a tank having a steel roof.

IV. Design Feature in Civil Portion Basic Description of Outer Storage Tank

The PC outer tank is designed as "full containment" tanks, in accordance with BS7777.

The PC outer tank is able to contain the liquid LNG and boil off gas in the event of a rupture of the inner tank. The outer wall is able to keep the entire amount of LNG in the event of leakage. The dike is not needed for full containment tanks.

Type of Outer Tank

The tank structure is the double wall tank with by 9% Ni steel inner wall, pre-stressed concrete outer wall and vapor barrier on inside of outer wall.

The outer roof is made of reinforcing concrete and has a spherical form. The steel liner is located on the inside of the roof for vapor barrier and functions as formwork during construction.

The PC outer wall is connected rigidly to both bottom concrete slab and outer concrete roof.

The foundation type of tank is pile foundation by steel pipe piles.

The inner surface of the vapor barrier on the outer wall is covered by cold resistance relief (PUF: Poly-Urethane Foam).

The Components and Function

- **Foundation**

The foundation type of tank is the pile foundation driving into bedrock formation. It supports the tank, PC outer wall, bottom slab and outer roof in all load condition.

Also, it is stable for long-term settlement.

- **Bottom Slab**

The bottom slab is the reinforcing concrete structure to install on the ground directly with the brine heating system. It supports the tank, PC outer wall and outer roof in all load condition.

- **PC Outer Wall**

PC outer wall is a pre-stressed concrete structure with vapor barrier and PUF insulation on the inside.

When the inner wall is able to perform that safety and operation function, the PC outer wall supports the outer roof, and it maintains pressure of side insulation and gas pressure. When content liquid leaked all quantity from the inner wall, it is a safe structure for liquid pressure and thermal load.

The top part of the PC outer wall is the ring beam, which is pre-stressed, and maintains the horizontal load by the RC roof weight.

- **Outer Roof**

The outer roof is a concrete structure with steel cupola.

It supports a suspended deck and it is a safe structure for gas pressure.

- **PUF Insulation**

PUF insulation is situated on the inside surface of the vapor barrier, it is a sprayed PUF structure protecting glass mesh.

It maintains liquid pressure and thermal load acting PC outer wall after leakage.

V. Design Principle

Selection of Applicable design codes : API 620; BS 7777; DIN 4119

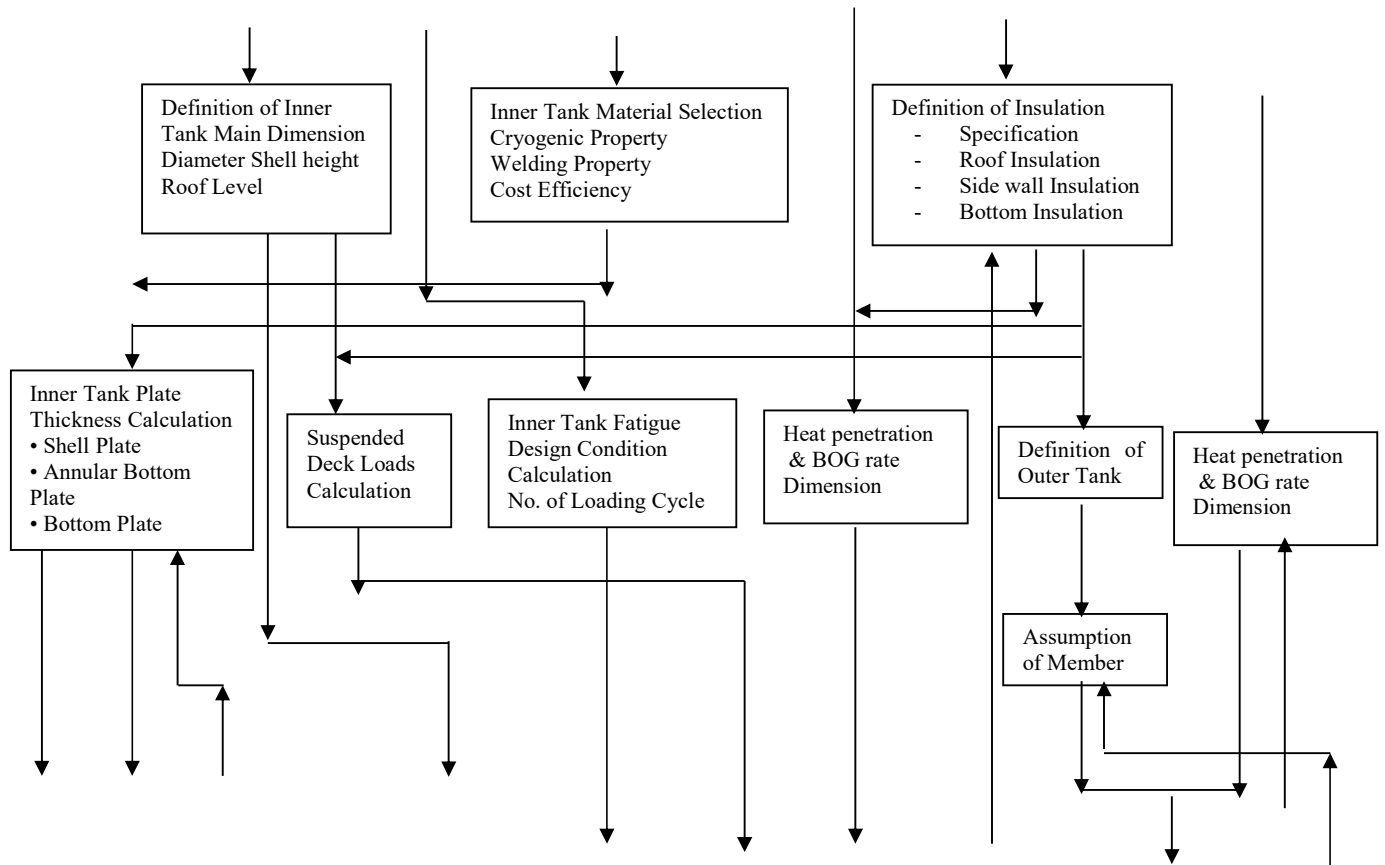
1. Basic Design Condition

(1) LNG Property Design temperature : -162 deg.C Design Gravity: 480 kg./m ³	(2) LNG Capacity 140,000 m ³	(3) Design Pressure 290 mbarG	(4) Tank Dimension Inner tank Diameter: 84,000 mm
(5) Seismic Loads Maximum Ground Acceleration OBE : 0.1 G, SSE : 0.2G	(6) Running Condition Maximum Met Rate: 11,000 m ³ /H Maximum Outlet Rate: 990 m ³ /H	(7) Design Bolt-off Rate 0,075% day	
(8) Ambient Condition Temperature: 35 deg.C , Pressure : Atmospheric Pressure	(9) Hydrostatic Test 125% of LNG Design Liquid Pressure	(10) Emergency Load External Impact Load Thermal Load etc.	

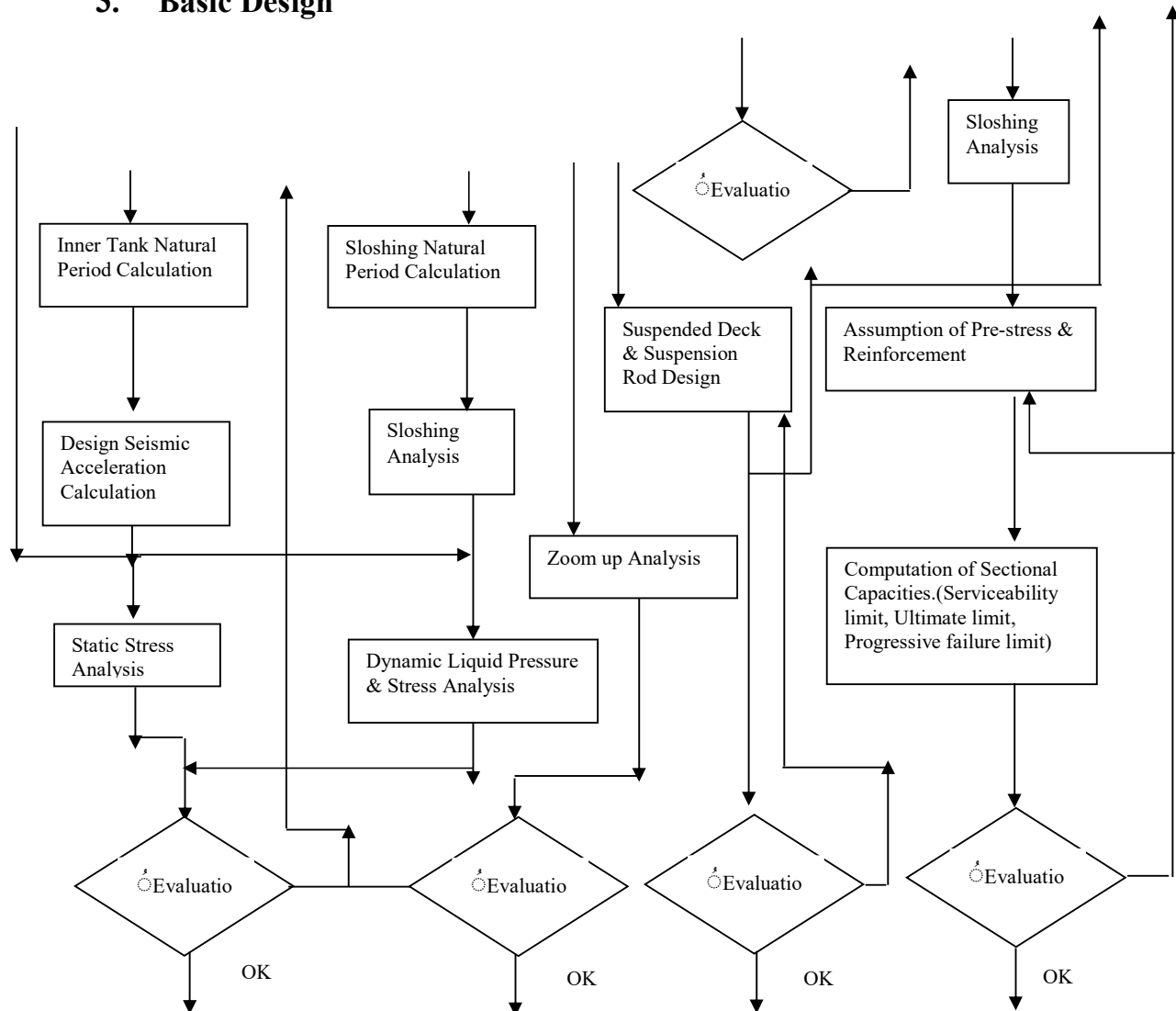


2. Definition of Basic

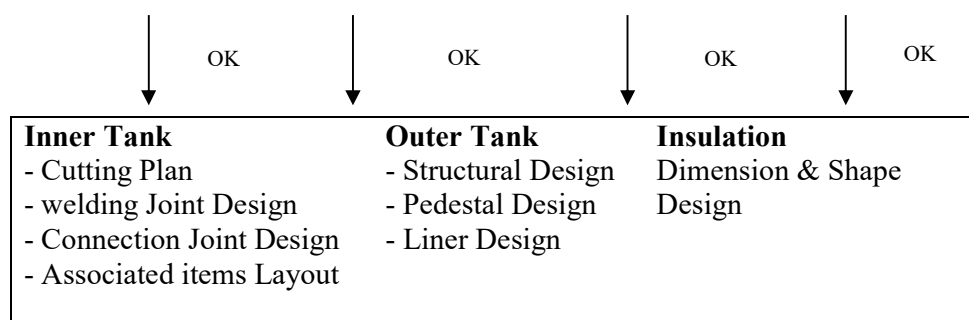
Technical Specification



3. Basic Design



4. Detail Design



LNG Tank Roof Simulation

The analyse model to analysis the steel roof with FEM(Finite Element Method) is designed as follows.

- **Analysis Model**

1. FEM-Analysis program
2. Analysis model
Analysis model is a 180° model (= half of the whole roof) for the symmetry of the roof structure.
3. The used Elements:
Bar element, plate element (including shear panel element)

The photos below show the contour of deformation of the steel roof from the results of the FEM analysis

CONSTRUCTION & ERECTION

Construction

1. Placing concrete of the bottom slab and PC wall will be executed in same time.
2. Reinforcing work of bottom slab and Bottom heater piping work

INSULATION

BASIC PERLITE INFORMATION

Origins and Characteristics

Perlite is not a trade name but a generic term for a naturally occurring volcanic glass. Formed from rhyolitic volcanic flows, it is a siliceous rock, it is similar chemically to obsidian, and it has enough entrapped moisture in it to "expand" when heated.

The distinguishing feature that sets perlite apart from other volcanic glasses is this ability to be "processed or expanded." When heated to a suitable point in its softening range, it expands from four to twenty times its original volume.

This expansion is due to the presence of two to six percent combined water in the crude perlite rock. Then quickly heated to above 871 °C), the crude rock pops in a manner similar to popcorn as the combined water vaporizes and creates countless tiny bubbles that account for the amazing light weight and other exceptional physical properties of expanded perlite.

Three stages of perlite production shown above illustrate the great increase in volume after firing.

The same weight of perlite, 1 oz. (28 gm.), is shown as crude perlite, crushed crude perlite, and expanded perlite.

The expansion process also creates one of perlite's most distinguishing characteristics: its white color. While the crude rock may range from transparent light gray to glossy black, the color of expanded perlite ranges from snowy white to grayish white.

Expanded perlite can be manufactured to weigh as little as 32 kg/m³ making it adaptable for numerous applications.

Since perlite is a form of natural glass, it is classified as chemically inert and has a pH of approximately 7.

Eventually cryogenic perlite is placed in the large interstitial space between the outer and inner tank (the annular space).

THERMAL RESISTANCE VALUES

Thermal "R" Values for 1 in (0.0254m) Thickness

Density	Mean Temperature, F ° (C °)		
	40 (4)	75 (24)	105 (41)
2.0-4.1 (32.0-65.6)	4.3-3.9 (0.78-0.69)	3.7-3.3 (0.65-0.58)	3.7-3.2 (0.65-0.56)
4.1-7.4(65.6-118.4)	3.9-3.3 (0.69-0.58)	3.3-2.8 (0.58-0.49)	3.2-2.7 (0.56-0.47)
7.4-11.0(118.4-176.0)	3.3-2.9(0.58-0.51)	2.8-2.4 (0.49-0.42)	2.7-2.4 (0.47-0.42)

TYPICAL ELEMENTIAL ANALYSIS

Silicon

Aluminum	33.8
Potassium	7.2
Sodium	3.5
Iron	3.4
Calcium	0.6
Magnesium	0.6
Trace	0.2
Oxygen (by difference)	0.2
Net Total	47.5
Bound Water	97.0
Total	3.0
	100.00

Typical Physical Properties

Color	
Refractive Index	White
Free Moisture, Maximum	1.5
pH (of water slurry)	0.5%
Specific Gravity	6.5-8.0
Bulk Density (normal)	2.2-2.4
Mesh Sizes (normal)	2-15lb/ft ³
Softening Point	4-40 and finer mesh
Fusion Point	1600-2000F
Specific Heat	2300-2450F
Thermal Conductivity	0.2BTU/lb F
	.27-.41 BTU.in/h.ft ² .F

Definitions

Barrel (bbl): 42 gallons; 5.62 cubic feet; or 0.159 cubic meters.

Barrel of Oil Equivalent (BOE): the oil equivalence of natural gas is normally based on the amount of heat released when the gas is burned as compared with burning a barrel of oil. For a typical natural gas, burning 6,000 standard cubic feet liberates about the same amount of heat as burning one barrel of an average crude.

Barrels per calendar day (*bled*): total throughput divided by number of calendar days. The total divided by actual number of days in operation (i.e., stream days) gives the stream-dayrate, which equals or exceeds the calendar-day-rate. Calendar day is a term describing the throughput of a facility that occurs on a daily basis averaged over a long period of time. A calendar day rate times 365 gives the average annual rate.

Barrels per day (b/d, bpd, or bbl/d): a unit of measurement used in the industry for the production rates of oil fields, pipelines, and transportation.

Base pressure: standard unit of pressure used in determining gas volume. Volumes are measured at operating pressures and then corrected to base pressure volume. Base pressure is normally defined in any gas measurement contract. The standard value for natural gas in the United States is 14.73 Asia, established in 1969 by the American National Standards Institute as standard Z-132.1. Also called "base conditions". The standard pressure specified in US state regulations on base pressure varies slightly from state to state.

Base temperature: an arbitrary temperature to which measurements of a volume of gas are referred. The standard value in the United States is 60° F (520° R) for natural gas as established by the American National Standards Institute as standard Z-132.1.

Battery limits: The perimeter of the real estate containing the gas process equipment.

Boil-off gas: vaporized methane from LNG.

Boil-off vapor: usually refers to the gases generated during the storage of volatile liquefied gases, such as LNG. LNG boils at slightly above -163°C at atmospheric pressure and is loaded, transported and discharged at this temperature, which requires special materials, insulation and handling equipment to deal with the low-temperature and the boil-off vapor (heat leakage keeps the cargo surface constantly boiling).

Bottled gas: liquefied petroleum gas (LPG) stored in a liquid state in steel containers at moderate pressure and ambient temperatures.

British thermal unit (Btu): The standard unit for measuring the amount of heat energy. A prestressed concrete sidewall is constructed to protect the outer shell of the LNG Tank from fire, floods, and hostile attacks and also serves to contain the LNG in the event of a tank failure.

required to raise the temperature of one pound of water by one degree Fahrenheit (1°F) at or near 39.2°F.

Bubble point: the temperature and pressure at which a liquid first begins to vaporize to gas.

Build-own-transfer (BOT): Generally refers to an independent power project (see below) where the for-profit energy company agrees to build the plant and then transfer ownership to the host government after the government has purchased enough electricity to pay for the plant plus provide a mutually acceptable profit to the energy company.

Calorific value: the quantity of heat produced by the complete combustion of a fuel.

This can be measured dry or saturated with water vapor, net or gross. The general convention is dry and gross. See also Heating value

Catalyst: In chemical manufacturing, typically a metal-based particle introduced directly in the process stream that increases the rate of a reaction without itself being consumed. Common catalysts in gas processing applications include cobalt, iron, nickel and copper.

Cathodic protection: a method employed to minimize the rate of electrochemical corrosion of pipelines or structures.

Celsius (C): temperature scale based on the freezing (0 degrees) and boiling (100 degrees) points of water at atmospheric pressure; formerly known as Centigrade. To convert Celsius to Fahrenheit, multiply the number by 1.8 and add 32.

Compressed natural gas (CNG): Natural gas compressed to a volume and density that is practical as a portable fuel supply. Even when compressed, the natural gas is not a liquid, but a super-saturated fluid.

Condensate: a hydrocarbon liquid that forms by precipitation from a gas. When the liquid precipitates in the reservoir during pressure depletion, the liquid is referred to as retrograde condensate. Surface production of hydrocarbon liquids through primary separation facilities is referred to as condensate where it comes from a gas reservoir. Natural gas condensates consist primarily of pentanes (C_5H_{12}) and heavier components; there will be some propane and butane dissolved within the mixture.

Cubic capacity: the volumetric measurement of the ship's cargo compartments.

Cubic feet per day (cf/d): at standard conditions, the number of cubic feet of natural gas produced from a well over a 24 hour period, normally an average figure from a longer period of time. Generally expressed as mcf/d = thousand cubic feet per day, mmcf/d = million cubic feet per day, or bcf/d = billion cubic feet per day.

Cubic meter (cm): unit of measurement for gas volume. The amount of gas required to fill the volume of one cubic meter.

Dew point: The temperature to which a given unit of gas must be cooled at constant pressure for saturation to occur.

Feed gas: In general, the natural gas directly used by a liquefaction or processing plant to manufacture the final product (e.g., LNG, methanol, DME, diesel, etc.).

Flare: a flame used to burn off unwanted natural gas; a "flare stack" is the steel structure on a processing facility from which gas is flared.

Fractionation: the process of separating a fluid mixture into its primary constituents, e.g., separating a natural gas condensate into ethane, propane, butanes and heavier components.

Front-end engineering and design (FEED): A detailed plan for the construction of a large-scale, complex facility or integrated supply chain, including inlet transportation, processing, loading, shipping and receiving. The FEED is used by the EPC contractor (see above) to submit a lump-sum bid to the customer.

Front End Engineering and Design (FEED) Contract: 1) a legal agreement setting out the terms for all activities required to define the design of a facility to a level of definition necessary for the starting point of an EPC contract; 2) Generally, the second contracting phase for the development of the export facilities in the LNG chain which provides greater definition than the prior Conceptual design phase. In an LNG project, the single most important function of the FEED contract is to provide the maximum possible definition for the work ultimately to be performed by the Engineering, Procurement, and Construction (EPC) contractor. This enables potential EPC contractors to submit bids on a lump-sum basis, with the least possibility that the contract cost will change through undefined work or through claims for unanticipated changes in the work. Clear definition of contract costs is important not only for cost control purposes, but also for purposes of project financing -LNG project lenders will normally limit their lending commitment to a specific percentage of forecast project costs, and cost overruns will have to be covered by the borrower's equity investment. See Engineering, Procurement and Construction (EPC) Contract

Fuel gas: a process stream internal to a facility that is used to provide energy for operating the facility.

Fuel loss: a proportion of natural gas received by a pipeline or local distribution company that is retained to compensate for lost and unaccounted for natural gas.

Gas-to-liquids (GTL): refers to processes that convert natural gas to ambient liquid fuels, such as diesel, naphtha, kerosene, DME and methanol.

Gas-to-oil ratio (GOR): the number of standard cubic feet of gas produced per barrel of crude oil or other hydrocarbon liquid. In some parts of the world, the units are cubic meters of gas per cubic meter of liquid produced.

Gas treatment: removal of gas phase impurities, such as sulfur compounds, carbon dioxide and water vapor from natural gas.

Grid: a network of pipelines through which gas is transported.

Heat of radiation: Generally the heat, measured in units of energy per unit of area, radiated during a fire. The measurement is often used to determine the setback distances between pieces of equipment in an industrial site (also see *vapor dispersion*).

Heat of vaporization (a.k.a., latent heat of vaporization): The quantity of heat necessary to change one gram of liquid to vapor, without change of temperature.

Hydrocarbon: an organic chemical compound of hydrogen and carbon in gaseous, liquid, or solid phase.

Inert gas: a chemically inert gas, resistant to chemical reaction with other substances.

Joule-Thompson effect: The decrease in temperature, which takes place when a gas expands through a throttling device such as a nozzle. Sometimes used to refrigerate gases for liquefaction.

Kilowatt (kW): a measurement of electric power equal to one thousand watts.

Knot: unit of speed in navigation, which is the rate of one nautical mile (6,080 feet or 1,852 meters) per hour.

Liquefaction plant: Plant for the manufacture of liquefied natural gas.

Liquefied Natural Gas (LNG): Natural gas, primarily methane, that has been cooled to minus 160°C (minus 259°F) at atmospheric pressure and stored in insulated containers in a liquid state.

LPG (Liquefied Petroleum Gas): Generally refers to a mixture of propane, butane and minor constituencies of other liquefied gas derived from petroleum.

Maximum allowable operating pressure (MAOP): the maximum gas pressure at which a pipeline system or process facility is allowed to operate.

Methane: The most common hydrocarbon gas, methane is odorless and colorless and burns efficiently with few by-products. It is the simplest molecule in the carbon-chain series of hydrocarbons.

Methanol (CH₃OH): Methanol is the simplest alcohol, containing one carbon atom. It is a colorless, tasteless liquid with a very faint odor and is commonly known as "wood alcohol."

Pipeline: a tube for the transportation of crude oil or natural gas between two points, either offshore or onshore

Regassification plant: a plant that accepts deliveries of liquefied natural gas (LNG) and vaporizes it back to gaseous form by applying heat so that the gas can be delivered into a pipeline system.

SCADA System (Supervisory Control and Data Acquisition): a computerized automation system that brings together the following technologies: telemetry, telecontrol, supervisory control, and data acquisition, analysis and presentation. When a SCADA system is employed in an LNG process plant or pipe line, information from remote data gathering devices is made available to a central location. Moreover, information gathered can be used by a human operator as the basis for issuing commands to the remote locations.

Specific gravity: the ratio of the density of a substance to the density of a reference substance, both at specified physical conditions. As applied to gas, air is the reference substance and the physical conditions are a specified temperature and atmospheric pressure.

Standard metering: base standard conditions, plus agreed corrections, to which all natural gas volumes are corrected for purposes of comparison and payment.

Sweet gas: natural gas which contains such small amounts of hydrogen sulfide (and other sulfur compounds) and carbon dioxide that it can be transported or used without purifying, with no deleterious effect on piping and equipment.

Vapor pressure: the pressure exerted by a vapor that is in equilibrium with a liquid.

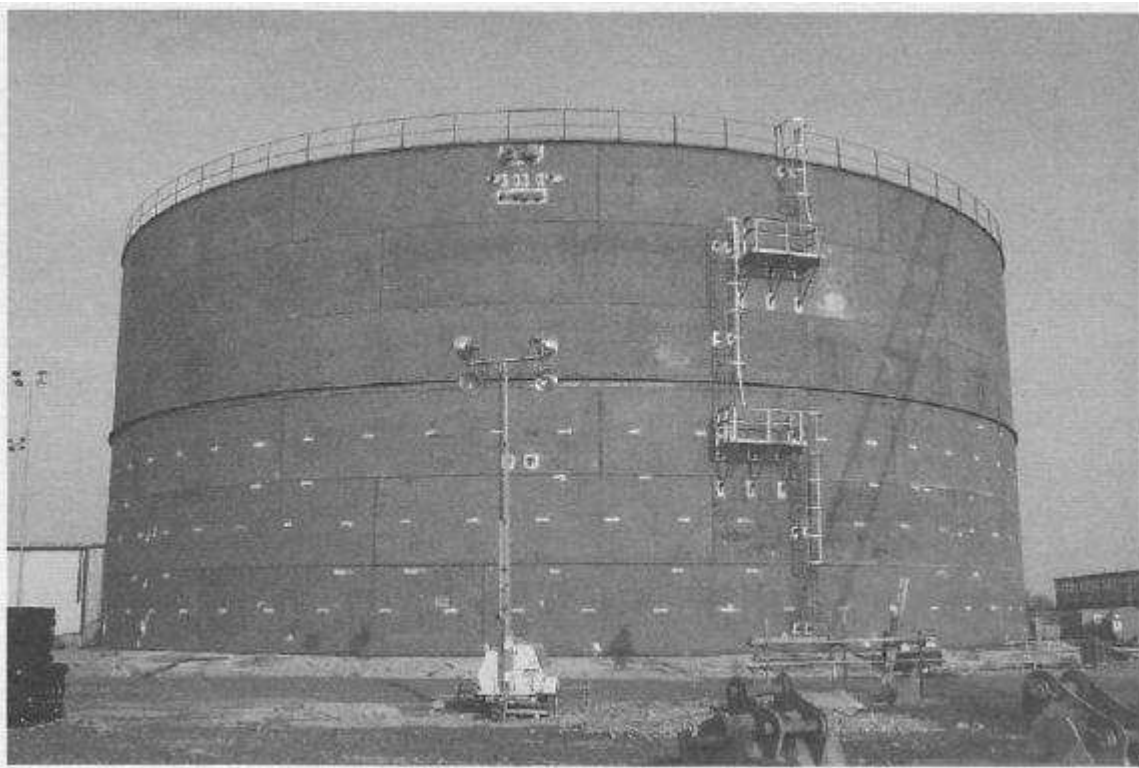
APPENDIX

TANK DESIGN & DETAILING

Introduction

The API 650 standard is designed to provide the petroleum industry with tanks of adequate safety and reasonable economy for use in the storage of petroleum, petroleum products, and other liquid products commonly handled and stored by the various branches of the industry. This standard does not present or establish a fixed series of allowable tank sizes; instead, it is intended to permit the purchaser to select whatever size tank may best meet his needs. This standard is intended to help purchasers and manufacturers in ordering, fabricating, and erecting tanks; it is not intended to prohibit purchasers and manufacturers from purchasing or fabricating tanks that meet specifications other than those contained in this standard.

This standard has requirements given in two alternate systems of units. The requirements are similar but not identical. These minor differences are due to issues such as numerical rounding and material supply. When applying the requirements of this standard to a given tank, the manufacturer shall either comply with all of the requirements given in SI units or shall comply with all of the requirements given in US Customary units. The selection of which set of requirements (SI or US Customary) shall apply to a given tank shall be by mutual agreement between the manufacturer and purchaser.



Types of tanks (based on Roof fixing)

1. Fixed Roof Tank
2. Floating Roof Tank

Types of Tank based on Roof

1. Flat Roof
2. Cone Roof
3. Domed Roof

Types of Floating Roof Tanks

1. Internal Floating Roof Tank

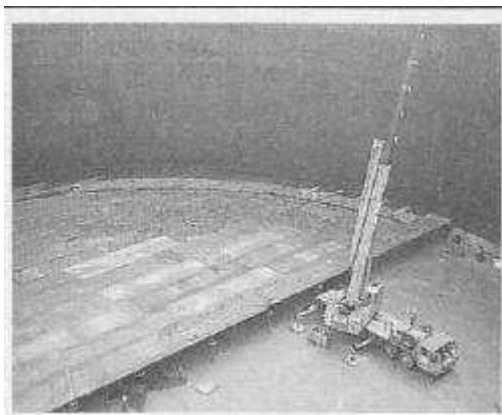
2. External Floating Roof Tank

Main Parts of Tank

1. Tank Shell
2. Bottom plate
3. Annular Plate
4. Backing strip
5. Anchor chairs and Anchor bolt arrangements
6. Draw of sump
7. Cleanout catch
8. Nozzles
9. Shell man way
10. Roof man way
11. Fire safety
12. Primary & Secondary Wind girder
13. Curb angle or compression ring
14. Roof plate
15. Crown plate
16. Vent Nozzles
17. Overflow pipes
18. Roof Structures and support structures
19. Internal pipe supports
20. Internal man way rungs and internal ladder with support clips
21. External cage Ladder and spiral Staircase ladders and platforms with support clips
22. Roof handrails

For Floating Roof tanks

1. Drain system
2. Double Deck or single Deck
3. Seal or foam
4. Pantoon Legs
5. Deck legs
6. Rim plate & rim pontoons
7. Rollin ladder
8. Pantoon man way
9. Deck man way



Standards:

API Standard 650,	Welded Steel Tanks for Oil Storage
API Standard 620,	Recommended Rules for Design and Construction of Large Welded Low Pressure Storage Tanks
API RP 2000,	Venting Atmospheric and Low Pressure Storage Tanks

Standard Selection conditions:

Atmospheric pressure no refrigerated tanks shall be designed to API 650. Closed Top subject to low pressure shall additionally satisfy Appendix F.

Higher pressure tanks up to 15 psig shall comply with API 620 and shall include all API 650 requirements for materials and examinations.

API 650 tanks with wall thickness up to and including 0.5 inch shall be to Appendix A except that Group I materials of Table 2-3 shall not be used below 20°F.

Shop assembled API 650 tanks shall comply with Appendix J except that a minimum of spot radiography shall be applied with joint efficiency of 0.85.

**1. TANK GA PREPARATION:**

1. Fix the layout for tank overall dimensions in elevation, top view and side view.
2. Compare the overall dimensions and reference dimensions
3. To draw all the attachments and tank parts should be maintain completely 1:1 scale
4. Put all the orientation for Man ways , draw of sump, Nozzles and internal and external ladder clips, earthing boss or Clips, wind girder, lightning clips, piping support clips and etc.
5. All nozzle sizes and standards, schedules, type of flanges to be used, type of faces to Be used in flanges, if required any blind flanges, Davit Man ways, hinged type man ways, Vent and all nozzle elevation should be Fixed in Bottom of tank (bottom of shell plate). These items should be come in nozzle Details.
6. General notes, assembly notes are added in notes.
7. Which type of materials used in tank and attachment parts is come in material of Construction.
8. Add the design notes in Design Data table

9. Total weight of the tank and centre of gravity should be added.
10. If any internal (or) external surface preparation is there, this notes also added.
11. Client gives any standards to be follow the tank detailing, that standard also should
Give the Standard requirements
12. If any tolerance given, that is also added in overall dimensions
13. Structural also added in the GA drawing.
14. If any legends there these items also include

Major dimensions specified in GA Drawing

1. Tank total height
2. Tank ID
3. Tank plate thickness in via course
4. If any wind girder is there that elevation should be added
5. Nozzle orientations and ladder positions (internal or external), ladder clips
And piping supports, all attachments. etc
6. Nozzle elevations (X,Y) minimum two dimensions
7. If Roof Nozzle there, that case angel and distance for center line of tank
8. Structural column to column distances overall length for columns
9. Sump Orientation

SURFACE PREPARATION AND PAINTING: (Example)

SURFACE PREPARATION AND PAINTING					
	DESCRIPTION		NO. OF COATS	DFT	REMARKS
INTERNAL SURFACES	SURFACE PREPARATION	BLAST CLEAN TO SA2.5	—	—	
EXTERNAL SURFACES (TANK & NOZZLES)	SURFACE PREPARATION	BLAST CLEAN TO SA2.5	—	—	
	PRIMER	INORGANIC ZINC SILICATE	1	75	
	INTERMEDIATE	EPOXY HIGH BUILD PAINT	1	100	
	FINISH	ACRYLIC POLYURETHANE PAINT	1	40	

Design Data (example):

DESIGN DATA		
DESIGN CODE		API 650 TENTH EDITION—NOVEMBER 1998
ITEM NO		TANK—1
INTERNAL DESIGN PRESSURE	Kg/cm2 (g)	10.5
EXTERNAL DESIGN PRESSURE	Kg/cm2 (g)	—
OPERATING PRESSURE	Kg/cm2 (g)	6.5 min/7.5 (NOM)
HYDROSTATIC PRESSURE	Kg/cm2 (g)	15.75
DESIGN TEMPERATURE	°C	60
OPERATING TEMPERATURE	°C	35(NOM)/43(MAX)
SHELL JOINT EFFICIENCY	%	100
HEAD JOINT EFFICIENCY	%	100
POST WELD HEAT TREATMENT		NO
X—RAY EXAMINATION		FULL
SHELL CORROSION ALLOWANCE	mm	1.5
HEAD CORROSION ALLOWANCE	mm	1.5
CAPACITY	m3	588.8
WIND		ASCE—7/02;EXPOSURE=D; I=1.15; V=38m/Sec
EARTHQUAKE		UBC—1997; ZONE 2A; I=1.00; SOIL FACTOR=5
THERMAL INSULATION	mm	NO
FLUID CONTAINED		WATER OR OIL

NOZZLE DATAS: (Example)

A1	OPENING FOR N2,CN 1B	2	–	14	–	–	–	–	–	–	REF DWG		–	–	–	–	–	–
A0	SKIRT ACCESS	1	–	14	–	–	–	–	–	–	REF DWG		–	–	–	–	–	–
CN1A	LEVEL GAUGE	1	2	16.7	ASME B16.5	300#	LWN	RF	–	–	3365		1.1	1.1	1.5	0.2	0.2	0.3
CN1B	LEVEL GAUGE	1	2	8.7		300#	WN	RF	–	–	3365		1.1	1.1	1.5	0.2	0.2	0.3
M1	MANWAY	1	24	12		150#	WN-BF	RF	74	97	3350		17.9	17.9	25.3	33.8	33.8	47.7
J1	PRESSURE TRANSMITTER	1	2	16.7		300#	LWN	RF	–	–	REF DWG		1.1	1.1	1.5	0.2	0.2	0.3
N5	VENT	1	6	10.97		150#	WN-BF	RF	–	–	REF DWG		3.4	3.4	4.8	2.4	2.4	3.4
N4	AIR OUTLET	1	6	10.97		150#	WN	RF	58	32	REF DWG		3.4	3.4	4.8	2.4	2.4	3.4
N3	PRESSURE RELIEF VALVE	1	6	10.97		150#	WN	RF	58	32	REF DWG		3.4	3.4	4.8	2.4	2.4	3.4
N2	DRAIN	1	2	8.7		150#	WN	RF	–	–	REF DWG		0.9	0.9	1.2	0.2	0.2	0.3
N1	AIR INLET	1	6	10.97		150#	WN	RF	65	35	3265		3.4	3.4	4.8	2.4	2.4	3.4
NOZZLE MARK	DESCRIPTION	QTY.	SIZE IN INCH PIPE DIMENSION	THK. (mm)	STD.	RATING	TYPE	FACING	HT SELFREINF	THK	NOZZ PROJ FROM C. OF VESSEL	REMARKS	FX	FY	FZ	MX	MY	MZ
NOZZLE SCHEDULE													NOZZLE LOADS					
													DIRECT LOADS (KN)			MOMENT LOADS (KN)		

STANDARDS, SPECIFICATIONS: (Example)

STANDARDS, SPECIFICATION AND DRAWING			
S.NO.	DOCUMENT No.	DESCRIPTION	REV.
1	00-RA-E-20023	TECHNICAL SUPPLY SPECIFICATION	02
2	8762-00-SP-808	NOZZLE DETAILS	F1
3	8762-00-SP-809	MINIMUM NOZZLE LOADS	F2
4	8762-00-SP-B11	MANWAY DAVIT DETAILS	F1
5	8762-00-SP-800	ENGINEERING STD GENERAL REQUIREMENT FOR WELDED UNFIRED PRESSURE VESSELS	F3
6	8762-00-SP-827	NAMEPLATE AND BRACKET DETAILS	F1
7	8762-00-SP-832	FABRICATION DIMENSIONAL TOLERANCES	F2
8	8762-00-SP-842/00-ZA-E-20221	POSITIVE MATERIAL IDENTIFICATION	02/02
9	8762-00-SP-844	GENERAL REQUIREMENT FOR WELDING	F3
10	8762-00-SP-846/00-ZA-E-20220	GENERAL MATERIAL REQUIREMENT	F1/02
11	00-GA-E-60701	PROTECTIVE PAINT AND COATINGS	06
12	00-RA-E-20002	INSPECTION DATA SHEET	02
13	STD.CR.GEN.7009	ANCHOR BOX & SUPPORT FOR VERTICAL VESSEL	02
14	STD.CR.GEN.7071	LIFTING LUGS TO LIFT EQUIPMENT UP TO 2000KN	01
15	STD.CR.GEN.7076	RETENTION LUG APPLIED TO SKIRT BOTTOM	01
16	8762-00-SP-817	PLATFORM BRACKETS(VERTICAL VESSELS)	F2
17	8762-00-SP-818	LADDER CONNECTION TO VERTICAL VESSELS	F1
18	8762-00-SP-826	MANWAYS INTERNAL RINGS	F1

MATERIAL OF CONSTRUCTION: (Example)

MATERIAL OF CONSTRUCTION	
BOTTOM PLATE	SA 283 Gr.C
SHELL PLATE	SA 283 Gr.C
ROOF PLATE	SA 283 Gr.C
NOZZLE NECK FROM PIPE	SA 106.Gr.B
NOZZLE NECK FROM FORGING	S.A 105
FITTING	SA 234 WPB
WIND GRIDER	SA 283 Gr.C
CURBE ANGLE OR TOP RING	SA 283 Gr.C
STRUCTURALS	IS 2062 Gr.A
INTERNALS WELDED (REMOVABLE)	IS 2062 Gr.A
SUPPORTS ANDE CLIPS	IS 2062 Gr.A
INTERNAL BOLTING AND NUT	SA 193 Gr.b / SA 194 Gr.2H
GASKET	SPIRAL WOOND GASKET-WITH OUTER & INNER RING-
	TB-GUA 5365-3165.5+GRAPH.98%-C.S.

Pressure rating

Design pressures up to 500 mbar:

- Non-pressure, up to 10 mbar
- Low-pressure, up to 25 mbar
- High-pressure, up to 60 mbar
- Very high-pressure, up to 500 mbar

Maximum negative pressure = -20 mbar.

Valid for negative pressure = up to -8.5 mbar

Temperature range is from 300°C down to -40°C.

SHELL DEVELOPMENT DRAWING

Vertical Joints in Shell

Butt joints with complete penetration and complete fusion as attained by double Welding or by other means which will obtain the same quality of joint

Horizontal Joints in Shell

Complete penetration and complete fusion butt weld.

Shell to Bottom Plate Joint

Continuous fillet weld laid on each side of the shell plate. The size of each weld shall be the thickness of the thinner plate.

1. Shell plate development detail (use $\pi * D$ formula, D is mean dia of tank)
2. Cutting layout drawing
3. Shell plate to Annular plated welding detail
4. shell plate to Shell plate (longitudinal and circumference) welding details
5. Wind Girder to shell plate welding detail
6. Wind Girder to Wind girder welding details
7. Curb angle to shell plate welding detail
8. Bill of materials
9. General notes
10. Section Views for plate to plate welding details

Shell plate Development Drawing involved components

1. Nozzle od and Rf pad od locations and dimensions
2. Man way od and man way Rf pad od locations and clean out catch
3. Earthing Boss or clips locations and overall dimensions
4. Lightening clips, Piping supports clips (X or Y dimension and plate weld line to clip end dimension)
5. Wind Girder positions and welding joints
6. Curb angle locations
7. Internal and external ladder clips locations

Shell course design details one foot method (example)

Allowable steel stresses:

To keep the selection of shell plate material within the band of **carbon and carbon manganese** weldable steels the maximum allowable design stress which may be used is 260 N/mm² or two thirds of the material, specified minimum yield strength at room temperature, whichever is the lower. This limit of 260 N/mm²

discourages the use of steels with a minimum specified yield strength in excess of **390 N/mm²**, **because of their increased hardness and reduced weldability.**

(CL 3.6.3.2, TABLE 3.2 & CL 3.6.1.1 Note:1 of API-650)

$t_t = 4.9 D (H-0.3)/St$ - Hydro test thick

$t_d = 4.9 D (H-0.3)G/Sd + CA$ - Design calculated thick.

Shell course (Number from Bottom most)	Considered Material Specification	Ht of Course (m)	Assumed Thickness (mm)	Nominal Tank Dia (m)	Ht from Bottom of Courses to Bottom of overflow nozzle (m)	Sd (Mpa)	(C.A) (mm)	Cal. Thick (mm)	Hydro test Thick (mm)	Provided Ht(m)x Thk.(mm) course
First (Bottom most)	S355 J 2 G 3 FF	2.5	12	36.012	11.719	196	1.5	11.57	9.6	2.5mx12mm
Second	S355 J 2 G 3 FF	2.5	10	36.010	9.219	196	1.5	9.37	7.5	2.5mx10mm
Third	S355 J 2 G 3 FF	2.5	8	36.008	6.719	196	1.5	7.16	5.4	2.5mx8mm
Fourth	S235 JRG 2 FN	1.5	6	36.006	4.219	157	1.5	5.82	4.04	1.5mx6mm
Fifth	S235 JRG 2 FN	1.5	6	36.006	2.719	157	1.5	4.16	2.50	1.5mx6mm
Sixth	S235 JRG 2 FN	1.425	6	36.006	1.219	157	1.5	2.51	0.95	1.425mx6mm

D – Dia of tank

H – Design Liquid level

G – Specific gravity of liquid

Sd – 2/3 of yield stress

2/5 of tensile stress

Less value only taken

St – 3/4 of yield stress

3/7 of tensile stress

Less value only taken

Thickness of the bottom course or ring, which is restricted by API 650 to a maximum of **1 3/4 inch**.

Major Dimensions specified:

1. Overall length
2. Course length
3. circumference length
4. orientation angle
5. between angles length
6. weld to weld distance (longitudinal and circumference) length
7. weld Gap (longitudinal and circumference)
8. Nozzle positions angles and distance
9. Attachments and all types of clips positions and angles
10. welding details should be maintain weld sizes, welding angles, which type of weld should be used
11. part no. in all plates, curb angle, all attachment clips with out nozzle and nozzle pads
12. If any legends there these items also include

BOTTOM PLATE DEVELOPMENT

Bottom Plates

Single-welded full-fillet lap joint or single-welded butt joint with backing strip.

The bottom plates shall project at least 1inch width beyond the outside edge of the weld attaching the bottom to shell plate

1. Bottom plate development drawing
2. Cutting layout drawing
3. plate to plate welding detail
4. three plate welding detail
5. Bottom plate to Annular plate and Back strip welding detail
6. Section Views for plate to plate welding details
7. Bill of materials
8. General Notes

DESIGN OF BOTTOM PLATE:

(CL 3.4.1 of API-650) and BS 2654

Bottom plate thickness = $6\text{mm} + C.A$

Min plate thickness for **Stainless steel tanks**

Lap welded bottom plate = 5mm

But welded bottom plate = 3mm

Min plate thickness for **Carbon steel tanks**

Lap welded bottom plate = 6mm

But welded bottom plate = 5mm

DESIGN OF ANNULAR PLATE:

(CL 3.5.3 & Table 3.1 of API-6500)

$$\text{Hydrostatic Stress} = \frac{4.9 \times D \times (H - 0.3)}{THK} \quad (\text{example})$$

$$= \frac{4.9 \times 36.012 \times (11.719 - 0.3)}{12}$$

$$= 167.92 < 210 \text{ (210 is material allowable stress in design temperature)}$$

Hydrostatic Stress < 210 Mpa

Annular Plate Thickness provided = 12mm

Annular plate width

(CL 3.5.2 of API-650)

$$\text{Annular plate radial width} = 215 t_b / (HG)^{0.5}$$

Min radial width will be maintain 600 mm as per Cl 3.5.2

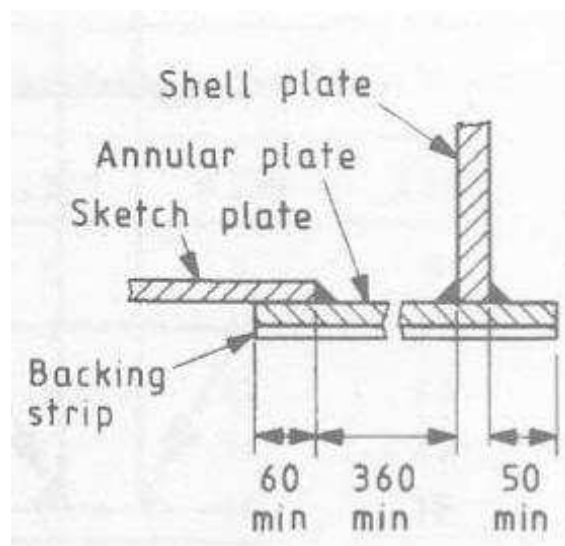
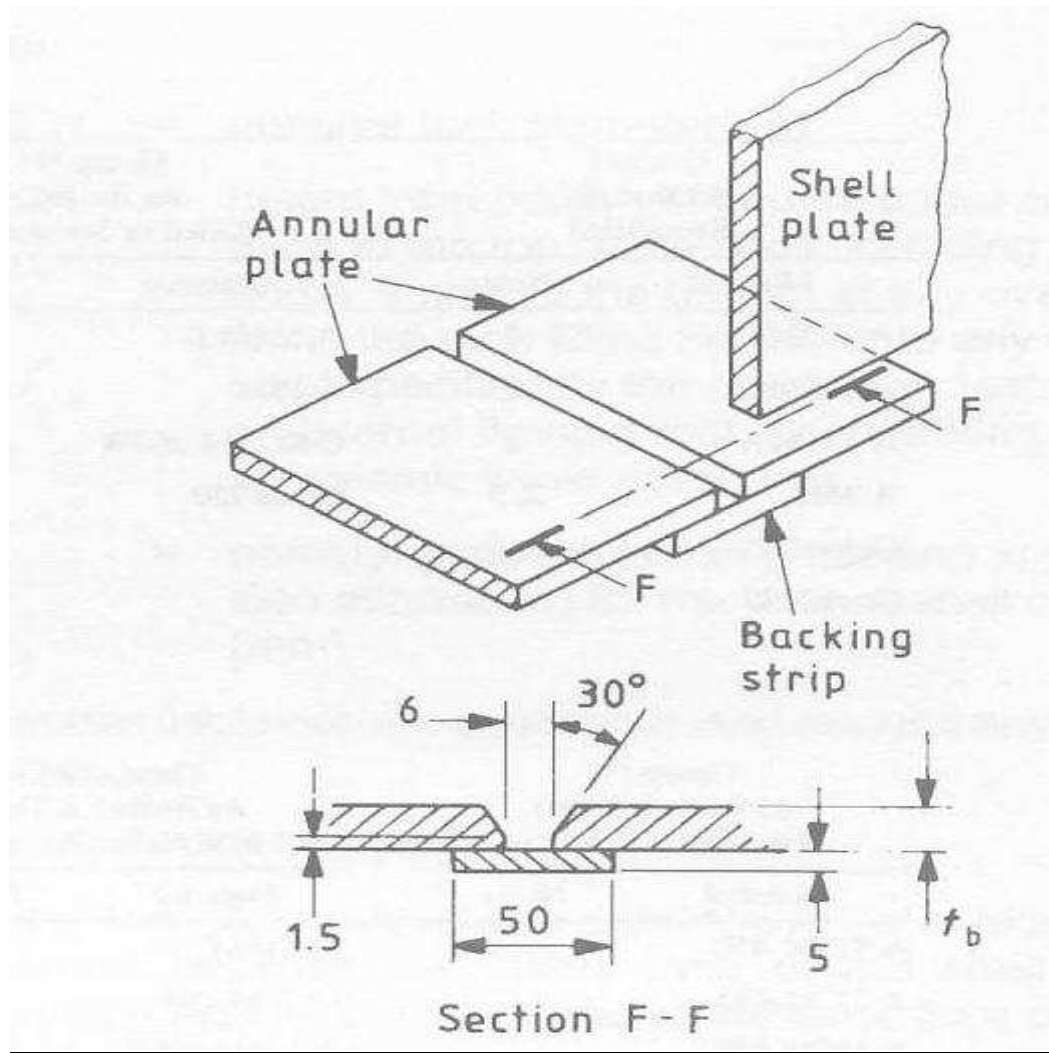
t_b = Thickness of the annular plate in mm

H = Maximum design liquid level

G = Design specific gravity of the liquid to be stored

Major Dimensions specified:

1. Overall developed OD
2. plate course width
3. welding gap
4. Center of Bottom plate to middle plate fixing dimensions(vertical & horizontal)
5. Bottom plate slope
6. Type of weld, welding size and welding angle
7. plate edge preparation dimensions in welding detail
8. If any draw of sump is there that is also put the weld detail



ROOF PLATE DEVELOPMENT

Roof Plates

Single-welded full-fillet lap joint. Roof plates shall be welded to the top angle of the tank with continuous fillet weld on the top side only.

1. Roof plate development drawing
2. Cutting layout drawing
3. plate to plate welding detail
4. Section Views for plate to plate welding details
5. Bill of materials
6. General Notes
7. Crown plate to Roof plate detail

Types of Roofs

1. Fixed Roof
 1. Cone Roof
 2. Doom Roof
 3. Umbrella Roof
2. External floating roofs
 1. Types of external floating roof
 1. Single-deck pontoon type
 2. Double-deck type
 - 2 Other types of floating roof
 1. BIPM roof
 2. Buoy roof
- 3 Internal floating roofs
 1. Types of internal floating roofs
 1. Pan roof
 2. Honeycomb roof
 3. Pontoon and skin roof

DESIGN OF ROOF PLATE:

For CONE

$$t = D/400 \sin \theta$$
$$t = \frac{1}{2} \text{ in (Max)}$$
$$\theta = 37 \text{ deg (9:12 slope)}$$
$$\theta = 9.28 \text{ deg (2:12 slope)}$$

For DOOM

$$t = R/200 \text{ but not lesser than } 3/16 \text{ in}$$
$$t = \frac{1}{2} \text{ in}$$
$$R = 0.8 D \text{ (min)}$$
$$R = 1.2D \text{ (max)}$$

Unless otherwise specified by the purchaser

(Cl 3.10.2.2 of API-650)

Minimum Thickness of Roof Plate = 5mm + C.A

Considering the Bottom Plate Thickness as 6mm.

Roof plate Thickness provided min = 5mm

Major Dimensions specified:

1. Overall developed OD
2. Plate course width
3. Welding gap
4. Center of Roof plate to middle plate fixing dimensions (vertical & horizontal)
5. Roof plate slope
6. Type of weld, welding size and welding angle
7. Plate edge preparation dimensions in welding detail
8. Roof Nozzles, RF pads, Roof man ways, positions and angles
9. Roof cutting angle
10. Crown plate cutting angle.

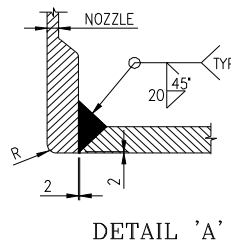
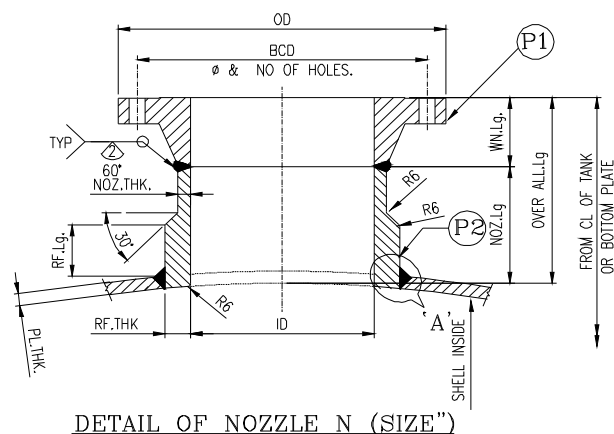
CUTTING ANGLE CALCULATION :

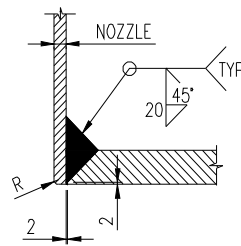
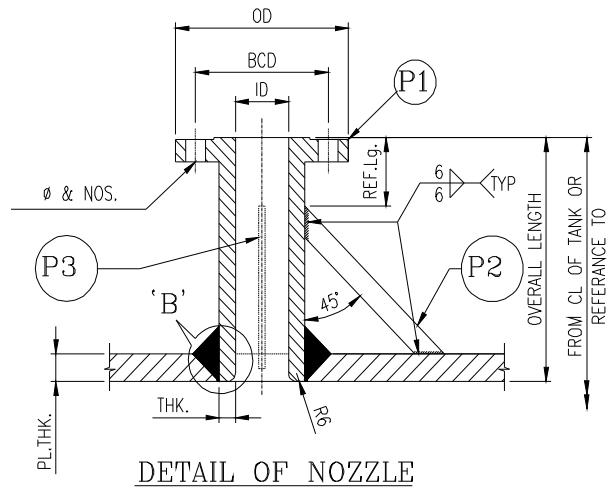
$$(R / r * 360) - 360$$

NOZZLE DETAILING

1. Nozzle and Man way weld details
2. Nozzle design as per CL 3.7 in API 650 follow

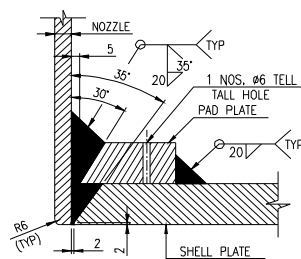
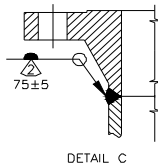
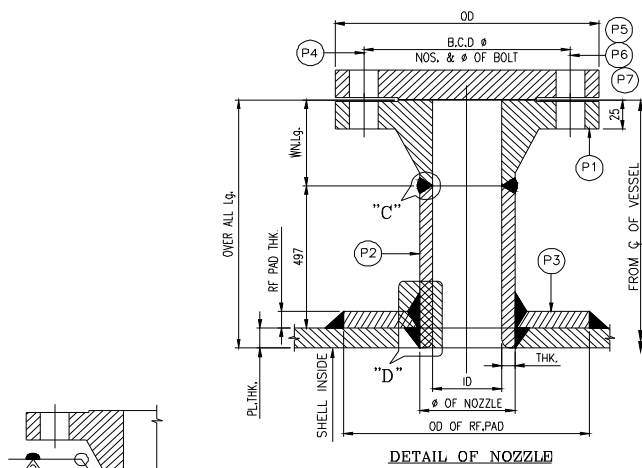
Reinforce nozzle welding detail (example)





DETAIL 'B'

Lesser than 3" and 250 and above lg provide Stiffener plate 2 no apart 90 deg in 45 deg angle



DETAIL D
WITH PAD PLATE
WELDING DETAILS

Manways

The number of manways to be provided are shown in the table below:

TANK NOMINAL DIA. (FT)	MANWAYS IN SHELL	MANWAYS FIXED ROOF	IN ROOF FLOATING ROOF DECK
Up to 20	1 - 24 inch	1 - 24 inch	1 - 30 inch
over 20 to 60	2 - 24 inch	1 - 24 inch	1 - 30 inch
over 60 to 120	3 - 24 inch	1 - 24 inch	2 - 30 inch
over 120	2 - 24 inch 1 - 30 inch	2 - 24 inch	2 - 30 inch

Floating roofs

Types

1. Metallic pan roofs:

These are in contact with the liquid and have peripheral rim

2. Metallic bulkhead roofs:

These are in contact with the liquid and have open – top bulkheads.

3. Metallic pontoon roofs

These are in contact with the liquid and have closed pontoons

4. Metallic double - deck roofs:

These are in contact with the liquid

5. Metallic roof on floats:

These roofs have their deck above the liquid.

6. Metallic sandwich – panel roofs:

These have surface – coated honeycomb panels and are in contact with the liquid

7. Plastic sandwich – panel roofs:

These are surface coated rigid panels and are in contact with the liquid

8. Roof seals design shall:

1. Be sufficiently flexible and have sufficient range of movement to accommodate roof movements and flexing of the roof and tank wall.
2. Remain stable in sunlight, tank liquid, tank vapour etc.
3. Prevent contact between organic materials and the tank contents.
4. Have metallic components galvanised unless otherwise agreed.
5. Ensure contact between seal and shell above liquid level. Shoe type seals to have 90% minimum contact and flexible seal type 100% minimum contact. No gap shall exceed 0.25 inch or be circumferentially longer than 48 inches.
6. Include primary and secondary seals unless otherwise agreed.
7. Include rim seal vents.
8. Sleeves for leg supports shall remain above liquid level when the deck is fully deflected.
9. Internal floating roofs shall comply with API 650 Appendix H except that minimum thickness shall be 6mm for aluminium and stainless steel. Pan type floating roofs shall not be used. Fixed internal ladders are not permitted.

Tank Height to Dia ratio by Sesmic Zone

Sesmic Zone	Max tank height (Height to Dia ratio)
1	2.4:1
2	1.25:1
3	0.67:1
4	0.5:1 (Small tank, soft soil)
4	0.6:1 (large tank, firm soil)

Rectangular Tanks

Ratio of sides

The sides are equal

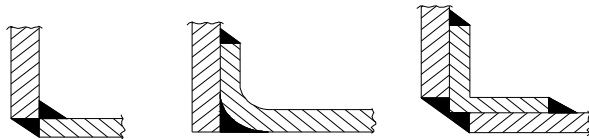
$$B = 3 \text{ root of } V$$

V = Volume

If Rectangular

$$\text{Length} = 1.5 B$$

$$\text{Width} = 0.667 B$$



Welding for corer plates (welding size – 0.75 x Thick of min size plate)

Materials selection

Nominal composition	Criteria
C – Steel	Plain Carbon steel
C – Si Steel	Exceed 0.1%Silicon
C – Mn Steel	Exceed 1.0%Mangnese
C – Mo Steel	Carbon with molybdenum added at the midpoint of the Range specified
C – Mn – Si Steel	

I. Selection of Materials for Service Environment

1. Design Factors

Design factors to consider include:

- Operating temperature and pressure
- Service environment
- Cost
- Design life
- Reliability and safety

2. Typical selections

3. Application Criteria for Common Pressure Vessels Materials

4. Summary of Temperature Limitations

II. Selection of Materials for Brittle Fracture Prevention

1. Definition of Brittle Fracture

2. Design to Prevent Brittle Fracture

3. Recommended Practice for Selecting Steels for New Construction of Pressure Vessels

4. Typical Carbon Steel Selections to Avoid Brittle Fracture in Pressure Vessels

5. Steel Selection for Pressure Vessels Subject to Auto refrigeration

6. Factors Controlling Susceptibility to Brittle Fracture: Additional Technical Information

III. Material Selections idias and construction

1. Determine Minimum design metal temperature” (MDMT).

2. Determine Minimum pressuring temperature” (MPT)

3. Maximum allowable stress values shall be in accordance with the API Standard, section 3.6.2 Table 3.2.

4. For austenitic stainless steel tanks the allowable stress shall be to the rules of API 620 Appendix Q

5. Annular bottom plates shall be to the same material specification and grade as the bottom shell course.

6. Cast fittings shall not be used in the shell or bottom of the tank

7. For stainless steel tanks to API rules, the material specifications and allowable stress rules of API 620 Appendix Q shall be used.

8. Corrosion allowance shall be added to the minimum annular plate thicknesses of API 650 Table 3-1.

9. Minimum thicknesses of internal structural members shall be 6mm plus corrosion allowance.

10. Wind girders on floating roof tanks shall be 3 feet 6 inches below the top of the curb angle and shall have a minimum width of 18 inches outside the curb angle. If used as a walkway the girder shall comply with API 650 paragraph 3.9.4.

11. For stainless steel tanks the wind girder section modules of API 650 shall be multiplied by 21000/S, where S is the stainless steel design stress (psi).

12. Fixed roof API 650 tanks shall have a frangible joint between the top angle and the roof plates.

13. For fixed roof pressurised design to API 650 Appendix F the area formula in F.5. shall also be multiplied by 24000/S, for stainless steel design.

14. For Floting roof Bearing plates 0.375 inches thick shall be provided under each support leg.

15. For Floting roof Thickness of the outer rim shall be 0.25 inches plus corrosion allowance minimum.

16. Roof decks shall be continuously welded from the top side and pontoon bulkheads shall be welded at the top to be vapour tight.

17. A continuous foam dam shall be provided on tanks 100 feet diameter and over. The dam shall be of 0.187 inch plate and shall be to NFPA No. 11 Appendix A-3.2.11.1.

Information to be specified by the purchaser

- 1 The following basic information to be specified by the purchaser shall be fully documented. Both the definitive requirements specified throughout the Standard and the documented items shall be satisfied before a claim of compliance with the Standard can be made and verified.
- 2 (a) Geographical location of the tank.
- 3 (b) Diameter and height or the capacity of the tank, including ullage. Where only the capacity of the tank is specified
- 4 Ground conditions shall be included.
- 5 (c) Whether fixed or floating roof is to be supplied and the type of roof if the purchaser has specific preferences, i.e. for Fixed roofs (cone, dome, membrane, etc.) or floating roofs (pontoon, double deck, etc.).
- 6 (d) All relevant properties of the contained fluid, including the relative density and corrosion allowance (if, how and Where required).
- 7 (e) The design vapor pressure and vacuum conditions inside the tank
- 8 (f) The minimum and maximum design metal temperatures
- 9 (g) The size, number and type of all mountings required showing locations. Maximum filling and emptying rates And any special venting arrangement
- 10 (h) The minimum depth of product which is always present in the tank
- 11 (i) If the tank is to be thermally insulated
- 12 (j) Areas of responsibility between the designer, the manufacturer and the erector of the tank when these are not the same.
- 13 (k) Quality of the water to be used during tank water test
- 14 (l) Expected maximum differential settlements during water testing and service lifetime of the tank (see Appendix A).
- 15 (m) Other specifications which are to be read in conjunction with this Standard.

For Reference

1. Guide to storage tanks and equipment design by: Bob Long and Bob Garner
2. API 650 Standard

Prepared by

I. ROBERT ANTO RENI.

Types Of Tanks

The most popular, are the four basic types of tanks for storage of petroleum and products :

- 1- Fixed -roof tanks**
- 2- Floating -roof tanks**
- 3- Variable - vapor- space tanks**
- 4- Pressure tanks**

Each type is designed for specific storage requirements .

For example for stocks having low V-pressure the fixed roof tank generally will be the most economical selection .

For stocks of high volatility produces like motor gasoline , the floating – roof tank generally will be the best choice.

For stocks which boil at pressure and storage temperature , pressure tanks are the best type .

Effective loss-control operation of each tank is dependent upon certain accessory such as breather – valves and automatic for close gage hatch's

Maintenance Of Tanks

Tanks should be inspected at regular intervals , the frequency of inspection usually determined by experience.

Leak Detection In High Press. Tanks .

- 1- Observation of escaping vapors as waves .*
- 2- Hearing the hiss of escaping vapors .*
- 3- Smelling*
- 4- Gas detectors*
- 5- Applying soap .*

Opening on fixed roof tanks for; venting , gagging and sampling .

Accessory for venting :

Breather valve (pressure -vacuum relief valve) to prevent either the back flow of air to tank or the scape of vapors . The breather valve is either metal to metal type or diaphragm and liquid - seal

valves .

- Tank painting is important to reduce evaporation losses as well as preserving the tank.
- Use of insulation . on the the roof and shell of storage tanks tends to reduce heat losses .

Fixed – roof tanks :

It is the effective conservation device for stocks of degassed crude oil and water

Floating – Roof Tanks:

It is the effective conservation device for stocks of high volatile products it's design eliminates the vapors space , low losses from breathing and filling excellent for fire protection and corrosion resistance .

The 1st floating roof tank was the pan type (Single deck) which cover the liquid surface . This type has some disadvantage such as:

As it is single deck, heat of the sun during middle of the day transferred directly to the liquid surface , which leads to product losses , the pan roof may sink under heavy loads above it.

Therefore the double deck roof (Pontoon Type) was offered to give more stability and load carrying capacity in addition to the trapped air between the two decks which act as the temp. insulator that eliminates product losses due to temperature .

The roof can be put in the maint. position and also in the operating position by using the movable shoes (arms) on it .

** Fig- 1, 2 & 3*

Variable – Vapor- Space – Tanks

This type is effective in reducing breathing losses, expanded vapors are stored temporarily in a gasholder device and vented to the atmosphere only when gasholder capacity is exceeded. By cooling, the vapors from the gas holder are drawn back into the tank

- *Fig- 4, 5 & 6*

Pressure tank :

It is a vessel , either Cylindrical or spherical shape that can withstand relatively large pressure variation. Today , there are low pressure tanks up to atmospheric pressure and high pressure tanks operating up to 250 PSI or more , the max, allowable working pressure is limited by tank size and code requirements .

Utilization of tanks in Process Area

1- Washing tanks

Where the oil production is passed through water phase in the bottom of the tank this mainly to enlarge the water droplets to be easy settled in the settling tanks .

2- Settling Tanks

In which the oil coming from wash tanks enter the settling tanks from bottom and come out from the top this to give the small water droplets the retention time to be collected together forming a large droplets and becomes easily settled .

3- Storage Tank .

this to work as a capacitor upstream the treatment facilities, calculating prod./shipping crude and also to store the treated products which are ready for shipping .

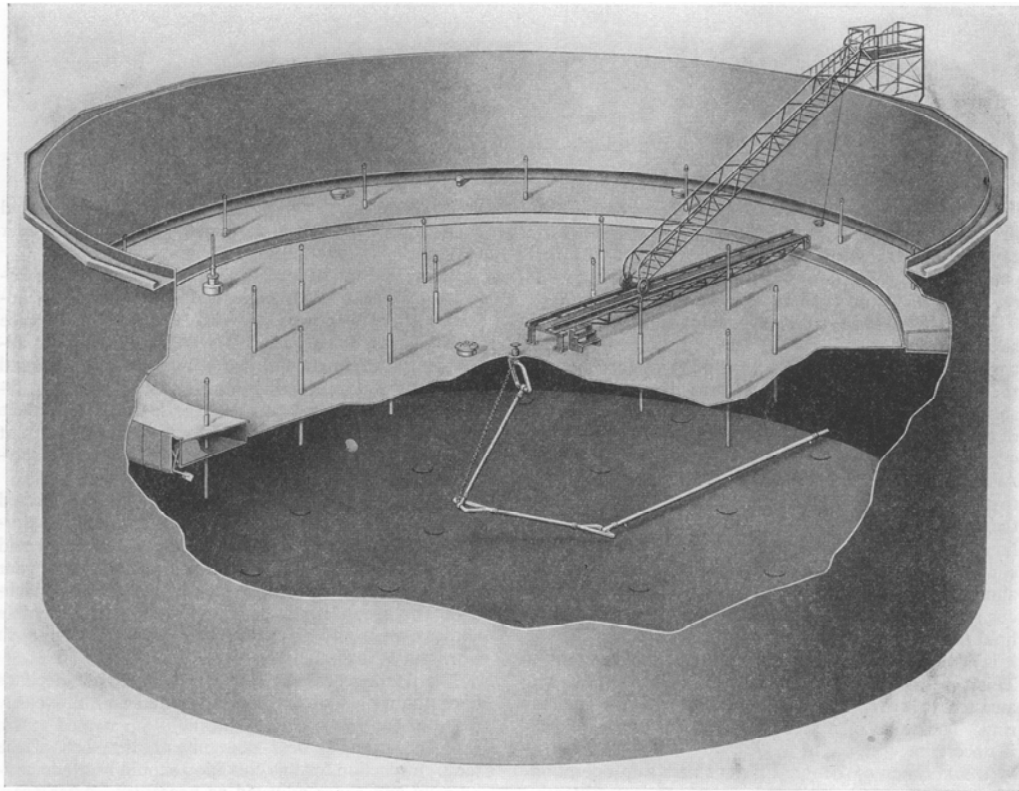


Fig-01

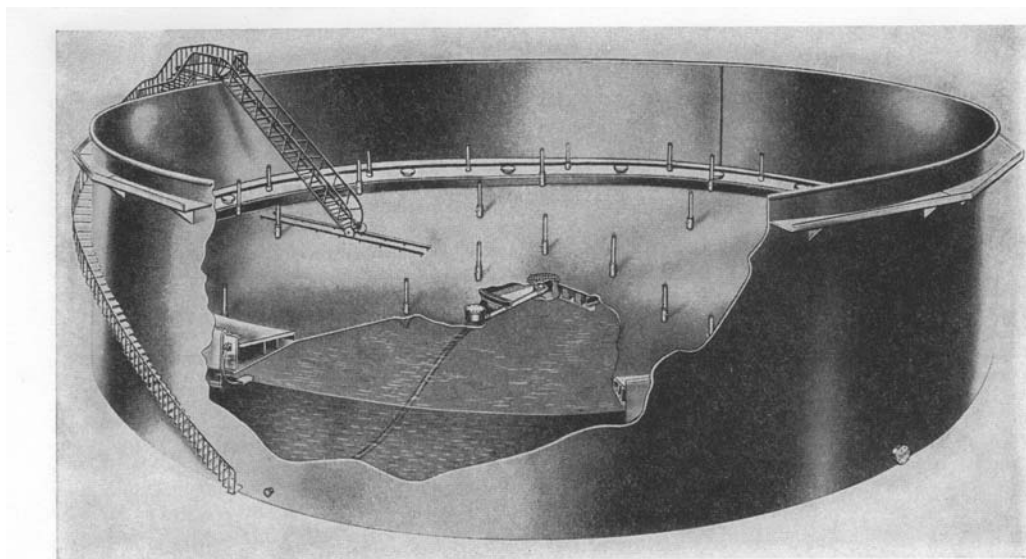


Fig-02

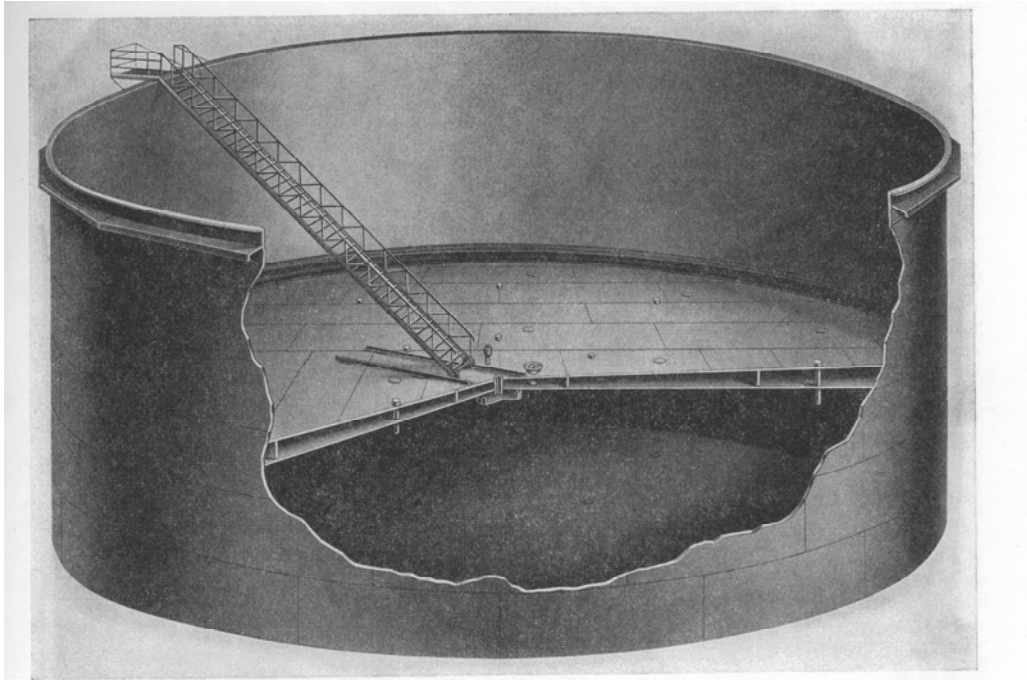


Fig-03

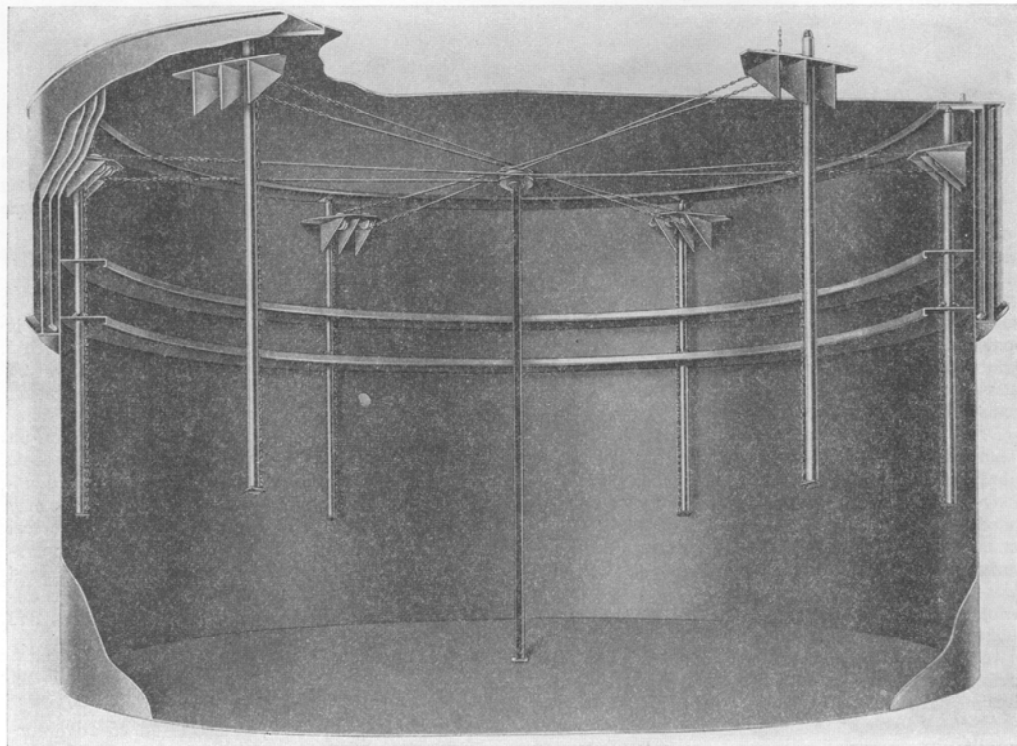


Fig-04

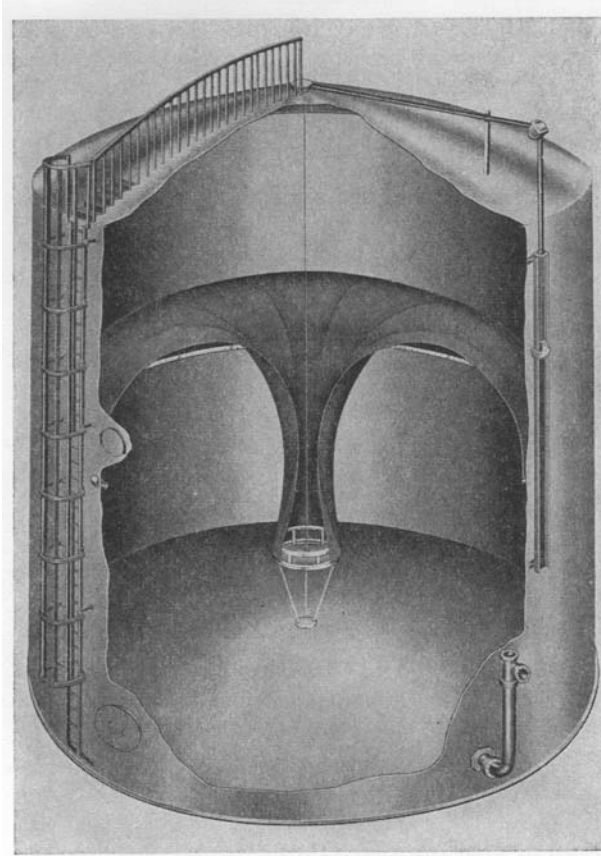


Fig-05

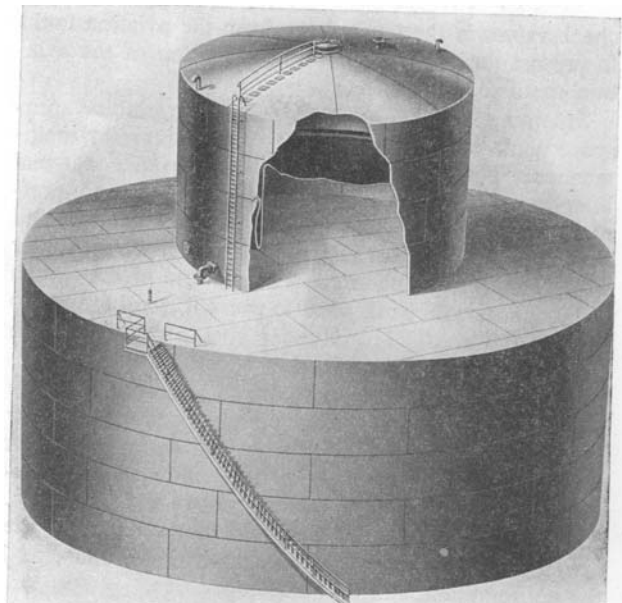


Fig-06

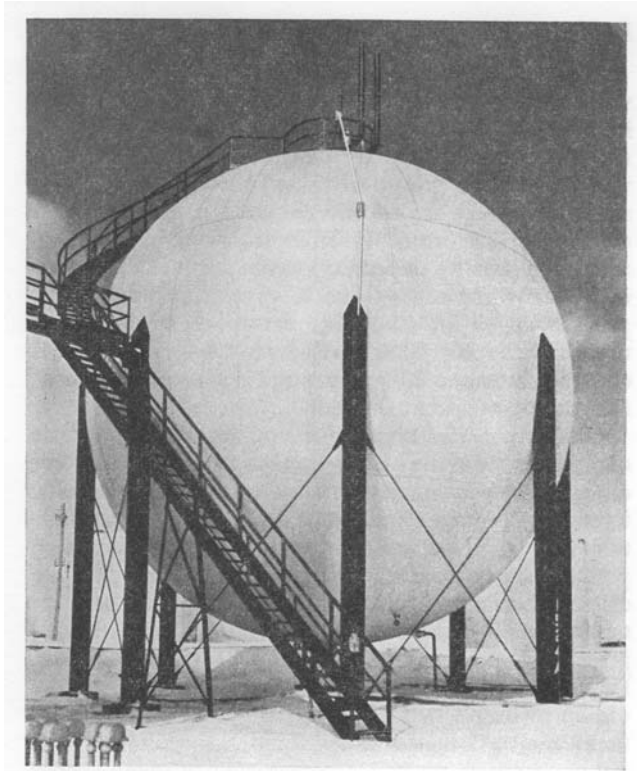


Fig-07



Pressure Vessel Thickness Calculation



Design Formulas

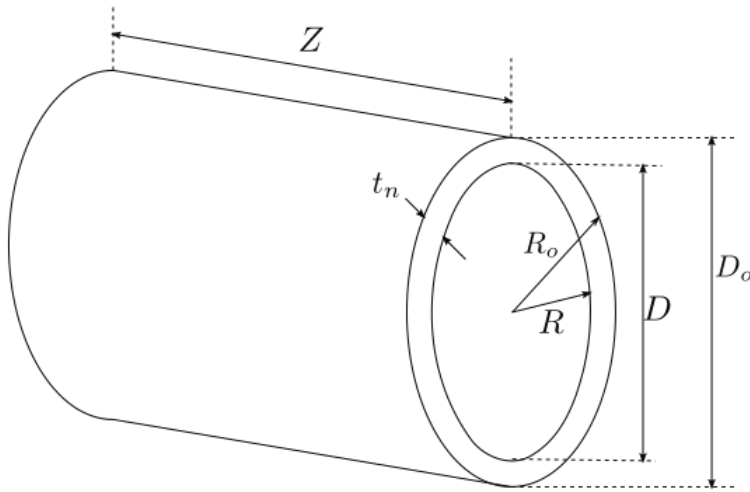
Minimum thickness requirement (UG-16)

The minimum thickness requirement of any pressure retaining component (excluding corrosion allowance) is 1.5 mm in accordance with the provisions of UG-16 i.e.

(1) 

$$t_u = 1.5mm$$

Thickness, MAWP and Volume of Cylindrical Shells



Cylindrical Shell

Thickness

The thickness required (t_c) to handle circumferential stress arising due to internal pressure (P_i) is given as:

If $P_i \leq 0.385SE$, using **UG-27(1)**

(2)¶

$$t_c = \frac{P_i R}{SE - 0.6P_i}$$

else if $P_i > 0.385SE$, using **Appendix 1-2(1)**

(3)¶

$$t_c = R \left(e^{\frac{P_i}{SE}} - 1 \right)$$

The thickness required (t_l) to handle longitudinal stress arising due to internal pressure (P_i) is given as:

If $P_i \leq 1.25SE$, using **UG-27(2)**

(4)¶

$$t_l = \frac{P_i R}{2SE + 0.4P_i}$$

else if $P_i > 1.25SE$, using **Appendix 1-2(3)**

(5)¶

$$t_l = R(\sqrt{Z} - 1)$$

where,

$$Z = \left(\frac{P_i}{SE} + 1 \right)$$

The shell thickness excluding corrosion allowance (t) is the highest of the thickness amongst t_c, t_p, t_u :

$$t = \max(t_c, t_p, t_u)$$

MAWP

The MAWP for the available thickness is determined for circumferential stress ($MAWP_c$) as:

If $t \leq \frac{R}{2}$, using **UG-27(1)**

(6)¶

$$MAWP_c = \frac{SEt}{R + 0.6t}$$

else if $t > \frac{R}{2}$, using **Appendix 1-2(2)**

(7)¶

$$MAWP_c = SE \log_e \left(\frac{R + t}{R} \right)$$

The MAWP for the available thickness is determined for longitudinal stress ($MAWP_l$) as:

If $t \leq \frac{R}{2}$, using **UG-27(2)**

(8)¶

$$MAWP_l = \frac{2SEt}{R - 0.4t}$$

else if $t > \frac{R}{2}$, using **Appendix 1-2(4)**

$$MAWP_l = SE(Z - 1)$$

where,

$$Z = \left(\frac{R + t}{R} \right)^2$$

The shell MAWP ($MAWP$) is the lowest of the MAWP amongst $MAWP_c$ and $MAWP_l$:

$$MAWP = \min(MAWP_c, MAWP_l)$$

Volume

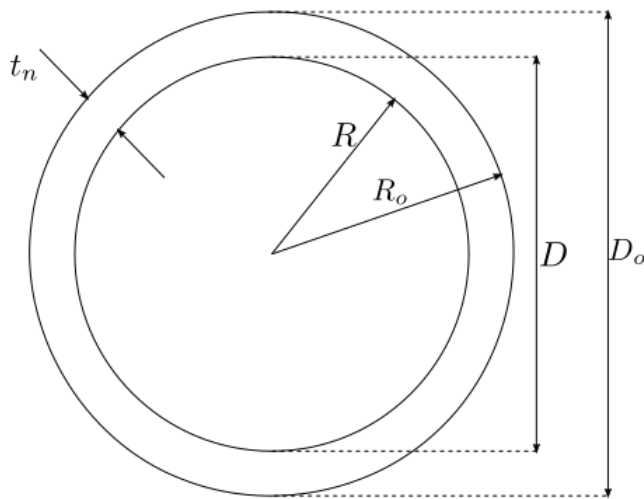
The inner volume (V) of a cylindrical shell is obtained from the following:

$$V = \pi R^2 S$$

The volume of steel (V_m) for weight computation is obtained from the following:

$$V_m = \pi S (R_o^2 - R^2)$$

Thickness, MAWP and Volume of Spherical Shells



Spherical Shell

Thickness

If $P_i \leq 0.665SE$, using **UG-27(3)**

(10)¶

$$t = \frac{P_i R}{2SE - 0.2P_i}$$

else if $P_i > 0.665SE$, using **Appendix 1-3(1)**

(11)¶

$$t = R \left(e^{\left[\frac{0.5P_i}{SE} \right]} - 1 \right)$$

MAWP

If $t \leq 0.356R$, using **UG-27(3)**

(12)¶

$$MAWP = \frac{2SEt}{R - 0.4t}$$

else if $t > 0.356R$, using **Appendix 1-3(2)**

(13)¶

$$MAWP = 2SE \log_e \left(\frac{R + t}{R} \right)$$

Volume

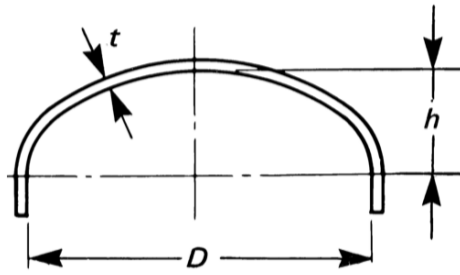
The inner volume (V) of a spherical shell is obtained from the following:

$$V = \frac{4}{3}\pi R^3$$

The volume of steel (V_m) for weight computation is obtained from the following:

$$V_m = \frac{4}{3}\pi (R_o^3 - R^3)$$

Thickness, MAWP and Volume of Ellipsoidal Head



(a) Ellipsoidal

For an ellipsoidal head the aspect ratio (β) is defined as:

(14)¶

$$\beta = \frac{D}{2h}$$

where:

h is the inner height of the head

D is the inner diameter of the head skirt

this can be used to determine the inner height (h) of the ellipsoid when the aspect ratio (β) is known:

(15)¶

$$h = \frac{D}{2\beta}$$

Factor (K) for ellipsoid is obtained as:

(16)¶

$$K = \frac{1}{6} [2 + \beta^2]$$

Thickness

Using the equation **Appendix 1-4(1)**, the thickness for ellipsoidal head is given as:

(17)¶

$$t = \frac{P_i D K}{2SE - 0.2P_i}$$

MAWP

Using the equation **Appendix 1-4(1)**, the MAWP for ellipsoidal head is given as:

$$MAWP = \frac{2SEt}{KD + 0.2t}$$

Volume

The inner volume (V) of an ellipsoidal head is obtained from the following:

$$V = \frac{2}{3}\pi R^2 h$$

The volume of steel (V_m) for weight computation is obtained from the following:

$$V_m = \frac{2}{3}\pi(R_o^2 h_o - R^2 h)$$

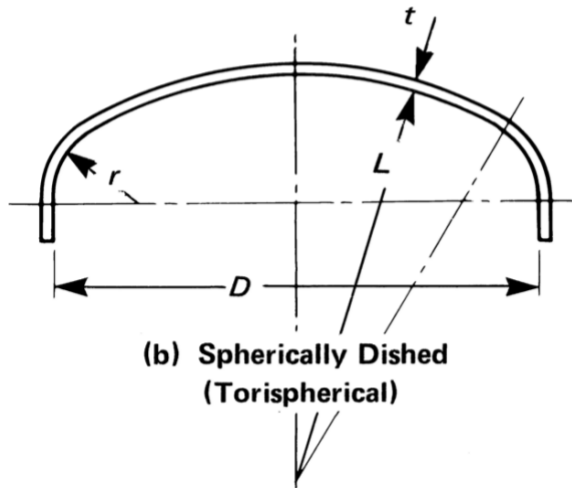
where :

$$R = \frac{D}{2}$$

$$R_o = R + t$$

$$h_o = h + t$$

Thickness, MAWP and Volume of Torispherical Head



The following relationships are applicable:

$$\text{Outer Diameter } D_o = D + 2t$$

$$\text{Outer Crown Radius } L_o = L + t$$

$$\text{Outer knuckle radius } r_o = r + t$$

Factor M for the torispherical head is obtained as:

$$M = \frac{1}{4} \left(3 + \sqrt{\frac{L}{r}} \right)$$

where :

L is the inner crown radius as shown in figure above

r is the knuckle radius as shown in figure above

Thickness

Using the equation **Appendix 1-4(3)**, the thickness for torispherical head is given as:

(18)¶

$$t = \frac{P_i LM}{2SE - 0.2P_i}$$

MAWP

Using the equation **Appendix 1-4(3)**, the MAWP for torispherical head is given as:

(19)¶

$$MAWP = \frac{2SEt}{LM + 0.2t}$$

Volume

The inner volume of the torispherical head is given by:

$$V = V(D, L, R) = \frac{\pi}{3} \left[2hL^2 - (2r^2 + c^2 + 2rL)(L - h) + 3r^2 c \sin^{-1} \left(\frac{L - h}{L - r} \right) \right]$$

where :

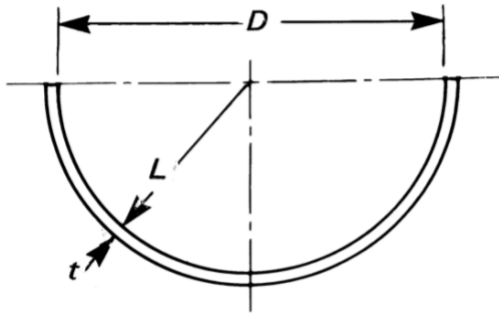
$$c = \frac{D}{2} - r$$

$$h = L - \sqrt{(r + c - L)(r - c - L)}$$

The volume of steel (V_m) for weight computation is obtained by the subtracting the inner volume of the toridome from the outer volume of the toridome:

$$V_m = V(D_o, L_o, r_o) - V(D, L, r)$$

Thickness, MAWP and Volume of Hemispherical Head



(c) Hemispherical

The following relationships are applicable:

$$\text{Inner Radius } R = \frac{D}{2}$$

$$\text{Outer Radius } R_o = R + t$$

Thickness

If $P_i \leq 0.665SE$, using **UG-27(3)**

$$t = \frac{P_i R}{2SE - 0.2P_i}$$

else if $P_i > 0.665SE$, using **Appendix 1-3(1)**

$$t = R \left(e^{\left[\frac{0.5P_i}{SE} \right]} - 1 \right)$$

MAWP

If $t \leq 0.356R$, using **UG-27(3)**

$$MAWP = \frac{2SEt}{R - 0.4t}$$

else if $t > 0.356R$, using **Appendix 1-3(2)**

$$MAWP = 2SE \log_e \left(\frac{R+t}{R} \right)$$

Volume

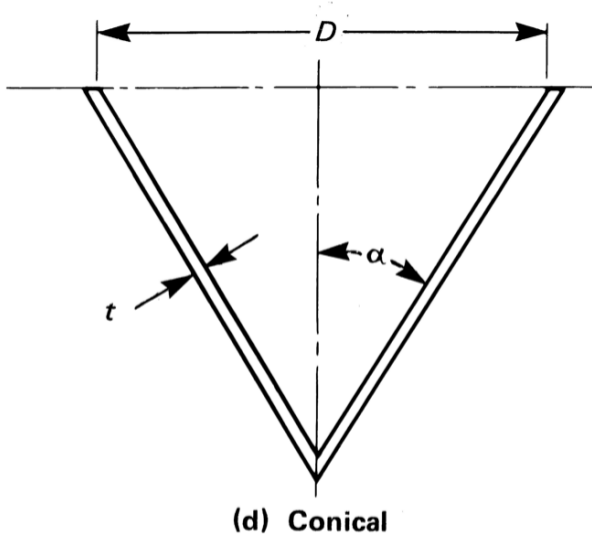
The inner volume (V) of a hemispherical shell is obtained from the following:

$$V = \frac{2}{3}\pi R^3$$

The volume of steel (V_m) for weight computation is obtained from the following:

$$V_m = \frac{2}{3}\pi(R_o^3 - R^3)$$

Thickness, MAWP and Volume of Conical Head



The following relationships are applicable:

$$\text{Inner radius } R = \frac{D}{2}$$

$$\text{Outer radius } R_o = \frac{D+2t}{2}$$

$$\text{Inner height } h = \frac{D}{2\tan\alpha}$$

$$\text{Outer height } h_o = h + t$$

Thickness

For semi apex angle, α not exceeding 30 degrees, the thickness and MAWP are obtained using the following formulas.

The thickness for conical head is obtained as :

(20)¶

$$t = \frac{P_i D}{2\cos\alpha(SE - 0.6P_i)}$$

MAWP

The MAWP for conical head is obtained as :

$$MAWP = \frac{2SEt\cos\alpha}{D + 1.2t\cos\alpha}$$

Volume

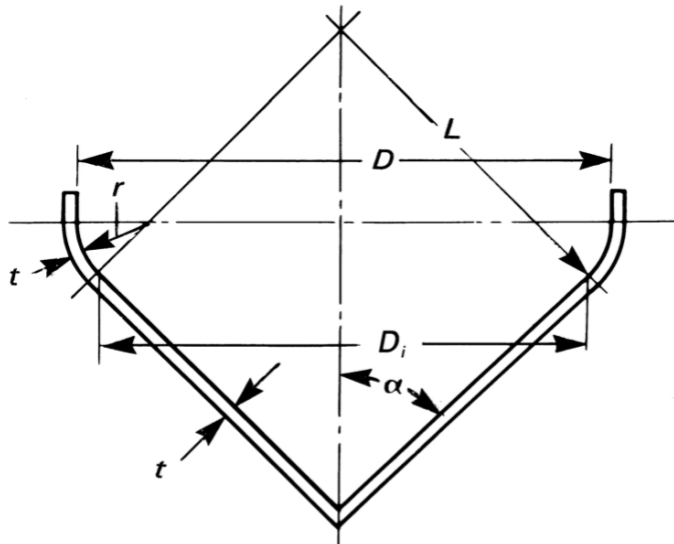
The inner volume (V) of a conical head is obtained from the following:

$$V = \frac{2}{3}\pi R^2 h$$

The volume of steel (V_m) for weight computation is obtained from the following:

$$V_m = \frac{4}{3}\pi(R_o^2 h_o - R^2 h)$$

Thickness, MAWP and Volume of Toriconical Head



(e) Toriconical
(Cone Head With Knuckle)

The following relationships are applicable:

the inside diameter of the conical portion $D_i = D - 2r(1 - \cos\alpha)$

the inner crown radius $L = \frac{D_i}{2\cos\alpha}$

Thickness

The thickness of the knuckle portion ($t_{knuckle}$) can be obtained using Appendix 1-4(3) as given in (18) above.

The thickness of the conical portion (t_{cone}) can be obtained using Appendix 1-4(5) as given in (20).

The thickness of the toricone is obtained as:

$$t = \max(t_{knuckle}, t_{cone})$$

MAWP

The MAWP of the knuckle portion ($MAWP_{knuckle}$) can be obtained using Appendix 1-4(3) as given in (19) above.

The MAWP of the conical portion ($MAWP_{cone}$) can be obtained using Appendix 1-4(5) as given in (21) above.

The MAWP of the toricone is obtained as the minimum of the two.

$$MAWP = \min(MAWP_{knuckle}, MAWP_{cone})$$

Volume

Presently the program estimates the volume of the toricone, with a cone so the equations given in conical head sections apply. In future this may change by making use of more accurate relationships.

Calculation Procedure

Shell Evaluation

Step -1 :: Determine the unknown dimensions of the vessel shell from the dimensions as provided.

If the user has provided outer diameter (D_o) of the vessel then the inner diameter (D) can be obtained as :

$$D = D_o - 2t_n$$

If the user has provided inner diameter (D) of the vessel then the outer diameter (D_o) can be obtained as :

$$D_o = D + 2t_n$$

The inner (R) and outer (R_o) radius of the shell can be determined as:

$$R = \frac{D}{2}$$
$$R_o = \frac{D_o}{2}$$

Step -2 : Establish the dimensions under corroded conditions. The dimensions as used in the formulas shall be considered after considering the removal of material on account of corrosion. This implies adding the specified corrosion allowance on the inner dimensions which are exposed to the fluid and deducting the corrosion allowance from the nominal thickness provided. Thus,

$$D_{cor} = D + 2ca$$

$$R_{cor} = R + ca$$

$$t_{cor} = t_n - ca$$

Step -3 : Based on the value of internal design temperature lookup and interpolate the allowable stress of the specified material as furnished in ASME-II Part D.

Step -4 : Establish the minimum thickness of any component required to meet the requirement of UG-16 as below.

$$t_u = 1.5mm$$

Step -5 : Calculate the thickness of the shell based on the internal design pressure i.e. t_c and t_l for cylinder and t_{sph} for sphere.

For cylindrical shell the thickness (t) shall be the maximum amongst t_c , t_l and t_u i.e.

$$t = \max(t_c, t_l, t_u)$$

For spherical shell the thickness (t) shall be the maximum amongst t_{sph} and t_u i.e.

$$t = \max(t_{sph}, t_u)$$

Step -5 : Calculate the required thickness of the shell (t_r) of the vessel shell after adding the corrosion allowance i.e. :

$$t_r = t + ca$$

The provided shell thickness (t_n) is adequate if the provided nominal thickness exceeds the required thickness (t_r):

$$t_n \geq t_r$$

Step -6 : Calculate the MAWP of the shell using the design formulas as applicable for the shell Shape (cylindrical or spherical) with the inner shell dimensions under corroded conditions. The thickness available (t_{cor}) under corroded conditions shall be used for the purpose of MAWP calculation.

Head Evaluation

Step -7 :: Determine the dimensions of the head.

It is assumed that the inner dimension of the head skirt is the same as the inner dimension of the cylindrical shell. Thus, $D_1 = D_2 = D$ and $R_1 = R_2 = \frac{D}{2}$.

The outer diameters of the head are obtained as:

$$D_{o1} = D_1 + 2t_{n1}$$

$$D_{o2} = D_2 + 2t_{n2}$$

The outer radii of the head are obtained as:

$$R_{o1} = \frac{D_{o1}}{2}$$

$$R_{o2} = \frac{D_{o2}}{2}$$

Step -8 : Determine the dimensions of the head in corroded conditions.

$$D_{cor1} = D_1 + 2ca$$

$$R_{cor1} = R_1 + ca$$

$$h_{cor1} = h_1 + ca$$

$$L_{cor1} = L_1 + ca$$

$$r_{cor1} = r_1 + ca$$

$$t_{cor1} = t_{n1} - ca$$

The relationship for head 2 are identical to the above.

Step -9 : Calculate the thickness of Head 1 (t_{h1}) and Head 2 (t_{h2}) for the internal design pressure based on the relevant formula as applicable to the head shape. The calculated thickness of the head shall be obtained by application of the provisions of UG-16 for minimum thickness i.e.

$$t_1 = \max(t_{h1}, t_u)$$

$$t_2 = \max(t_{h2}, t_u)$$

Step -10 : The required thickness of the heads (t_{r1} and t_{r2}) is obtained by adding the corrosion allowance to the calculated thickness.

$$t_{r1} = t_1 + ca$$

$$t_{r2} = t_2 + ca$$

The provided head thickness (t_{n1} / t_{n2}) is adequate if it exceeds the required thickness (t_{r1}/t_{r2}):

$$t_{n1} \geq t_{r1}$$

$$t_{n2} \geq t_{r2}$$

Step -11 : Calculate the MAWP of Head-1 ($MAWP_1$) and Head-2 ($MAWP_2$) using the design formulas as applicable for the head shape (ellipsoidal, torispherical, hemispherical, conical or toriconical) with head inner dimensions under corroded conditions. The thickness available (t_{cor1}/t_{cor2}) under corroded conditions shall be used for the purpose of MAWP calculation.

Overall MAWP and Hydrotest Pressure

Step -12 : Determine the overall MAWP of the vessel which is the least amongst the MAWP as determined for the shell and the heads.

$$MAWP = \min(MAWP_{sh}, MAWP_1, MAWP_2)$$

Step -13 : Determine the hydrotest pressure requirements as per the provisions of UG-99 (b).

$$P_t = 1.3MAWP\left(\frac{S_t}{S}\right)$$

where :

S_t is the allowable stress of the material at hydrotest temperatures.

Volumes and Weights

Step -14 :: Determine the inner volume of the shell (V_{sh}), Head-1 (V_1) and Head-2 (V_2) using the formulas as applicable to the geometry.

The volume of the vessel (V) is obtained as:

$$V = V_{sh} + V_1 + V_2$$

Step -15 :: Determine the material volume (steel volume) of the shell (V_{msh}), Head-1 (V_{m1}) and Head-2 (V_{m2}) using the formulas as applicable to the geometry. Knowing the density of steel (ρ_{steel}) the fabricated weight of the shell (W_{sh}), Head-1 (W_1) and Head-2 (W_{w2}) can be obtained as:

$$W_{sh} = \rho_{steel} * V_{msh}$$

$$W_1 = \rho_{steel} * V_{m1}$$

$$W_2 = \rho_{steel} * V_{m2}$$

The fabrication weight of the vessel is obtained as:

$$W = W_{sh} + W_1 + W_2$$

Knowing the markup weight as a percent (ζ) for additional items like vessel supports, nozzles etc. the gross fabrication weight of the vessel is obtained as:

$$W_{gross} = W(1 + \frac{\zeta}{100})$$

Knowing the density of water (ρ_{water}) the hydrotest weight of the vessel (W_t) is obtained as:

$$W_t = W_{gross} + \rho_{water}V$$

Date of Issue: July 2013

Affected Publication: API Standard 650, *Welded Tanks for Oil Storage*, Twelfth Edition, March 2013

ERRATA

This errata corrects editorial errors in the twelfth edition of API Standard 650.

Replace the following pages with the attached:

4-7

4-8

4-9

5-16

5-34

5-35

5-61

5-87

8-7

C-2

F-3

F-4

M-2

P-5

S-7

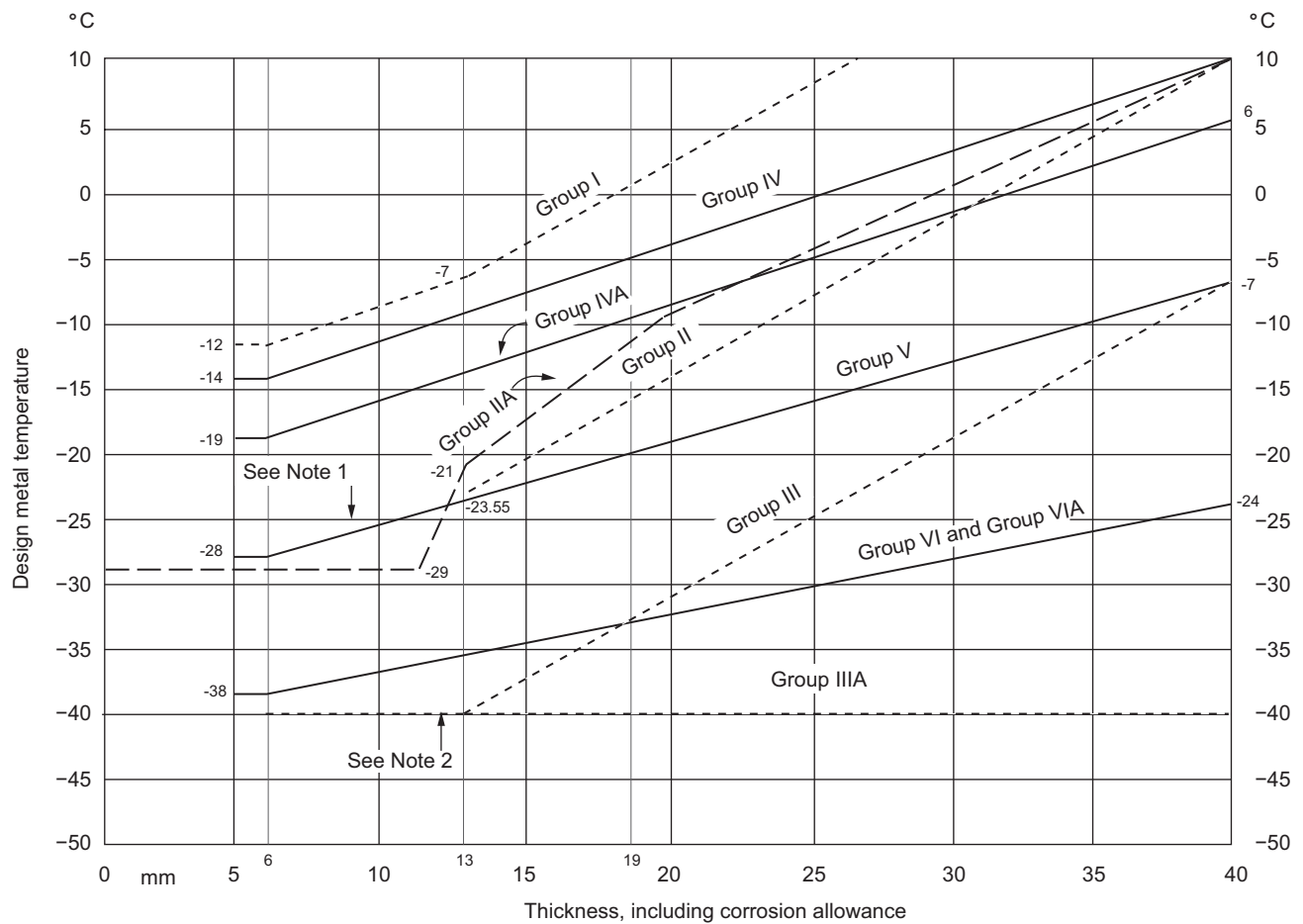
V-2

V-8

V-11

V-23

X-5



NOTE 1 The Group II and Group V lines coincide at thicknesses less than 13 mm.

NOTE 2 The Group III and Group IIIA lines coincide at thicknesses less than 13 mm.

NOTE 3 The materials in each group are listed in Table 4.4a and Table 4.4b.

NOTE 4 **Deleted.**

NOTE 5 Use the Group IIA and Group VIA curves for pipe and flanges (see 4.5.4.2 and 4.5.4.3).

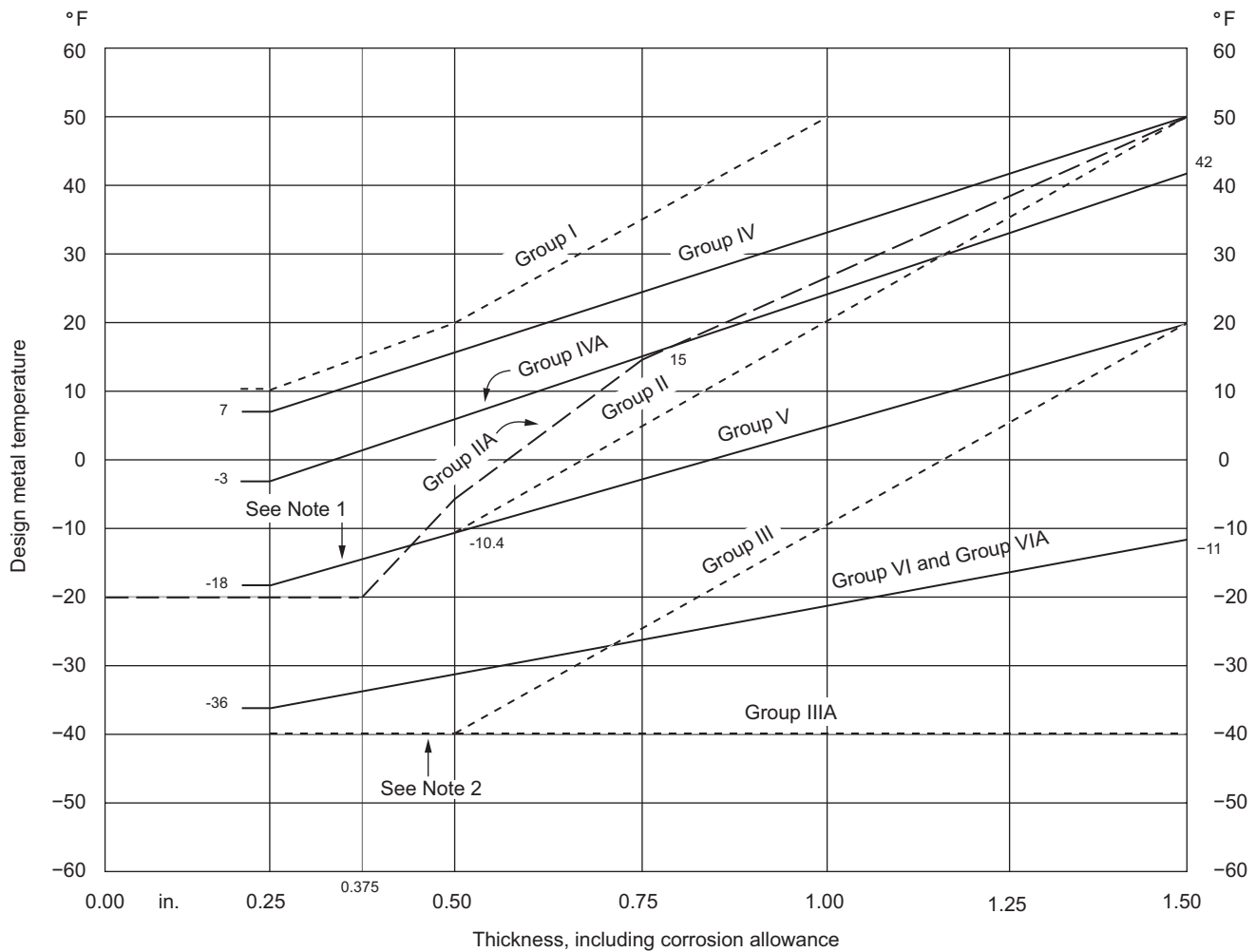
NOTE 6 Linear equations provided in Table 4.3a can be used to calculate Design Metal Temperature (DMT) for each API material group and the thickness range.

Figure 4.1a—Minimum Permissible Design Metal Temperature for Materials Used in Tank Shells without Impact Testing (SI)

(normalized, normalized and tempered, or quenched and tempered), notch toughness shall be demonstrated on each plate as heat treated when 4.2.11.2 requirements are specified. Isothermal lines of lowest one-day mean temperature are shown in Figure 4.2.

4.2.10.4 Plate used to reinforce shell openings and insert plates shall be of the same material as the shell plate to which they are attached or shall be of any appropriate material listed in Table 4.4a, Table 4.4b, Figure 4.1a, and Figure 4.1b. Except for nozzle and manway necks, the material shall be of equal or greater yield and tensile strength and shall be compatible with the adjacent shell material (see 4.2.10.1 and 5.7.2.3, Item d).

4.2.10.5 The requirements in 4.2.10.4 apply only to shell nozzles and manholes. Materials for roof nozzles and manholes do not require special toughness.



NOTE 1 The Group II and Group V lines coincide at thicknesses less than $\frac{1}{2}$ in.

NOTE 2 The Group III and Group IIIA lines coincide at thicknesses less than $\frac{1}{2}$ in.

NOTE 3 The materials in each group are listed in Table 4.4a and Table 4.4b.

NOTE 4 Deleted.

NOTE 5 Use the Group IIA and Group VIA curves for pipe and flanges (see 4.5.4.2 and 4.5.4.3).

NOTE 6 Linear equations provided in Table 4.3b can be used to calculate Design Metal Temperature (DMT) for each API material group and the thickness range.

Figure 4.1b—Minimum Permissible Design Metal Temperature for Materials Used in Tank Shells without Impact Testing (USC)

4.2.11 Toughness Procedure

4.2.11.1 When a material's toughness must be determined, it shall be done by one of the procedures described in 4.2.11.2, 4.2.11.3, and 4.2.11.4, as specified in 4.2.10.

4.2.11.2 Each plate as rolled or heat treated shall be impact tested in accordance with 4.2.9 at or below the design metal temperature to show Charpy V-notch longitudinal (or transverse) values that fulfill the minimum requirements of Table 4.5a and Table 4.5b (see 4.2.9 for the minimum values for one specimen and for subsize specimens). As used here, the term plate as rolled refers to the unit plate rolled from a slab or directly from an ingot in its relation to the location and number of specimens, not to the condition of the plate.

Table 4.3a—Linear Equations for Figure 4.1a (SI)

API Group #	Thickness Range	Equation
I	$6 \leq X < 13$	$Y = 0.714X - 16.286$
I	$13 \leq X \leq 25$	$Y = 1.417X - 25.417$
II	$6 \leq X < 13$	$Y = 0.634X - 31.81$
II	$13 \leq X \leq 40$	$Y = 1.243X - 39.72$
IIA	$10 \leq X < 13$	$Y = 2.667X - 55.667$
IIA	$13 \leq X \leq 19$	$Y = 2X - 47$
IIA	$19 \leq X \leq 40$	$Y = 0.905X - 26.19$
III	$6 \leq X \leq 13$	$Y = -40$
III	$13 \leq X \leq 40$	$Y = 1.222X - 55.89$
IIIA	$6 \leq X \leq 40$	$Y = -40$
IV	$6 \leq X \leq 40$	$Y = 0.7059X - 18.235$
IVA	$6 \leq X \leq 40$	$Y = 0.7353X - 23.412$
V	$6 \leq X \leq 40$	$Y = 0.6176X - 31.71$
VI, VIA	$6 \leq X \leq 40$	$Y = 0.4112X - 40.471$
Y = Design Metal Temperature (°C) X = Thickness including corrosion (mm)		

Table 4.3b—Linear Equations for Figure 4.1b (USC)

API Group #	Thickness Range	Equation
I	$0.25 \leq X < 0.5$	$Y = 40X$
I	$0.5 \leq X \leq 1.0$	$Y = 60X - 10$
II	$0.25 \leq X < 0.5$	$Y = 30.4X - 25.6$
II	$0.5 \leq X \leq 1.5$	$Y = 60.4X - 40.6$
IIA	$0.375 \leq X < 0.5$	$Y = 120X - 65$
IIA	$0.5 \leq X \leq 0.75$	$Y = 80X - 45$
IIA	$0.75 \leq X \leq 1.5$	$Y = 46.667X - 20$
III	$0.25 \leq X \leq 0.5$	$Y = -40$
III	$0.5 \leq X \leq 1.5$	$Y = 60X - 70$
IIIA	$0.25 \leq X \leq 1.5$	$Y = -40$
IV	$0.25 \leq X \leq 1.5$	$Y = 34.4X - 1.6$
IVA	$0.25 \leq X \leq 1.5$	$Y = 36X - 12$
V	$0.25 \leq X \leq 1.5$	$Y = 30.4X - 25.6$
VI, VIA	$0.25 \leq X \leq 1.5$	$Y = 20X - 41$
Y = Design Metal Temperature (°F) X = Thickness including corrosion (in.)		

4.2.11.3 For plate in the as-rolled condition, the thickest plate from each heat shall be impact tested. For TMCP material, each plate-as-rolled shall be impact tested. Impact testing shall be in accordance with 4.2.9 and shall fulfill the impact requirements of 4.2.11.2 at the design metal temperature.

- **4.2.11.4** The Manufacturer shall submit to the Purchaser test data for plates of the material demonstrating that based on past production from the same mill, the material has provided the required toughness at the design metal temperature.

4.3 Sheets

Sheets for fixed and floating roofs shall conform to ASTM A1011M, Grade 33. They shall be made by the open-hearth or basic oxygen process. Copper-bearing steel shall be used if specified on the purchase order. Sheets may be ordered on either a weight or a thickness basis, at the option of the tank Manufacturer.

4.4 Structural Shapes

4.4.1 Structural steel shall conform to one of the following:

- ASTM A36M/A36.
- ASTM A131M/A131.
- ASTM A992M/A992.

Table 5.1a—Annular Bottom-Plate Thicknesses (t_b) (SI)

Plate Thickness ^a of First Shell Course (mm)	Stress ^b in First Shell Course (MPa)			
	≤ 190	≤ 210	≤ 220	≤ 250
$t \leq 19$	6	6	7	9
$19 < t \leq 25$	6	7	10	11
$25 < t \leq 32$	6	9	12	14
$32 < t \leq 40$	8	11	14	17
$40 < t \leq 45$	9	13	16	19

^a Plate thickness refers to the corroded shell plate thickness for product design and nominal thickness for hydrostatic test design.

^b The stress to be used is the maximum stress in the first shell course (greater of product or hydrostatic test stress). The stress may be determined using the required thickness divided by the thickness from “a” then multiplied by the applicable allowable stress:

Product Stress = $((t_d - CA) / \text{corroded } t) (S_d)$

Hydrostatic Test Stress = $(t_t / \text{nominal } t) (S_t)$

NOTE The thicknesses specified in the table, as well as the width specified in 5.5.2, are based on the foundation providing uniform support under the full width of the annular plate. Unless the foundation is properly compacted, particularly at the inside of a concrete ringwall, settlement will produce additional stresses in the annular plate.

Table 5.1b—Annular Bottom-Plate Thicknesses (t_b) (USC)

Plate Thickness ^a of First Shell Course (in.)	Stress ^b in First Shell Course (lbf/in. ²)			
	≤ 27,000	≤ 30,000	≤ 32,000	≤ 36,000
$t \leq 0.75$	0.236	0.236	$9/32$	$11/32$
$0.75 < t \leq 1.00$	0.236	$9/32$	$3/8$	$7/16$
$1.00 < t \leq 1.25$	0.236	$11/32$	$15/32$	$9/16$
$1.25 < t \leq 1.50$	$5/16$	$7/16$	$9/16$	$11/16$
$1.50 < t \leq 1.75$	$11/32$	$1/2$	$5/8$	$3/4$

^a Plate thickness refers to the corroded shell plate thickness for product design and nominal thickness for hydrostatic test design.

^b The stress to be used is the maximum stress in the first shell course (greater of product or hydrostatic test stress). The stress may be determined using the required thickness divided by the thickness from “a” then multiplied by the applicable allowable stress:

Product Stress = $((t_d - CA) / \text{corroded } t) (S_d)$

Hydrostatic Test Stress = $(t_t / \text{nominal } t) (S_t)$

NOTE The thicknesses specified in the table, as well as the width specified in 5.5.2, are based on the foundation providing uniform support under the full width of the annular plate. Unless the foundation is properly compacted, particularly at the inside of a concrete ringwall, settlement will produce additional stresses in the annular plate.

500 mm (20 in.) and 600 mm (24 in.) shell manholes: twenty-eight 20 mm-diameter ($\frac{3}{4}$ in.) bolts in 23 mm ($\frac{7}{8}$ in.) holes
 750 mm (30 in.) and 900 mm (36 in.) shell manholes: forty-two 20 mm-diameter ($\frac{3}{4}$ in.) bolts in 23 mm ($\frac{7}{8}$ in.) holes
 (Bolt holes shall straddle the flange vertical centerline.)

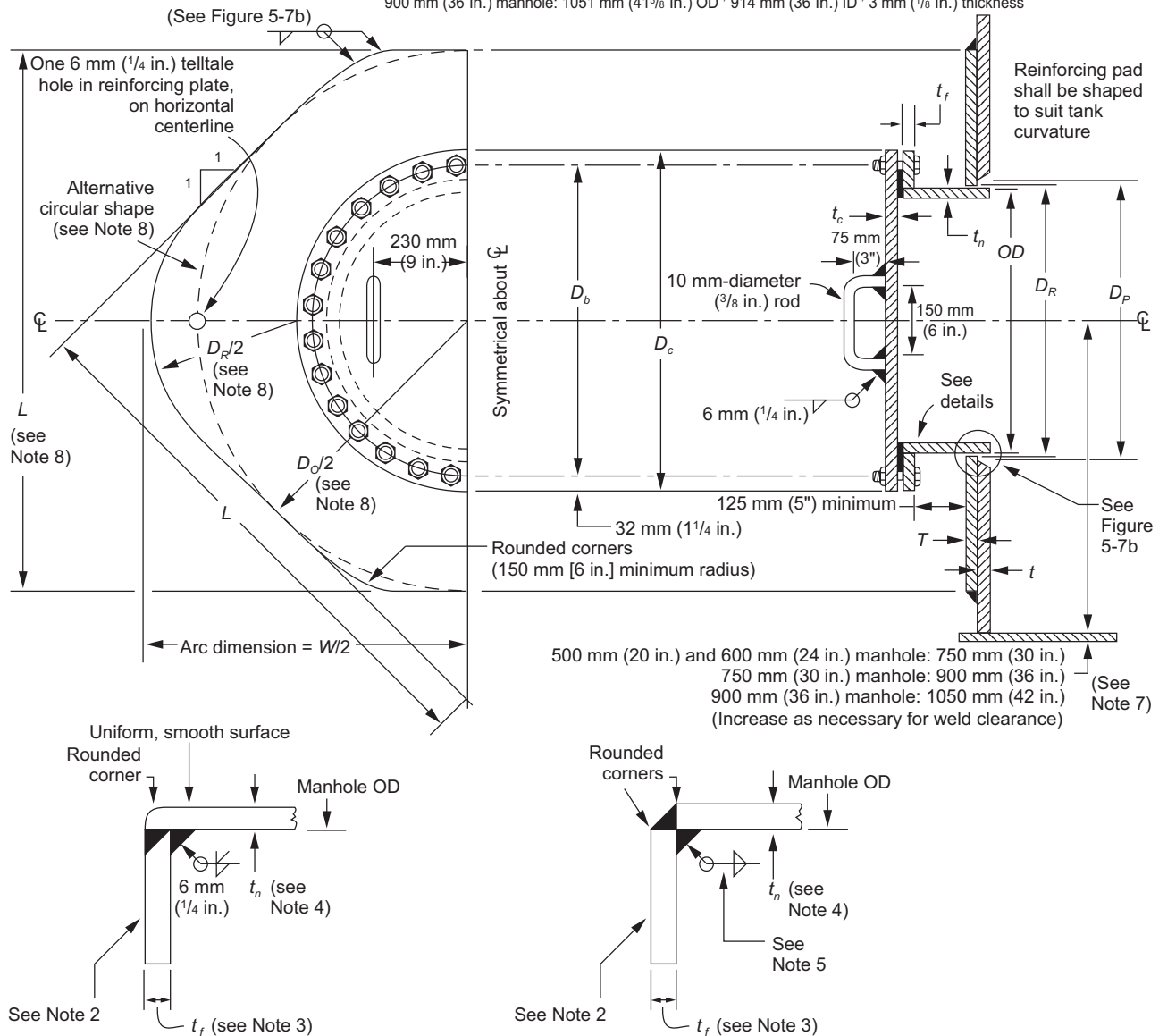
Gasket (see Note 1):

500 mm (20 in.) manhole: 645 mm ($25\frac{3}{8}$ in.) OD ' 508 mm (20 in.) ID ' 3 mm ($\frac{1}{8}$ in.) thickness

600 mm (24 in.) manhole: 746 mm ($29\frac{3}{8}$ in.) OD ' 610 mm (24 in.) ID ' 3 mm ($\frac{1}{8}$ in.) thickness

750 mm (30 in.) manhole: 899 mm ($35\frac{3}{8}$ in.) OD ' 762 mm (30 in.) ID ' 3 mm ($\frac{1}{8}$ in.) thickness

900 mm (36 in.) manhole: 1051 mm ($41\frac{3}{8}$ in.) OD ' 914 mm (36 in.) ID ' 3 mm ($\frac{1}{8}$ in.) thickness



500 mm (20 in.) and 600 mm (24 in.) manhole: 750 mm (30 in.)
 750 mm (30 in.) manhole: 900 mm (36 in.)
 900 mm (36 in.) manhole: 1050 mm (42 in.)
 (Increase as necessary for weld clearance)

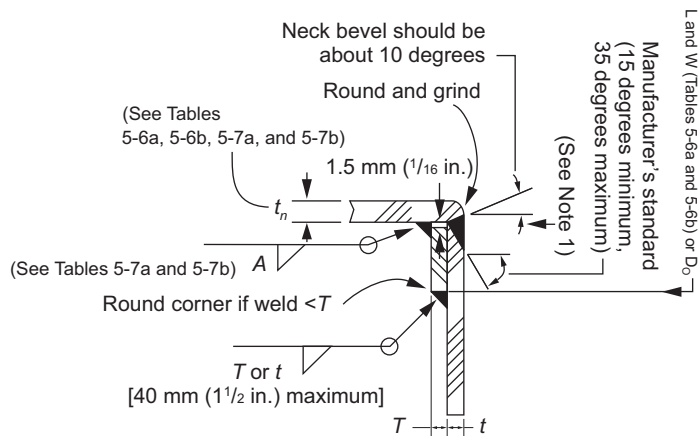
NOTES

1. Gasket material shall be specified by the Purchaser. See 5.7.5.4.
2. The gasketed face shall be machine-finished to provide a minimum gasket-bearing width of 19 mm ($\frac{3}{4}$ in.).
3. See Table 5.3a and Table 5.3b.
4. See Table 5.4a and Table 5.4b.
5. The size of the weld shall equal the thickness of the thinner member joined.
6. The shell nozzles shown in Figure 5.8 may be substituted for manholes.

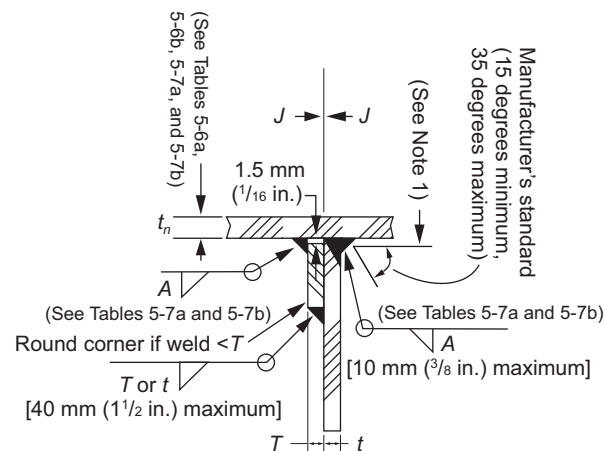
7. The minimum centerline elevations allowed by Table 5.6a, Table 5.6b, and Figure 5.6 may be used when approved by the Purchaser.
8. For dimensions for OD, D_R, D_O, L, and W, see Table 5.6a and Table 5.6b, Columns 2, 4, 5, and 6. For Dimension D_P see Table 5.7a and Table 5.7b, Column 3.
9. At the option of the Manufacturer, the manhole ID may be set to the OD dimension listed in Table 5.6a and Table 5.6b, Column 2. Reinforcement area and weld spacing must meet 5.7.2 and 5.7.3 requirements respectively.

Figure 5.7a—Shell Manhole

Nozzle

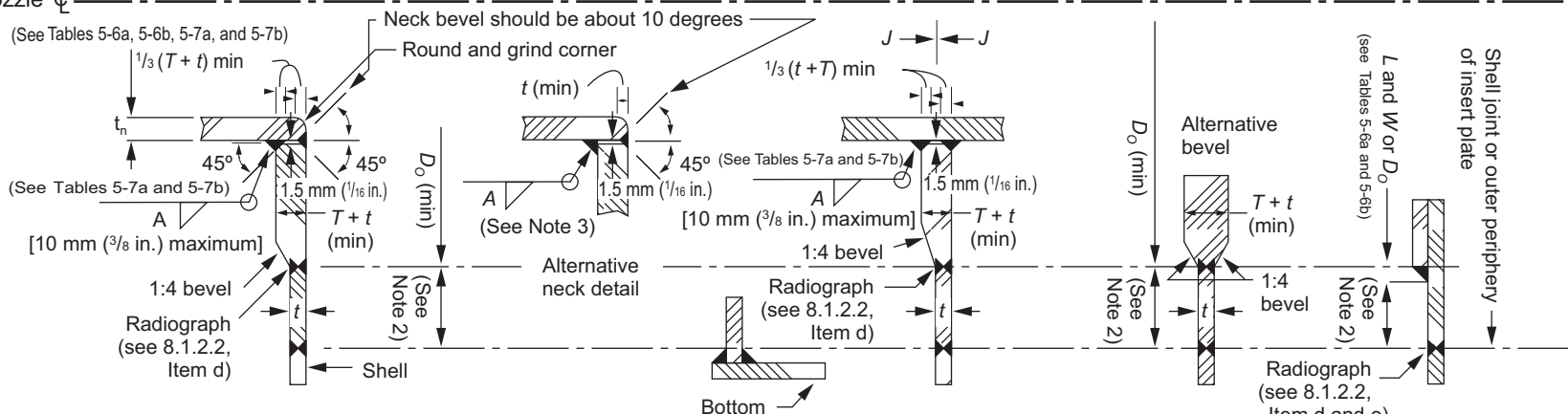


Manhole or Nozzle



Nozzle

Nozzle



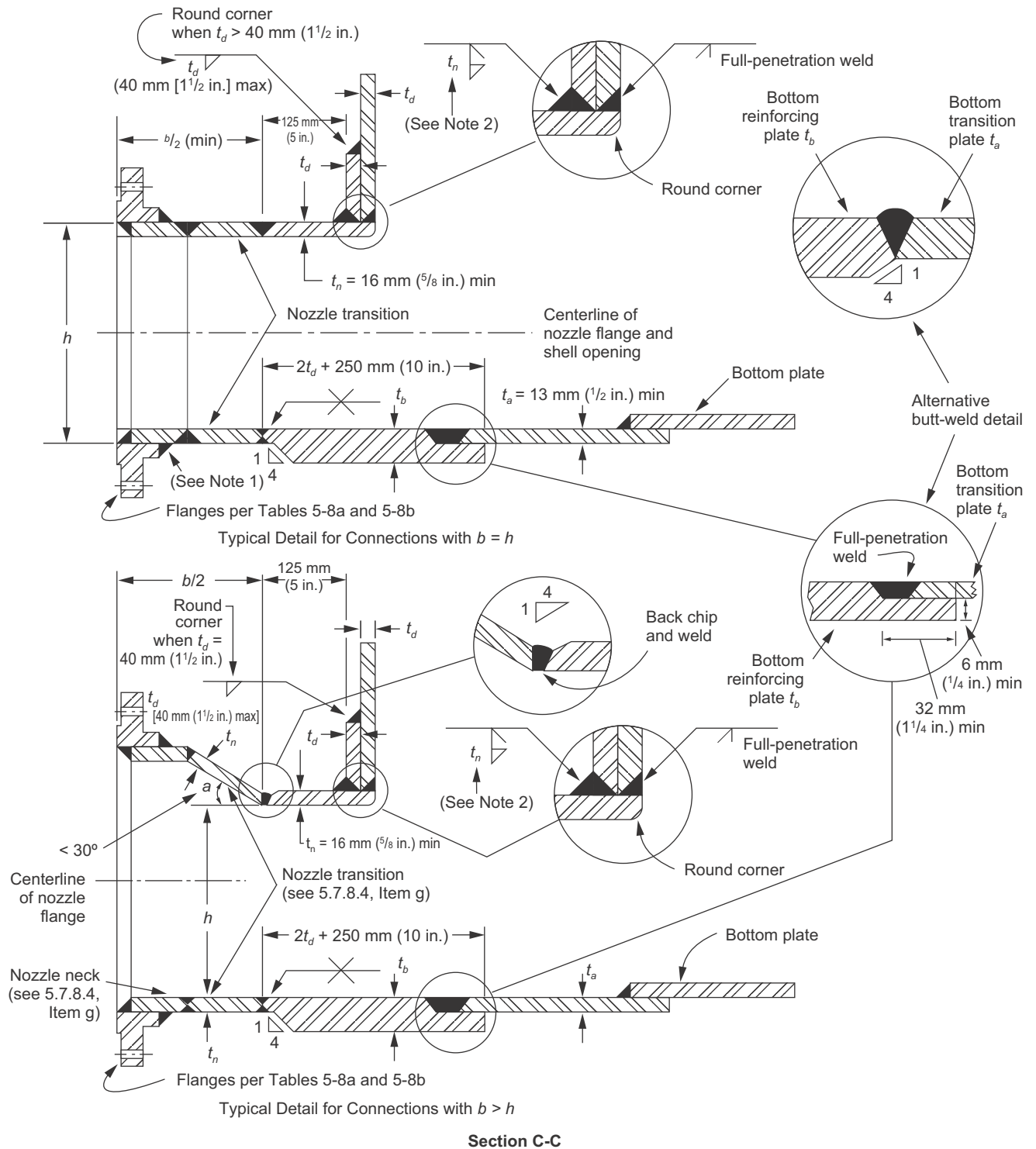
Insert-type Reinforcement for Manholes and Nozzles

Notes:

1. See Table 5.7a and Table 5.7b, Column 3, for the shell cutout, which shall not be less than the outside diameter of the neck plus 13 mm ($1/2$) in.
2. See 5.7.3 for minimum spacing of welds at opening connections.
3. The weld size shall be either A (from Table 5.7a and Table 5.7b, based on t) or t_n (minimum neck thickness from Table 5.4a, Table 5.4b, Table 5.6a, Table 5.6b, Table 5.7a and Table 5.7b), whichever is greater.

4. Other permissible insert details are shown in Figure 5.8 of API Standard 620. The reinforcement area shall conform to 5.7.2.
5. Dimensions and weld sizes that are not shown are the same as those given in Figure 5.7a and Table 5.4a through Table 5.8b.
6. Details of welding bevels may vary from those shown if agreed to by the Purchaser.

Figure 5.7b—Details of Shell Manholes and Nozzles



Note 1: Flange weld sizes shall be the smaller of the available hub material for t_n .

Note 2: Thickness of thinner plate joined 13 mm ($\frac{1}{2} \text{ in.}$) maximum.

Figure 5.14—Flush-type Shell Connection (Continued)

In USC units:

$$t_b = \frac{h^2}{14,000} + \frac{b}{310} \sqrt{HG} + CA$$

where

t_b is the minimum thickness of the bottom reinforcing plate, in inches;

h is the vertical height of clear opening, in inches;

b is the horizontal width of clear opening, in inches;

H is the maximum design liquid level (see 5.6.3.2), in feet;

G is the specific gravity, not less than 1.0.

The minimum value of t_b shall be:

16 mm ($5/8$ in.) for $HG \leq 14.4$ m (48 ft)

17 mm ($11/16$ in.) for 14.4 m (48 ft) $< HG \leq 16.8$ m (56 ft)

19 mm ($3/4$ in.) for 16.8 m (56 ft) $< HG \leq 19.2$ m (64 ft)

- g) The corroded thickness of the nozzle neck and transition piece, t_n , shall be not less than 16 mm ($5/8$ in.). External loads applied to the connection may require t_n to be greater than 16 mm ($5/8$ in.).

5.7.8.5 All materials in the flush-type shell connection assembly shall conform to the requirements in Section 4. The material of the shell plate in the connection assembly, the shell reinforcing plate, the nozzle neck attached to the shell, the transition piece, and the bottom reinforcing plate shall conform to 4.2.9 and Figure 4.1 for the respective thickness involved at the design metal temperature for the tank. The notch toughness of the bolting flange and the nozzle neck attached to the bolting flange shall be based on the governing thickness as defined in 4.5.5.3 and used in Figure 4.1. Additionally, the yield strength and the tensile strength of the shell plate at the flush-type shell connection and the shell reinforcing plate shall be equal to, or greater than, the yield strength and the tensile strength of the adjacent lowest shell course plate material.

5.7.8.6 The nozzle transition between the flush connection in the shell and the circular pipe flange shall be designed in a manner consistent with the requirements of this standard. Where this standard does not cover all details of design and construction, the Manufacturer shall provide details of design and construction that will be as safe as the details provided by this standard.

5.7.8.7 Where anchoring devices are required by Annex E and Annex F to resist shell uplift, the devices shall be spaced so that they will be located immediately adjacent to each side of the reinforcing plates around the opening.

5.7.8.8 Adequate provision shall be made for free movement of connected piping to minimize thrusts and moments applied to the shell connection. Allowance shall be made for the rotation of the shell connection caused by the restraint of the tank bottom-to-shell expansion from stress and temperature as well as for the thermal and elastic movement of the piping. Rotation of the shell connection is shown in Figure 5.15.

5.7.8.9 The foundation in the area of a flush-type connection shall be prepared to support the bottom reinforcing plate of the connection. The foundation for a tank resting on a concrete ringwall shall provide uniform support for both the bottom reinforcing plate and the remaining bottom plate under the tank shell. Different methods of supporting the bottom reinforcing plate under a flush-type connection are shown in Figure 5.13.

- d) A **self-supporting umbrella roof** is a modified dome roof formed so that any horizontal section is a regular polygon with as many sides as there are roof plates that is supported only at its periphery.

5.10.2 General

5.10.2.1 Loads: All roofs and supporting structures shall be designed for load combinations (a), (b), (c), (e), (f), and (g).

- **5.10.2.2 Roof Plate Thickness:** Roof plates shall have a nominal thickness of not less than 5 mm (³/₁₆ in.) or 7-gauge sheet. Increased thickness may be required for supported cone roofs (see 5.10.4.4). Any required corrosion allowance for the plates of self-supporting roofs shall be added to the calculated thickness unless otherwise specified by the Purchaser. Any corrosion allowance for the plates of supported roofs shall be added to the greater of the calculated thickness or the minimum thickness or [5 mm (³/₁₆ in.) or 7-gauge sheet]. For frangible roof tanks, where a corrosion allowance is specified, the design must have frangible characteristics in the nominal (uncorroded) condition.

5.10.2.3 Structural Member Attachment: Roof plates of supported cone roofs shall not be attached to the supporting members unless otherwise approved by the Purchaser. Continuously attaching the roof to cone supporting members may be beneficial when interior lining systems are required, however, the tank roof cannot be considered frangible (see 5.10.2.6).

- **5.10.2.4 Structural Member Thickness:** All internal and external structural members shall have a minimum nominal thickness (new) of 4.3 mm (0.17 in.), and a minimum corroded thickness of 2.4 mm (0.094 in.), respectively, in any component, except that the minimum nominal thickness shall not be less than 6 mm (0.236 in.) for columns which by design normally resist axial compressive forces.

5.10.2.5 Top Attachment: Roof plates shall be attached to the top angle of the tank with a continuous fillet weld on the top side.

- **5.10.2.6 Frangible Roof:** A roof is considered frangible (see 5.8.5 for emergency venting requirement) if the roof-to-shell joint will fail prior to the shell-to-bottom joint in the event of excessive internal pressure. When a Purchaser specifies a tank with a frangible roof, the tank design shall comply with a, b, c, or d, of the following:

a) For tanks 15 m (50 ft) in diameter or greater, the tank shall meet all of the following.

- 1) The slope of the roof at the top angle attachment does not exceed 2:12.
- 2) The roof support members shall not be attached to the roof plate.
- 3) The roof is attached to the top angle with a single continuous fillet weld on the top side (only) that does not exceed 5 mm (³/₁₆ in.). No underside welding of roof to top angle (including seal welding) is permitted.
- 4) The roof-to-top angle compression ring is limited to details a through e in Figure F-2.
- 5) All members in the region of the roof-to-shell joint, including insulation rings, are considered as contributing to the roof-to-shell joint cross-sectional area (A) and this area is less than the limit shown below:

$$A = \frac{D_{LS}}{2\pi F_y \tan \theta}$$

NOTE The terms for this equation are defined in Annex F.

The top angle size required by 5.1.5.9.e may be reduced in size if required to meet the cross sectional area limit.

The reinforcement need not be removed except to the extent that it exceeds the maximum acceptable thickness or unless its removal is required by 8.1.3.4 for radiographic examination.

8.5.3 A weld that fails to meet the criteria given in 8.5.1 shall be reworked before hydrostatic testing as follows:

- a) Any defects shall be removed by mechanical means or thermal gouging processes. Arc strikes discovered in or adjacent to welded joints shall be repaired by grinding and rewelding as required. Arc strikes repaired by welding shall be ground flush with the plate.
- b) Rewelding is required if the resulting thickness is less than the minimum required for design or hydrostatic test conditions. All defects in areas thicker than the minimum shall be feathered to at least a 4:1 taper.
- c) The repair weld shall be visually examined for defects.

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8.6 Vacuum Testing

8.6.1 Vacuum testing is performed using a testing box approximately 150 mm (6 in.) wide by 750 mm (30 in.) long with a clear window in the top, which provides proper visibility to view the area under examination. During testing, illumination shall be adequate for proper evaluation and interpretation of the test. The open bottom shall be sealed against the tank surface by a suitable gasket. Connections, valves, lighting and gauges, as required, shall be provided. A soap film solution or commercial leak detection solution, applicable to the conditions, shall be used.

8.6.2 Vacuum testing shall be performed in accordance with a written procedure prepared by the Manufacturer of the tank. The procedure shall require:

- a) performing a visual examination of the bottom and welds prior to performing the vacuum-box test;
 - b) verifying the condition of the vacuum box and its gasket seals;
 - c) verifying that there is no quick bubble or spitting response to large leaks; and
 - d) applying the film solution to a dry area, such that the area is thoroughly wetted and a minimum generation of application bubbles occurs.
- **8.6.3** A partial vacuum of 21 kPa (3 lbf/in.², 6 in. Hg) to 35 kPa (5 lbf/in.², 10 in. Hg) gauge shall be used for the test. If specified by the Purchaser, a second partial vacuum test of 56 kPa (8 lbf/in.², 16 in. Hg) to 70 kPa (10 lbf/in.², 20 in. Hg) shall be performed for the detection of very small leaks.

8.6.4 The Manufacturer shall determine that each vacuum-box operator meets the following requirements:

- a) has vision (with correction, if necessary) to be able to read a Jaeger Type 2 standard chart at a distance of not less than 300 mm (12 in.). Operators shall be checked annually to ensure that they meet this requirement; and
- b) is competent in the technique of the vacuum-box testing, including performing the examination and interpreting and evaluating the results; however, where the examination method consists of more than one operation, the operator performing only a portion of the test need only be qualified for that portion the operator performs.

8.6.5 The vacuum-box test shall have at least 50 mm (2 in.) overlap of previously viewed surface on each application.

8.6.6 The metal surface temperature limits shall be between 4 °C (40 °F) and 52 °C (125 °F), unless the film solution is proven to work at temperatures outside these limits, either by testing or Manufacturer's recommendations.

8.6.7 A minimum light intensity of 1000 Lux (100 fc) at the point of examination is required during the application of the examination and evaluation for leaks.

8.6.8 The vacuum shall be maintained for the greater of either at least 5 seconds or the time required to view the area under test.

8.6.9 The presence of a through-thickness leak indicated by continuous formation or growth of a bubble(s) or foam, produced by air passing through the thickness, is unacceptable. The presence of a large opening leak, indicated by a quick bursting bubble or spitting response at the initial setting of the vacuum box is unacceptable. Leaks shall be repaired and retested.

- **8.6.10** A record or report of the test including a statement addressing temperature and light intensity shall be completed and furnished to the Purchaser upon request.
- **8.6.11** As an alternate to vacuum-box testing, a suitable tracer gas and compatible detector can be used to test the integrity of welded bottom joints for their entire length. Where tracer gas testing is employed as an alternate to vacuum-box testing, it shall meet the following requirements:
 - a) Tracer gas testing shall be performed in accordance with a written procedure which has been reviewed and approved by the Purchaser and which shall address as a minimum: the type of equipment used, surface cleanliness, type of tracer gas, test pressure, soil permeability, soil moisture content, satisfactory verification of the extent of tracer gas permeation, and the method or technique to be used including scanning rate and probe standoff distance.
 - b) The technique shall be capable of detecting leakage of 1×10^{-4} Pa m³/s (1×10^{-3} std cm³/s) or smaller.
 - c) The test system parameters (detector, gas, and system pressure, i.e., level of pressure under bottom) shall be calibrated by placing the appropriate calibrated capillary leak, which will leak at a rate consistent with (b) above, in a temporary or permanent fitting in the tank bottom away from the tracer gas pressurizing point. Alternatively, by agreement between the Purchaser and the Manufacturer, the calibrated leak may be placed in a separate fitting pressurized in accordance with the system parameters.
 - d) While testing for leaks in the welded bottom joints, system parameters shall be unchanged from those used during calibration.

Annex C **(normative)**

External Floating Roofs

• C.1 Scope

C.1.1 This Annex provides minimum requirements that, unless otherwise qualified in the text, apply to single-deck pontoon-type and double-deck-type floating roofs. See Section 3 for the definition of these roof types. This Annex is intended to limit only those factors that affect the safety and durability of the installation and that are considered to be consistent with the quality and safety requirements of this standard. Numerous alternative details and proprietary appurtenances are available; however, agreement between the Purchaser and the Manufacturer is required before they are used.

C.1.2 The type of roof and seal to be provided shall be as specified on the Data Sheet, Line 30. If the type is not specified, the Manufacturer shall provide a roof and seal that is cost-effective and suitable for the specified service. Pan-type floating roofs shall not be used.

C.1.3 The Purchaser is required to provide all applicable jurisdictional requirements that apply to external floating roofs (see 1.3).

C.1.4 See Annex W for bid requirements pertaining to external floating roofs.

C.2 Material

The material requirements of Section 4 shall apply unless otherwise stated in this Annex. Castings shall conform to any of the following specifications:

- a) ASTM A27M, grade 405-205 (ASTM A27, grade 60-30), fully annealed;
- b) ASTM A27M, grade 450-240 (ASTM A27, grade 65-35), fully annealed or normalized and tempered, or quenched and tempered;
- c) ASTM A216M (ASTM A216) WCA, WCB, or WCC grades annealed and normalized, or normalized and tempered.

C.3 Design

C.3.1 General

- **C.3.1.1** The roof and accessories shall be designed and constructed so that the roof is allowed to float to the maximum design liquid level and then return to a liquid level that floats the roof well below the top of the tank shell without damage to any part of the roof, tank, or appurtenances. During such an occurrence, no manual attention shall be required to protect the roof, tank, or appurtenances. If a windskirt or top-shell extension is used, it shall contain the roof seals at the highest point of travel. The Purchaser shall provide appropriate alarm devices to indicate a rise of the liquid in the tank to a level above the normal and overfill protection levels (see NFPA 30 and API 2350). Overflow slots shall not be used as a primary means of detecting an overfill incident. If specified by the Purchaser (Table 4 of the Data Sheet), emergency overflow openings may be provided to protect the tank and floating roof from damage.
- **C.3.1.2** The application of corrosion allowances shall be a matter of agreement between the Purchaser and the Manufacturer. Corrosion allowance shall be added to the required minimum thickness or, when no minimum thickness is required, added to the minimum thickness required for functionality.

C.3.1.3 Sleeves and fittings that penetrate the single deck or lower decks of annular pontoons or lower decks of double-deck roofs, except for automatic bleeder vents, rim space vents, and leg sleeves, shall have a minimum wall thickness of "Standard Wall" for pipe NPS 6 and larger and 6 mm ($1/4$ in.) for all other pipe and plate construction unless otherwise specified on the Data Sheet, Table 5. Such penetrations shall extend into the liquid.

C.3.1.4 The annular space between the roof outer rim of the floating roof and the product side of the tank shell shall be designed for proper clearance of the peripheral seal (see C.3.13). All appurtenances and internal components of the tank shall have adequate clearance for the proper operation of the completed roof assembly.

- **C.3.1.5** For tanks greater than 60 m (200 ft) in diameter, the deck portion of single-deck pontoon floating roofs shall be designed to avoid flexural fatigue failure caused by design wind loads. Such designs shall be a matter of agreement between the Purchaser and the Manufacturer, using techniques such as underside stitch welding.

C.3.1.6 All conductive parts of the external floating roof shall be electrically interconnected and bonded to the outer tank structure. Bonding (grounding) shunts shall be provided on the external floating roof and shall be located above the uppermost seal. Shunts shall be 50-mm (2-in.) wide by 28-gauge (0.4-mm [$1/64$ -in.] thick) austenitic stainless steel as a minimum, or shall provide equivalent corrosion resistance and current carrying capacity as stated in API 2003. Shunt spacing shall be no more than 3 m (10 ft). All movable cover accessories (hatches, manholes, pressure relief devices, and other openings) on the external floating roof shall be electrically bonded to the external floating roof to prevent static electricity sparking when they are opened.

C.3.2 Joints

C.3.2.1 Joints shall be designed as described in 5.1.

C.3.2.2 If a lining is applied to the underside of the roof, all joints that will have a lining shall be seal-welded.

C.3.3 Decks

C.3.3.1 Roofs in corrosive service, such as covering sour crude oil, should be the contact type designed to eliminate the presence of any air-vapor mixture under the deck.

C.3.3.2 Unless otherwise specified by the Purchaser, all deck plates shall have a minimum nominal thickness of 4.8 mm ($3/16$ in.) (permissible ordering basis—37.4 kg/m², 7.65 lbf/ft² of plate, 0.180-in. plate, or 7-gauge sheet).

C.3.3.3 Deck plates shall be joined by continuous full-fillet welds on the top side. On the bottom side, where flexure can be anticipated adjacent to girders, support legs, or other relatively rigid members, full-fillet welds not less than 50 mm (2 in.) long on 250 mm (10 in.) centers shall be used on any plate laps that occur within 300 mm (12 in.) of any such members. A minimum of three fillet welds shall be made.

C.3.3.4 Top decks of double-deck roofs and of pontoon sections, which are designed with a permanent slope shall be designed, fabricated, and erected (with a minimum slope of 1 in 64) to minimize accumulation of standing water (e.g. pooling adjacent to a rolling ladder's track) when primary roof drains are open. This requirement is not intended to completely eliminate isolated puddles. When out of service, water shall flow freely to the primary roof drains. These decks shall preferably be lapped to provide the best drainage. Plate buckles shall be kept to a minimum.

C.3.3.5 The deck of single-deck pontoon floating roofs shall be designed to be in contact with the liquid during normal operation, regardless of service. The design shall accommodate deflection of the deck caused by trapped vapor.

C.3.3.6 All covers for roof openings, except roof drains and vents, shall have gaskets or other sealing surfaces and shall be provided with a liquid-tight cover.

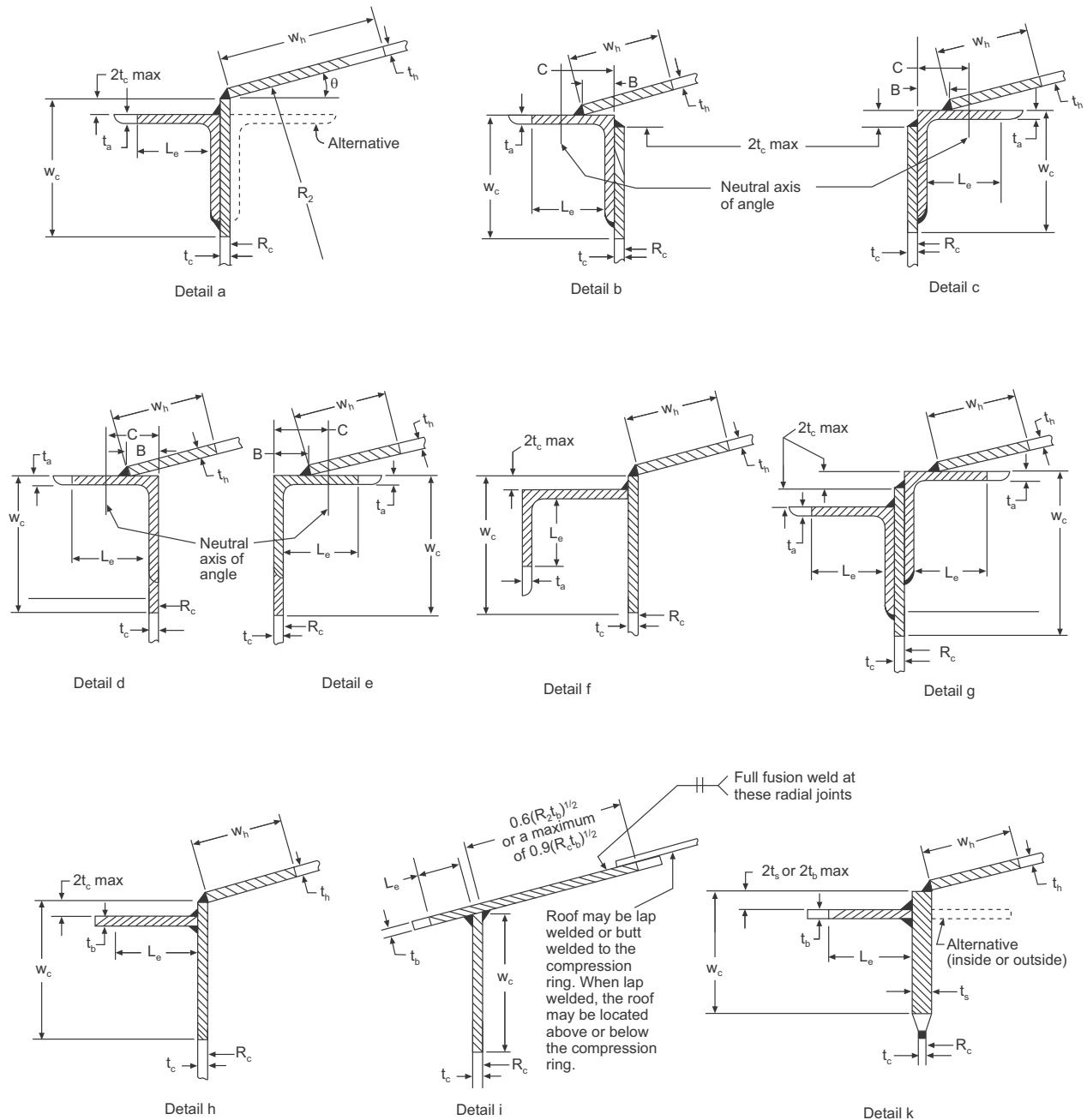


Figure F.2—Permissible Details of Compression Rings

where

P is the internal design pressure, in kPa;

A is the area resisting the compressive force, as illustrated in Figure F.1, in mm²;

F_y is the lowest minimum specified yield strength (modified for design temperature) of the materials in the roof-to-shell junction, in MPa;

θ is the angle between the roof and a horizontal plane at the roof-to-shell junction, in degrees;

$\tan \theta$ is the slope of the roof, expressed as a decimal quantity;

D_{LR} is the nominal weight of roof plate plus any attached structural, in N.

In USC units:

$$P = \frac{(0.962)(AF_y)(\tan \theta)}{D^2} + \frac{0.245 D_{LR}}{D^2}$$

where

P is the internal design pressure, in inches of water;

A is the area resisting the compressive force, as illustrated in Figure F.2, in inches²;

F_y is the lowest minimum specified yield strength (modified for design temperature) of the materials in the roof-to-shell junction, in lb/inch²;

θ is the angle between the roof and a horizontal plane at the roof-to-shell junction, in degrees;

$\tan \theta$ is the slope of the roof, expressed as a decimal quantity;

D_{LR} is the nominal weight of roof plate plus any attached structural, lbf.

F.4.2 For unanchored tanks, the maximum design pressure, limited by uplift at the base of the shell, shall not exceed the value calculated from the following equation unless further limited by F.4.3:

In SI units:

$$P_{\max} = \frac{0.000849DL_S}{D^2} + \frac{0.00127 D_{LR}}{D^2} - \frac{0.00153 M_w}{D^3}$$

where

$P_{\max}$ is the maximum design internal pressure, in kPa;

D_{LS} is the nominal weight of the shell and any framing (but not roof plates) supported by the shell and roof, in N;

M_w is the wind moment, in N-m;

D_{LR} is the nominal weight of roof plate plus any attached structural, in N.

Annex M **(normative)**

Requirements for Tanks Operating at Elevated Temperatures

M.1 Scope

M.1.1 This Annex specifies additional requirements for API Standard 650 tanks with a maximum design temperature exceeding 93 °C (200 °F) but not exceeding 260 °C (500 °F).

M.1.2 The following shall not be used for a maximum design temperature above 93 °C (200 °F):

- a) Open-top tanks (see 5.9).
- b) Floating-roof tanks (see Annex C).
- c) Structurally-supported aluminum dome roofs (see G.1.1 and note below).
- d) Internal floating roofs constructed of aluminum (see H.2.2 and note below).
- e) Internal floating roofs constructed of composite material (see H.2.2). Lower temperature limits may apply for this roof material type.

- **NOTE** An exception may be made by the Purchaser for Items c and d, if the following criteria are met:

- a) Allowable stress reductions for aluminum alloys are determined in accordance with Annex AL, and alloys are evaluated for the potential of exfoliation.
- b) Gaskets and seals are evaluated for suitability at the maximum design temperature.

M.1.3 Internal floating roofs in accordance with Annex H may be used for a maximum design temperature above 93 °C (200 °F), subject to the applicable requirements of this Annex. The vapor pressure of the liquid must be considered. Sealing devices, particularly those of fabric and nonmetallic materials, shall be suitable for the maximum design temperature.

M.1.4 Tanks for small internal pressures in accordance with Annex F may be used for a maximum design temperature above 93 °C (200 °F), subject to the requirements of M.3.6, M.3.7, and M.3.8.

M.1.5 Shop-assembled tanks in accordance with Annex J may be used for a maximum design temperature above 93 °C (200 °F), subject to the applicable requirements of this Annex.

M.1.6 The nameplate of the tank shall indicate that the tank is in accordance with this Annex by the addition of M to the information required by 10.1.1. In addition, the nameplate shall be marked with the maximum design temperature in the space indicated in Figure 10.1.

• **M.2 Thermal Effects**

This Annex does not provide detailed rules for limiting loadings and strains resulting from thermal effects, such as differential thermal expansion and thermal cycling, that may exist in some tanks operating at elevated temperatures. Where significant thermal effects will be present, it is the intent of this Annex that the Purchaser define such effects. The Manufacturer shall propose, subject to the Purchaser's acceptance, details that will provide strength and utility equivalent to those provided by the details specified by this standard in the absence of such effects.

For a maximum design temperature above 93 °C (200 °F), particular consideration should be given to the following thermal effects.

- a) Temperature differences between the tank bottom and the lower portion of the shell. Such thermal differences may result from factors such as the method and sequence of filling and heating or cooling, the degree of internal circulation, and heat losses to the foundation and from the shell to the atmosphere. With such temperature differences, it may be necessary to provide for increased piping flexibility, an improved bottom-to-shell joint, and a thicker annular ring or bottom sketch plates to compensate for increased rotation of the bottom-to-shell joint (see M.4.2).
- b) The ability of the bottom to expand thermally, which may be limited by the method of filling and heating. With such a condition, it may be necessary to provide improved bottom welding in addition to the details suggested in Item a.
- c) Temperature differences or gradients between members, such as the shell and the roof or stairways, the shell and stiffeners, the roof or shell and the roof supports, and locations with insulation discontinuities.
- d) Whether or not the contents are allowed to solidify and are later reheated to a liquid, including the effect on columns, beams, and rafters. The possible build-up of solids on these components and the potential for plugging of the vent system should also be considered.
- e) The number and magnitude of temperature cycles the tank is expected to undergo during its design life.

M.3 Modifications in Stress and Thickness

M.3.1 For a maximum design temperature not exceeding 93 °C (200 °F), the allowable stress specified in 5.6.2 (see Table 5.2a and Table 5.2b) for calculating shell thickness need not be modified.

M.3.2 For a maximum design temperature exceeding 93 °C (200 °F), the allowable stress specified in 5.6.2 shall be modified as follows: The allowable stress shall be two-thirds the minimum specified yield strength of the material multiplied by the applicable reduction factor given in Table M-1a and Table M-1b or the value given in Table 5.2a and Table 5.2b for product design stress, whichever is less.

M.3.3 For operating temperatures exceeding 93 °C (200 °F), the yield strength F_y in 5.10.4.4 shall be multiplied by the applicable reduction factor given in Table M.1a and Table M.1b.

M.3.4 The allowable stress of 145 MPa (21,000 lbf/in²) in the equation for shell-plate thickness in A.4.1 shall be multiplied by the applicable reduction factor given in Table M.1a and Table M.1b.

M.3.5 The requirements of 5.7.5 for shell manholes, 5.7.7 for flush-type cleanout fittings and of 5.7.8 for flush-type shell connections shall be modified. The thickness of bottom reinforcing plate for flush-type shell cleanouts and flush-type shell connections and bolting flange and cover plates for shell manhole and flush-type shell cleanouts shall be multiplied by the ratio of 205 MPa (30,000 lbf/in.²) to the material yield strength at the maximum design temperature if the ratio is greater than one.

M.3.6 The structural allowable stresses specified in 5.10.3, including the allowable stresses dependent on the modulus of elasticity, shall be multiplied by the yield strength reduction factors from Table M-1a and Table M-1b at the maximum design temperature.

M.3.7 If the anchors are insulated, the allowable stresses specified in Table 5.21a and Table 5.21b shall be multiplied by the ratio of the material's yield strength at the maximum design temperature to 205 MPa (30,000 lbf/in.²) if the ratio is less than 1.0 (see Tables M.1a and M.1b for yield strength reduction factors).

$$\theta_L = \frac{M_L}{K_L} - \tan^{-1} \left(\frac{F_R}{L K_R} \right) + \theta$$

$$\theta_C = \frac{M_C}{K_C}$$

K_R , K_L , and K_C are the shell stiffness coefficients determined from Figures P.2a through P.2l. W_R , θ_L , and θ_C are the resultant radial deflection and rotation of the shell at the opening connection resulting from the piping loads F_R , M_L , and M_C and the product head, pressure, and uniform or differential temperature between the shell and the tank bottom. F_R , M_L , and M_C shall be obtained from analyses of piping flexibility based on consideration of the shell stiffness determined from Figures P.2a through P.2l, the shell deflection and rotation determined as described in P.2.5.1 and P.2.5.2, and the rigidity and restraint of the connected piping system.

P.2.7 Determination of Allowable Loads for the Shell Opening

P.2.7.1 Construction of Nomograms

P.2.7.1.1 Determine the nondimensional quantities $X_A/(Rt)^{0.5}$, $X_B/(Rt)^{0.5}$, and $X_C/(Rt)^{0.5}$ for the opening configuration under consideration.

P.2.7.1.2 Lay out two sets of orthogonal axes on graph paper, and label the abscissas and ordinates as shown in Figure P.3a and Figure P.3b, where Y_C , Y_F , and Y_L are coefficients determined from Figure P.4a and Figure P.4b.

P.2.7.1.3 Construct four boundaries for Figure P.3a and two boundaries for Figure P.3b. Boundaries b_1 and b_2 shall be constructed as lines at 45-degree angles between the abscissa and the ordinate. Boundaries c_1 , c_2 , and c_3 shall be constructed as lines at 45-degree angles passing through the calculated value indicated in Figure P.3a and Figure P.3b plotted on the positive x axis.

P.2.7.2 Determination of Allowable Loads

P.2.7.2.1 Use the values for F_R , M_L , and M_C obtained from the piping analyses to determine the quantities $(\lambda/2Y_F)(F_R/F_P)$, $(\lambda a Y_L)(M_L/F_P)$, and $(\lambda a Y_C)(M_C/F_P)$.

P.2.7.2.2 Plot the point $(\lambda/2Y_F)(F_R/F_P)$, $(\lambda a Y_L)(M_L/F_P)$ on the nomogram constructed as shown in Figure P.5a.

P.2.7.2.3 Plot the point $(\lambda/2Y_F)(F_R/F_P)$, $(\lambda a Y_L)(M_C/F_P)$ on the nomogram constructed as shown in Figure P.5b.

P.2.7.2.4 The external piping loads F_R , M_L , and M_C to be imposed on the shell opening are acceptable if both points determined from P.2.7.2.2 and P.2.7.2.3 lie within the boundaries of the nomograms constructed for the particular opening-tank configuration.

P.2.8 Manufacturer and Purchaser Responsibility

- **P.2.8.1** The Manufacturer is responsible for furnishing to the Purchaser the shell stiffness coefficients (see P.2.4) and the unrestrained shell deflection and rotation (see P.2.5). The Purchaser is responsible for furnishing to the Manufacturer the magnitude of the shell-opening loads (see P.2.6). The Manufacturer shall determine, in accordance with P.2.7, the acceptability of the shell-opening loads furnished by the Purchaser. If the loads are excessive, the piping configuration shall be modified so that the shell-opening loads fall within the boundaries of the nomograms constructed as in P.2.7.1.

S.3.6 Annex M—Modifications

S.3.6.1 Annex M requirements shall be met for stainless steel tanks with a maximum design temperature over 40 °C (100 °F) as modified by S.3.6.2 through S.3.6.7.

S.3.6.2 Allowable shell stress shall be in accordance with Table S.2a and Table S.2b.

S.3.6.3 In M.3.5, the requirements of 5.7.7 for flush-type cleanout fittings and of 5.7.8 for flush-type shell connections shall be modified. The thickness of the bottom reinforcing plate, bolting flange, and cover plate shall be multiplied by the greater of (a) the ratio of the material yield strength at 40 °C (100 °F) to the material yield strength at the maximum design temperature, or (b) the ratio of 205 MPa (30,000 psi) to the material yield strength at the maximum design temperature. (See Table S.5a and Table S.5b for yield strength.)

S.3.6.4 In M.3.6, the stainless steel structural allowable stress shall be multiplied by the ratio of the material yield strength at the maximum design temperature to the material yield strength at 40 °C (100 °F). (See Tables S.5a and S.5b for yield strength.)

S.3.6.5 In M.5.1, the requirements of 5.10.5 and 5.10.6 shall be multiplied by the ratio of the material modulus of elasticity at 40 °C (100 °F) to the material modulus of elasticity at the maximum design temperature. (See Tables S.6a and S.6b for modulus of elasticity.)

S.3.6.6 In M.6 (the equation for the maximum height of unstiffened shell in 5.9.7.1), the maximum height shall be multiplied by the ratio of the material modulus of elasticity at the maximum design temperature to the material modulus of elasticity at 40 °C (100 °F).

S.4 Fabrication and Construction

S.4.1 General

Special precautions must be observed to minimize the risk of damage to the corrosion resistance of stainless steel. Stainless steel shall be handled so as to minimize contact with iron or other types of steel during all phases of fabrication, shipping, and construction. The following sections describe the major precautions that should be observed during fabrication and handling.

S.4.2 Storage

Storage should be under cover and well removed from shop dirt and fumes from pickling operations. If outside storage is necessary, provisions should be made for rainwater to drain and allow the material to dry. Stainless steel should not be stored in contact with carbon steel. Materials containing chlorides, including foods, beverages, oils, and greases, should not come in contact with stainless steel.

S.4.3 Thermal Cutting

S.4.3.1 Thermal cutting of stainless steel shall be by the iron powder burning carbon arc or the plasma-arc method.

- **S.4.3.2** Thermal cutting of stainless steel may leave a heat-affected zone and intergranular carbide precipitates. This heat-affected zone may have reduced corrosion resistance unless removed by machining, grinding, or solution annealing and quenching. The Purchaser shall specify if the heat-affected zone is to be removed.

S.4.4 Forming

S.4.4.1 Stainless steels shall be formed by a cold, warm, or hot forming procedure that is noninjurious to the material.

Table S.2a—Allowable Stresses for Tank Shells (SI)

Type	Min. Yield MPa	Min. Tensile MPa	Allowable Stress (S_d) (in MPa) for Maximum Design Temperature Not Exceeding					
			40 °C	90 °C	150 °C	200 °C	260 °C	S_t Ambient
201-1	260	515	155	136	125	121	—	234
201LN	310	655	197	172	153	145	143	279
304	205	515	155	155	140	128	121	186
304L	170	485	145	132	119	109	101	155
316	205	515	155	155	145	133	123	186
316L	170	485	145	131	117	107	99	155
317	205	515	155	155	145	133	123	186
317L	205	515	155	155	145	133	123	186

NOTE 1 S_d may be interpolated between temperatures.

- NOTE 2 The design stress shall be the lesser of 0.3 of the minimum tensile strength or 0.9 of the minimum yield strength. The factor of 0.9 of yield corresponds to a permanent strain of 0.10 %. When a lower level of permanent strain is desired, the Purchaser shall specify a reduced yield factor in accordance with Table Y-2 of ASME Section II, Part D. The yield values at the different maximum design temperatures can be obtained from Table S.5a.
- NOTE 3 For dual-certified materials (e.g. ASTM A182M/A182 Type 304L/304), use the allowable stress of the grade specified by the Purchaser.

Table S.2b—Allowable Stresses for Tank Shells (USC)

Type	Min. Yield psi	Min. Tensile psi	Allowable Stress (S_d) (in psi) for Maximum Design Temperature Not Exceeding					
			100 °F	200 °F	300 °F	400 °F	500 °F	S_t Ambient
201-1	38,000	75,000	22,500	19,700	18,100	17,500	--	34,200
201LN	45,000	95,000	28,500	24,900	22,200	21,100	20,700	40,500
304	30,000	75,000	22,500	22,500	20,300	18,600	17,500	27,000
304L	25,000	70,000	21,000	19,200	17,200	15,800	14,700	22,500
316	30,000	75,000	22,500	22,500	21,000	19,300	17,900	27,000
316L	25,000	70,000	21,000	19,000	17,000	15,500	14,300	22,500
317	30,000	75,000	22,500	22,500	21,000	19,300	17,900	27,000
317L	30,000	75,000	22,500	22,500	21,000	19,300	17,900	27,000

NOTE 1 S_d may be interpolated between temperatures.

- NOTE 2 The design stress shall be the lesser of 0.3 of the minimum tensile strength or 0.9 of the minimum yield strength. The factor of 0.9 of yield corresponds to a permanent strain of 0.10 %. When a lower level of permanent strain is desired, the Purchaser shall specify a reduced yield factor in accordance with Table Y-2 of ASME Section II, Part D. The yield values at the different maximum design temperatures can be obtained from Table S.5b.
- NOTE 3 For dual-certified materials (e.g. ASTM A182M/A182 Type 304L/304), use the allowable stress of the grade specified by the Purchaser.

G_{out} is the unit weight of flood liquid, in kg/m^3 (lb/ft^3) (1000 kg/m^3 [62.4 lb/ft^3] for water);

H is the shell height, in m (ft);

$h_1, h_2, \dots, h_n$ is the height of shell courses 1, 2, 3, through n, respectively, in m (ft);

H_{in} is the height or depth of liquid inside tank, in m (ft);

H_{safe} is the maximum height of unstiffened shell permitted, based on t_{smin} , in m (ft);

H_{TS} is the Transformed height of tank shell, in m (ft);

I_{act} is the The actual moment of inertia of the stiffener ring region, in cm^4 (in.^4);

I_{reqd} is the required moment of inertia of the stiffener ring, in cm^4 (in.^4);

L_1, L_2 is the distances between adjacent intermediate stiffeners or intermediate stiffener and top of shell or bottom of shell, respectively, in m (ft);

L_r is the minimum roof live load on horizontal projected area of the roof, kPa (lb/ft^2) = 1.0 kPa (20 lb/ft^2);

L_s equals $(L_1 + L_2)/2$, in m (ft);

N is the number of waves into which a shell will buckle under external pressure;

N_s is the number of intermediate stiffeners;

P_e is the specified external pressure, in kPa (lb/ft^2);

P_r is the total design external pressure for design of roof, in kPa (lb/ft^2);

P_s is the total design external pressure for design of shell, in kPa (lb/ft^2). P_s = the greater of 1) the specified design external pressure, P_e , excluding wind or 2) $W + 0.4P_e$ (see 5.2.2 for an important consideration);

ψ is the stability factor (see V.8.1 for values);

Q is the radial load imposed on the intermediate stiffener by the shell, in N/m (lb/in.);

q_s is the first moment of area of stiffener for design of stiffener attachment weld, in cm^3 (in.^3);

R is the roof dish radius, in m (ft);

S is the specified snow load, in kPa (lb/ft^2);

S_d is the allowable design stress, in MPa , (lb/in.^2);

t is the nominal shell thickness, mm (in.);

t_b is the nominal thickness of bottom plate under the shell, in mm (in.);

t_{cone} is the required nominal thickness of cone roof plate, in mm (in.). Maximum corroded thickness shall be 12.5 mm (0.5 in.);

V.7.3.3 The length of dome or umbrella roof considered to be within the top tension/compression ring region is determined by the following equation:

In SI units:

$$X_{\text{dome}} = 19.0 \sqrt{RT_{\text{dome}}}$$

In USC units:

$$X_{\text{dome}} = 2.1 \sqrt{RT_{\text{dome}}}$$

V.7.3.4 The length of shell considered to be within the top tension/compression ring region is determined by the following equation (see Figure V.1b):

In SI units:

$$X_{\text{shell}} = 13.4 \sqrt{Dt_{s1}}$$

In USC units:

$$X_{\text{shell}} = 1.47 \sqrt{Dt_{s1}}$$

V.7.3.5 The required cross-sectional area of the top stiffener structural shape is determined by the following equation:

$$A_{\text{stiff}} = A_{\text{reqd}} - t_{s1}X_{\text{shell}} - t_{\text{dome}}X_{\text{dome}}$$

NOTE This value should be recalculated, if necessary, after selection of final shell thickness.

V.8 Shell

• V.8.1 Unstiffened Shells

The procedure utilizes the nominal thickness of thinnest shell course and the transformed shell method to establish intermediate stiffener number and locations. The equations in V.8.1.2 and V.8.1.3 contain variables for a stability factor, ψ , that is dependent upon the magnitude of the vacuum pressure. The equations also include a 0.8 “knockdown” factor for imperfections in the cylindrical shell geometry. Shells shall be checked for two conditions: 1) the combined wind plus vacuum, and 2) for vacuum pressure alone. Each condition shall be checked using the appropriate stability factor, ψ , as follows.

V.8.1.2 The design external pressure (using the appropriate ψ from V.8.1) and the specified external (vacuum) pressure (using $\psi = 3.0$) shall not exceed for an unstiffened tank:

In SI units:

$$P_s \text{ or } P_e \leq \frac{E}{15,203 \psi \left(\frac{H_{TS}}{D} \right) \left(\frac{D}{t_{smin}} \right)^{2.5}}$$

In USC units:

$$P_s \text{ or } P_e \leq \frac{0.6E}{\psi \left(\frac{H_{TS}}{D} \right) \left(\frac{D}{t_{smin}} \right)^{2.5}}$$

V.8.1.3 The equation in V.8.1.2 can be rewritten to calculate the nominal thickness of the thinnest shell course required for a specified design external pressure as:

In SI units:

$$t_{smin} \geq \frac{47.07 (\psi H_{TS} P_s)^{0.4} D^{0.6}}{(E)^{0.4}}$$

In USC units:

$$t_{smin} \geq \frac{1.23 (\psi H_{TS} P_s)^{0.4} D^{0.6}}{(E)^{0.4}}$$

V.8.1.4 For tanks with shell courses of varying thickness, the transformed shell height, H_{TS} , for the tank shell is determined in accordance with the following procedure:

- The transformed height of the shell is calculated as the sum of the transformed widths of the individual shell courses as described in Item b.
- The transformed width of each individual shell course is calculated by multiplying the actual shell height by the ratio $(t_{s1}/t_{act})^{2.5}$. Note that $t_{s1} = t_{act}$ for the top shell course.

The transformed shell height is determined from the following equation:

$$H_{TS} = h_1 \left(\frac{t_{s1}}{t_{s1}} \right)^{2.5} + h_2 \left(\frac{t_{s1}}{t_{s2}} \right)^{2.5} + \dots h_n \left(\frac{t_{s1}}{t_{sn}} \right)^{2.5}$$

The transformed shell height is an analytical model of the actual tank. The transformed shell has a uniform thickness equal to the topmost shell thickness and a height equal to the transformed height. This analytical model of the actual tank will have essentially an equivalent resistance to buckling from external pressure as the actual tank.

Intermediate stiffener spacings on 0.328 in. and 0.395 in. shell plate are,

$$L_s = [H_{\text{Safe}}](t_{\text{sx}}/t_{\text{smin}})^{2.5}$$

$$L_s = [5.84](0.328/0.3125)^{2.5} = 6.59 \text{ ft}$$

$$L_s = [5.84](0.395/0.3125)^{2.5} = 10.49 \text{ ft}$$

For equal transposed width we would like to locate 5 stiffeners on 0.3125 in. shell at spacing = 5.44 ft. However, this causes the 3rd stiffener (location = 5.44 ft $\times$ 3 = 16.32 ft) to be closer to the horizontal shell seam than we would prefer. Therefore, we will try to locate the 5 stiffeners on the 0.3125 in. shell at spacing = 5.75 ft (must be less than or equal to $L_s = 5.84$ ft).

Locate the 6th stiffener as follows:

$$\text{Available 0.3125-in. shell plate} = (4 \times 8 \text{ ft}) - (5 \times 5.75 \text{ ft}) = 3.25 \text{ ft}$$

$$\text{Maximum length of 0.328-in. shell} = (5.84 - 3.25) \times (0.328 / 0.3125)^{2.5} = 2.92 \text{ ft}$$

6th stiffener must be located no more than 2.92 ft on 0.328-in. shell. Stiffener can be located 1.5 ft on 0.328-in. shell

$$\text{Location of 6}^{\text{th}} \text{ stiffener} = 32 + 1.5 = 33.5 \text{ ft from top of tank}$$

Locate the 7th stiffener as follows:

$$\text{Available 0.328-in. shell} = (5 \times 8) - 33.5 = 6.5 \text{ ft}$$

$$\text{Maximum spacing on 0.328-in. shell} = L_s = 6.59 \text{ ft}$$

To keep stiffener away from horizontal shell seam, locate stiffener less than 6.59 ft.

$$\text{Location of 7}^{\text{th}} \text{ stiffener} = 33.5 + 5.75 = 39.25 \text{ ft}$$

Check the remaining unstiffened shell:

$$\text{Difference between actual and transformed shell height} = 48 - 43.54 = 4.45 \text{ ft}$$

$$\text{Length of 0.328-in. shell below stiffener} = 40 - 39.25 = 0.75 \text{ ft}$$

$$\text{Transformed shell stiffener spacing} = 0.75 \times (0.3125/0.328)^{2.5} + 8.0 \times (0.3125/0.395)^{2.5} = 5.12 \text{ ft. Must be less than or equal to } 5.84 \text{ ft } (H_{\text{Safe}}) - \text{OK}$$

9) If fewer stiffeners and thicker shell plates is a more economical solution, the design can be adjusted as follows:

Assume, for this example, a uniform shell thickness equal to the thickness of the lowest shell course, i.e. $t_{\text{avg}} = 0.395$ in.

H_{safe} is then calculated as follows:

$$H_{\text{safe}} = \frac{0.6(0.395)^{2.5}(30,000,000)}{3(75)^{1.5}(733.36)(86.4)}$$

$$H_{\text{safe}} = 10.48 \text{ ft}$$

For $t_{\text{avg}} = 0.395$ in., H_{TS} is recalculated to be equal to 48 ft.

Table X.2a—Allowable Stresses for Tank Shells (SI)

Alloy	Min Yield	Min Ten	Allowable Stress MPa for Design Temp Not Exceeding (S_t s)					
	MPa	MPa	40 °C	90 °C	150 °C	200 °C	260 °C	S_t ambient
S31803	450	620	248	248	239	230	225	266
S32003	450	655	262	231	218	215	212	281
S32101	450	650	260	234	223	215	212	278
S32202	450	650	262	258	226	214	209	281
S32205	450	655	262	234	225	208	191	281
S32304	400	600	240	229	213	205	200	257
S32550	550	760	303	302	285	279	272	325
S32520	550	770	308	270	265	256	251	331
S32750	550	795	318	319	298	279	268	343
S32760	550	750	298	314	259	256	256	319

NOTE 1 S_t s may be interpolated between temperatures.

NOTE 2 The design stress shall be the lesser of 2/5 of the minimum tensile strength or 2/3 of the minimum yield strength.

NOTE 3 The hydrotest stress shall be the lesser of 3/7 of the minimum tensile strength or 3/4 of the minimum yield strength.

NOTE 4 For dual certified materials, S31803/S32205 and S32550/S32520, use the allowable stress of the grade specified by the purchaser.

Table X.2b—Allowable Stresses for Tank Shells (USC)

Alloy	Min Yld	Min Ten	Allowable Stress PSI for Design Temp Not Exceeding (S_t s)					
	lbf/in ²	lbf/in ²	100 °F	200 °F	300 °F	400 °F	500 °F	S_t ambient
S31803	65,000	90,000	36,000	36,000	34,700	33,400	32,600	38,600
S32003	65,000	95,000	38,000	33,600	33,600	31,200	30,700	40,800
S32101	65,000	94,000	37,600	34,000	32,400	31,200	30,700	40,300
S32202	65,000	94,000	38,000	37,000	32,900	31,000	30,300	40,800
S32205	65,000	95,000	38,000	34,000	32,700	30,000	28,700	40,800
S32304	58,000	87,000	34,800	33,200	30,900	29,700	29,000	37,300
S32550	80,000	110,000	44,000	43,800	41,400	40,400	39,400	47,200
S32520	80,000	112,000	44,800	39,200	38,400	37,200	36,400	48,000
S32750	80,000	116,000	46,400	46,200	43,200	40,500	38,900	49,800
S32760	80,000	108,000	43,200	39,200	37,600	37,200	37,200	46,300

NOTE 1 S_t s may be interpolated between temperatures.

NOTE 2 The design stress shall be the lesser of 2/5 of the minimum tensile strength or 2/3 of the minimum yield strength.

NOTE 3 The hydrotest stress shall be the lesser of 3/7 of the minimum tensile strength or 3/4 of the minimum yield strength.

NOTE 4 For dual certified materials, S31803/S32205 and S32550/S32520, use the allowable stress of the grade specified by the purchaser.